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Editorial

In the ever-evolving landscape of academic research, innovation knows no bounds. We have the privilege of witnessing the unfolding of groundbreaking discoveries across various fields, each contributing to the collective advancement of human knowledge and understanding. In this editorial, we shed light on a diverse array of 26 research papers that exemplify the breadth and depth of contemporary scholarly inquiry.

This paper delves into the development of software and methodologies crucial for designing next-generation nuclear reactors. Through a meticulous approach encompassing system analysis and optimization techniques, the researchers have made strides in enhancing reactor safety and efficiency [1].

Leveraging the power of machine learning algorithms on health data sets, this study addresses the critical issue of depression detection. By comparing various algorithms, the research sheds light on effective methodologies for identifying and addressing mental health concerns in communities [2].

With the advent of autonomous vehicles, optimizing control policies becomes paramount. This paper explores the intersection of reinforcement learning and vehicle control, offering insights into achieving efficient and safe autonomous navigation [3].

In the realm of renewable energy, ensuring stable power flow is essential. This research introduces a bidirectional series resonant converter, offering a solution to voltage fluctuations in DC microgrids and paving the way for more reliable renewable energy integration [4].

With the advent of 5G technology, efficient resource allocation becomes pivotal. Through meticulous simulation and analysis, this study evaluates scheduling algorithms, providing valuable insights for optimizing data transmission in 5G networks [5].

Renewable energy sources like solar power face challenges such as the "Duck curve." This paper proposes a novel methodology using open-source tools to analyze and mitigate the effects of this phenomenon, contributing to the sustainable integration of solar energy into power systems [6].

Precision control in fluid systems necessitates optimized solenoid valves. By employing recursive methods and material selection strategies, this research showcases advancements in designing proportional solenoid valves for various applications, including medical devices [7].

Prefabricated building construction presents unique supply chain challenges. Through case studies and analysis, this research offers insights into optimizing supply chain integration, ultimately enhancing project efficiency and cost-effectiveness [8].

Preservation of historical structures requires innovative conservation methods. This paper introduces an electrochemical desalination model, offering a simple yet effective approach to mitigate salt weathering in brick structures, thereby contributing to cultural heritage preservation efforts [9].

With the rise of SDN technology, security concerns must be addressed. This research proposes a novel firewall application tailored for SDN networks, showcasing advancements in mitigating flooding attacks and enhancing network security [10].

This paper introduces novel methodologies for deriving transfer functions in the context of electromagnetic compatibility in inverters. By considering various resistances and circuit configurations, the research offers valuable insights for designing control systems in electrical complexes [11].

Delving into the profound implications of AI and autonomous robotics, this qualitative study calls for proactive measures to address ethical concerns. As technology evolves, safeguarding humanity from potential misuses becomes paramount, urging global action to ensure responsible AI development [12].

Quantitatively analysing student interactions with Blackboard Learning Management Systems, this research highlights a positive correlation between engagement and academic performance. It underscores the importance of leveraging digital platforms to enhance learning outcomes [13].

Amidst a dynamic industrial landscape, this study investigates automated quality inspection using deep neural networks. By replacing manual inspection with efficient AI-driven processes, the research showcases significant improvements in production efficiency and quality control [14].

Addressing the need for robust and self-regulating damper systems, this paper proposes a novel design incorporating linear generators. By harnessing vibrational energy, the model offers enhanced performance and reliability, paving the way for more efficient vehicle damping systems [15].

Introducing a streamlined payment solution for taxi services, this innovative gadget ensures secure transactions while enhancing user experience. By leveraging radio wave technology and internet connectivity, the system offers a seamless and efficient payment experience for passengers and drivers alike [16].

This research introduces a novel feature representation technique for offline signature verification using edge histograms. By employing SVM classification, the study showcases advancements in signature authentication, contributing to enhanced security measures [17].

Utilizing pragma-linguistic methods, this study explores competence manifestation in online interactions. By analysing language elements, the research offers insights into detecting competence cues, enriching our understanding of competency assessment in organizational contexts [18].

Addressing the complexities of software product line evolution, this work proposes a flexible management approach grounded in feature models with business component semantics. By formalizing software assets, the research aims to streamline evolution management processes [19].

Focusing on distribution system optimization, this study employs metaheuristic algorithms to identify optimal locations for photovoltaic systems and power quality conditioners. By enhancing computational efficiency and solution convergence, the research facilitates the integration of renewable energy sources into distribution networks [20].

Addressing the need for effective project management in the Indian construction sector, this research introduces a model for evaluating complexity. By identifying and weighing determinants, the framework offers a quantitative approach to managing complexity, enabling informed interventions at the planning stage [21].

In an era characterized by dynamic environments, the study focuses on assessing Mobile Business Intelligence (MBI) readiness in the South African telecommunications industry. Through quantitative research, the model identifies key factors essential for successful MBI implementation, offering insights for organizations seeking to leverage mobile technology [22].

Recognizing the importance of sustainable practices, this research explores barriers in green supply chain management. Through a comprehensive review, the study identifies obstacles

and prioritizes them, laying the foundation for effective environmental management strategies [23].

Proposing silicon carbide-based power electronics for extremely fast charging of electric vehicles (EVs), this paper highlights the benefits of DC power sources. By reducing charging time and improving efficiency, the technology offers a revolutionary solution for addressing climate emergencies [24].

Offering a novel approach to JSON specification, this research utilizes algebraic formal methods to enhance interoperability and security. By advocating for formal specification techniques, the study aims to streamline the design process of open standards, promoting clarity and consistency [25].

Focusing on robust control strategies for HVDC integration in meshed AC power grids, the research presents model-matching controllers to improve damping and robustness. Through rigorous testing and comparison, the study demonstrates the efficacy of the proposed controllers in enhancing grid stability and performance [26].

In conclusion, we applaud the tireless efforts of researchers worldwide in advancing the frontiers of science and technology. Their work not only enriches our understanding of the world but also inspires us to envision a future where ingenuity and collaboration transcend disciplinary boundaries, paving the way for transformative change on a global scale.

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CONTENTS

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Ideas at the Basis of Development of Software for Specific Nuclear Reactor Safety and Design

Viacheslav Sergeevich Okunev*

Department of Physics, Bauman Moscow State Technical University, Moscow, 105005, Russia
*Corresponding author: Viacheslav Sergeevich Okunev, Email: okunevvs@bmstu.ru

ABSTRACT: The main goal of the work was the development of software and codes for the design of new generation nuclear reactors. The problem is solved by the example of fast reactors with a liquid metal coolant. The problem is solved within the framework of system analysis methods and operations drawing methods. Three groups of methods for solving the problem can be distinguished: optimization methods, methods for calculating stationary states, methods for simulating emergency modes. When designing safe fast reactors, ATWS emergency modes and their combinations are primarily considered. All ATWS modes are grouped into five groups: TOP WS (Transient Overpower without Scram); LOF WS (Loss of Flow without Scram); OVC WS (Overcooling Accident without Scram); LOHS WS (Loss of Heat Sink without Scram) and LOCA WS (Loss of Coolant Accident without Scram). A number of auxiliary discrete multicriteria problems have been solved. To solve them, the method of displaced ideal, lexicographic methods, and maximin strategy of cooperative play were used. Decomposition methods are widely used in research. To solve the multicriteria (two-criterion) problem of continuous optimization, a strategy of sequential decision-making in positional games was used. As a result, a number of codes have been developed that collectively implement the decision-making methodology in the design of nuclear reactors. Among the auxiliary problems, the problems of optimizing the composition of the lead coolant, the problem of optimizing the choice of the fuel composition and structural materials are solved. The choice of parameters that have the greatest impact on the safety of a high-power reactor with a lead coolant is carried out. The proposed algorithms, procedures, methods and codes contribute to solving the problem of designing safe reactors of a new generation - energy sources that will provide human energy on the required scale for the long term.

KEYWORDS: Nuclear reactor, Software, Codes, Optimization methods, Multicriteria problems, Nuclear fuel

1. Introduction

1.1. Background

Increased energy consumption is helping to increase the world's population and meet the growing human needs for a better quality of life. Traditional sources of energy are based on the combustion of hydrocarbon fuels. Such fuel is extremely unevenly distributed in the earth's crust. This is the source of conflicts and wars between states. In addition, it requires the transportation of large volumes of fuel. The use of hydroelectric power plants leads to the alienation of territories and climate change in certain regions of the world. Hydroelectric power plants account for from 5.2% in the Middle East to almost 51% in Central and South America [1]. More than 60% of all electricity in the world is generated at thermal power plants, about 20% at hydroelectric power plants, about 17% at nuclear power plants and about 1% at geothermal, tidal, solar and wind power plants [2].

The development of safe nuclear energy contributes to the solution of a number of key problems. Among these tasks, the following are the most important:

- Providing mankind with energy for the long term;
- Economic growth;
- Ensuring energy security of the states of the world;
- ● Elimination of greenhouse gas emissions and environmental pollution (introduction into the

biosphere or appearance in it of new, usually uncharacteristic physical, chemical or biological pollutants, exceeding their natural level);
- Exclusion of alienation of territories during the construction of hydroelectric power plants;
- It is possible to achieve high energy release, "compact" fuel processing (at one site) and minimize the amount of fuel used.

These tasks can be solved by ensuring the internal security of nuclear fuel cycle enterprises and, first of all, nuclear reactors of a new generation. The elimination of accidents at nuclear power plants is possible when using, for example, liquid metal fast reactors (LMFRs) with innovative cermets fuel based on mononitride micro grains UN-PuN (or UN) and a coolant based on lead extracted from thorium ores (with a ^{208}Pb isotope content of at least 75 ... 80 %) [3].

In Russia, a project has been developed for the BREST-OD-300 reactor with mononitride fuel and lead coolant [4], the construction of which began in 2021.

1.2. Relevance of Research

The relevance of research is determined by the need for safety analysis (first of all, to exclude severe accidents) at the stage of conceptual development of the reactor. This is possible due to the appropriate choice of the composition and geometry of the core. Deterministic exclusion on this basis of severe accidents will minimize the risk of unacceptable releases of radioactive materials outside the station to practically zero.

In Russia, by the middle of the XXI century, a transition to large-scale nuclear power is predicted [4]. This will require a shift in the priorities for the development of nuclear power in the direction of increasing the self-protection of nuclear reactors. This is possible on the basis of the development of new computational and optimization research methods. Identify the techniques required primarily for innovative reactor designs and concepts, including LMFRs. Fast reactors are considered as promising structures for large-scale nuclear power. Research requires the solution of core optimization problems with constraints, including for functionals that characterize the entire set of emergency modes that are not deterministically excluded (safety functionals). First of all, emergency modes of the ATWS type (anticipated transient without scram) are considered [3].

The author considered five groups of emergency modes from among ATWS (and their combinations) [5, 6]:

- Transient Overpower without Scram (TOP WS);
- Loss of Flow without Scram (LOF WS);
- Overcooling Accident without Scram (OVC WS);
- Loss of Heat Sink without Scram (LOHS WS);
- Loss of Coolant Accident without Scram (LOCA WS).

Preliminary results of research in this area are presented in publications [3, 6].

2. Methods

2.1. Research Methods and Tasks

The reactor core is considered as a system of many elements in communication with each other [6]. The study of such systems is carried out within the framework of systems analysis and is solved on the basis of methods for researching operations associated with the construction, development and application of mathematical decision-making models. The decision-making model in the problem of creating a safe reactor has a large dimension, contains heterogeneous (numerical, logical, lexical) information, fuzziness, uncertainty, incompleteness, and others. In this regard, the rationalization (increase in efficiency) of the decision-making procedure has been carried out. The requirement for deterministic elimination of severe accidents is formalized in the form of restrictions for a number of safety functionalities corresponding to the preservation of the operability of safety barriers [3, 6]. In game theory, the problem of optimal design of a reactor, in which severe accidents are deterministically excluded, can be formulated as a game with a thinking adversary, which, in turn, with appropriate formalization of some intuitive concepts, can be reduced to solving a number of problems with varying degrees of formalization.

In practice, the design tasks for rectors can be classified as partly integer optimization problems. The following tasks are considered (in decreasing order of formalization), which form the basis of a unified methodology [3, 6].

Problems of mathematical programming in a deterministic setting allow you to get a single optimal solution. It is required to determine the control vector

$$\boldsymbol{u} = \{u_k\} = ? \ (k = 1, 2, \ldots, K).$$

The domain of definition of the control vector is

$$u_k^{min} \le u_k \le u_k^{max}.$$

The optimality criterion is

$$F_0(\boldsymbol{u}) \rightarrow \text{opt (min or max)},$$

There are task restrictions

$$F_i(\boldsymbol{u}) \le F_i^*, \ i = 1, 2, \ldots, I;$$

here F_i^* are the maximum admissible values of the corresponding functionals. The functionals F_0 and F_i also depend on state variables. These variables satisfy the known equations. As F_0 and F_i functionals are considered that characterize the basic requirements for energy sources of the future:

○ Safety,

○ Self-sufficiency in fuel,

○ Cost-effectiveness.

The control vector $\boldsymbol{u}$ includes the characteristics of the core.

For the first time, the problem of complex optimization of the core of a fast reactor, taking into account the constraints on neutron, thermo hydraulic and strength characteristics, ensuring reliable operation of the reactor at a given power, was solved by V.V. Khromov, A.M. Kuzmin and V.V. Orlov [7]. They proposed an iterative optimization method - the method of sequential linearization [7].

The author of this work has expanded the range of problems to be solved with the help of the developed auxiliary codes that allow solving the following problems:

○ it is necessary to take into account in the optimization studies the safety functionals that characterize the entire set of emergency situations;

○ solving problems without an optimality criterion for finding the area of safe layouts;

○ taking into account the uncertainty of scenarios for the development of emergency situations;

○ post-optimization analysis;

○ auxiliary applied multicriteria problems (see below).

The properties of the core materials were included in the control parameters. This made it possible to develop reactors with specified safety properties.

● Mathematical programming problems with undefined data v provide many solutions. The task is formulated as follows:

$$\boldsymbol{u} = \{u_k\} = ? \ (k = 1, 2, \ldots, K);$$

$$u_k^{min} \le u_k \le u_k^{max};$$

$$F_0(\boldsymbol{u}, \boldsymbol{v}) \rightarrow \text{opt};$$

$$F_i(\boldsymbol{u}, \boldsymbol{v}) \le F_i^*(\boldsymbol{v}); \ i = 1, 2, \ldots, I.$$

The functionals F_0 and F_i also depend on state variables. These variables satisfy the known equations.

By the end of the 1970s, L.S. Popyrin and others (Siberian Branch of the Academy of Sciences of the USSR) formulated methodological provisions for the implementation of optimization calculations in the power industry with the ambiguity of the initial data. In the 1980s, the staff of MEPhI, IPPE, and the Kurchatov Institute, using the simplest codes, obtained estimates of the effect of uncertainties in the initial data on the optimal layout of a fast reactor (without taking into account safety).

● The following applied multicriteria problems were solved [6].

○ In order to reduce the dimension of the optimal design problem and justify the safety of the reactor, based on the analysis of conflicts, the most significant safety functions are selected. The author proposes a hierarchical model for the study of conflicts, ways of overcoming them.

○ On the basis of the maximin principle, the tasks of ranking emergency situations according to the degree of hazard in reactors of different types were solved. The degree of hazard corresponds to the degree of significance from the point of view of the priority consideration of one or another emergency mode in the problems of optimal design.

○ the problem of ranking the coolants of fast reactors according to the degree of preference was solved using lexicographic methods.

○ The two-criterion problem of continuous optimization of a fast reactor for maximum power and minimum void reactivity effect with restrictions for various functionals, including safety functionals, was solved using the Dragon-M code, which was repeatedly modernized by the author, based on a multi-step decision-making procedure.

○ Discrete multicriteria problems of choosing the most preferable lead deposits with a high content of the ^{208}Pb isotope, choosing preferred (including conditionally equally safe) core layouts, ranking reactor parameters according to the degree of impact on reactor safety, are solved by the shifted ideal method. The algorithm of the method is presented in [8].

● To reduce the dimension of the optimization problem, including by identifying emergency situations that neutralize and aggravate each other (when they are superimposed) and exclude interrelated criteria, elements of the non-formalized theory of conflict were used.

To solve multicriteria problems, the well-known methods [8-10] and these methods, modified by the author, are used.

It is necessary to note the personal contribution of the author and the novelty of the article.

The Dragon code for complex calculation and optimization of fast reactors was developed at MEPhI (Russia) in the mid 1990s. Its authors are N.I. Geraskin, A.M. Kuzmin, D.V. Morin, A.E. Novikov and V.S. Okunev. The code did not take into account the functionals characterizing the safety of the reactor (safety functionals). For this reason, an upgrade of the Dragon code was required. Modernization of the Dragon code (Dragon-M) was carried out by the author.

The author formulated and included in the optimization code the functionals characterizing the emergency modes of the reactor. The author has developed the FRISS code for simulating emergency modes (including ATWS and their combinations). One version of the FRISS code can work as part of the Dragon optimization code. Combining all emergency modes into a small number of groups is a well-known approach proposed by the authors from Argonne National Laboratory (US DOE) in experiments on EBR-II [5]. Methods for combining emergency modes into groups are known and generally accepted [5].

Research experience has shown that the problem with restrictions on safety functionals does not have a solution for all existing nuclear reactors and most projects of new generation reactors. It has solutions for lead-cooled fast reactors.

The last update to the Dragon-M code was to expand the list of control parameters. Their composition included the properties of the core materials (density, thermal conductivity, heat capacity, neutron interaction cross sections). Modernization carried out by the author. When obtaining the optimal option, it was necessary to select materials with the necessary (optimal or acceptable) properties. This procedure was also carried out by the author.

The author proposes an algorithm (procedure) for making decisions. Similar procedures are commonly used in such studies. It can be considered generally accepted.

In order to refine the optimization results, the author has developed hierarchical models with adjustable accuracy based on the precision MCU code. The need to refine the results obtained using approximate models is known and generally accepted. In this work, it is necessary to clarify the values of the void effect of reactivity. In an inhomogeneous core, the diffusion approximation (adopted in the Dragon-M code) can give rough results. In order to refine the optimization results, the author has developed hierarchical models with adjustable accuracy based on the precision MCU code. The need to refine the results obtained using approximate models is known and generally accepted. In this work, it is necessary to clarify the values of the void effect of reactivity. In an inhomogeneous core, the diffusion approximation (adopted in the Dragon-M code) can give rough results.

2.2. Research Directions

To solve the problems of searching for the physical characteristics of the core of a fast reactor, research has been carried out in the following areas.

- Computational and optimization studies of the core of fast reactors of a new generation, including the development of effective models that take into account the constraints for safety functional, characterizing the totality of the most dangerous emergency situations.
- Post-optimization analysis for deterministic justification of the safety of fast reactors, including the development of models with adjustable accuracy based on precision neutron-physical calculations programs, and their use for exploratory computational experiments.
- Post-optimization analysis, which implies the development of effective models for comparing optimal reactor layouts according to different criteria and choosing the most preferable of them (conditionally equally safe).

The studies involve taking into account the uncertainty of scenarios for the development of emergency situations. In order to rationalize the decision-making procedure in the tasks of the initial design stage, substantiation and analysis of reactor safety, the methods, models, approaches and procedures proposed and implemented by the author are combined into a single methodology based on a systematic approach [6].

2.3. Decision Making Procedure. The Knowledge Base is the Basis for Making Decisions

Decision-making in the design problems of a new generation reactor presupposes the complex use of natural (human) and artificial (computer) intelligence. Routine operations, mainly related to the analysis and processing of numerical data, are performed by a computer. The volume of lexical information is relatively small and the human intellect can easily handle it. If necessary (although such a need is questionable) in the decision-making process, you can find a "niche" for the use of technical neural networks. In the general case, the decision-making procedure is possible using natural or technical neural networks. The final decision on the choice of the reactor layout option, which will subsequently be implemented (built), is made by a person.

It is possible to propose a decision-making procedure based on the sequential execution of a number of stages [6].

At the same time, it is formally convenient to distinguish three levels of the hierarchy of decision-makers. At the top level of the hierarchy, a decision is made (approved) by an official (for example, in Russia, this is the head of Rosatom State Corporation), who is in control of the situation as a whole and is able to pose the problem in the most general form (without mathematical formalization) and intuitively (for example, by a strong-willed decision, or on the basis of voting in the case of a collegial decision) to choose the most preferable (he liked) option, which will subsequently be implemented.

In order to minimize errors in decision-making at the upper hierarchical level, one of the main tasks of a decision-maker, the second (intermediate) level of the hierarchy, is to minimize the number of options transferred to the upper level and maximally facilitate the analysis of options through, for example, preliminary ranking of these options for a particular set of quality criteria. This will not only minimize errors, but also reduce the decision-making time at the top level of the hierarchy.

Such a global analysis practically does not require from the decision maker, the top level of specific training in the field of solving specific narrow-profile technical problems and problems of applied mathematics. The decision-maker at the second level of the hierarchy can be a team of experts - specialists in the field of nuclear technologies, systems analysis and control theory. The quality of the decisions made (there is a term - the reliability of the decisions made) at the second and third levels of the hierarchy directly depends on the professional qualifications of the decision maker.

The third (lower) level of the hierarchy of the decision-maker consists of teams of specialists in various fields of knowledge who, through interaction, are able to comprehensively solve the entire range of narrow-profile physical and mathematical, technical, technological, design and other problems. Their main task is to formulate, solve and analyze the results of a specific narrow-profile task.

Generally speaking, all decisions can be made by one specialist or a relatively small team of specialists who are proficient in decision-making theory and the appropriate physical and mathematical methods and design skills. This often happens, for example, in the preparation of conceptual projects for new generation reactors. In this case, the decisions made can be conditionally divided into three levels of hierarchy.

A similar procedure is implemented in the problems of optimal design of fast reactors of a new generation based on the computational and optimization program code "Dragon-M", i.e., in the general case, some computational and optimization code should serve as the base or the core of the decision making procedure.

In the proposed decision-making procedure, four knowledge bases are used sequentially. The knowledge (data) base is understood as an organized body of knowledge (data) intended for their storage, accumulation and processing using a computer.

- An external common (global) knowledge base represents the entire set of research results in the field of traditional, non-traditional and innovative nuclear technologies, all the experience accumulated by the scientific community over more than 60 years of development of these technologies. Such a "base" (in quotation marks, since such a unified and complete base on nuclear technologies does not yet exist) can be an information retrieval thesaurus that includes heterogeneous (lexical, numerical, graphic) information with a specific (given) system of semantic relations.

The base is considered "external", since its existence is assumed even before the design of a specific reactor and such a base, generally speaking, has nothing to do with the design of the reactor (it exists by itself and is replenished as new technologies develop). Today, for example, specialized encyclopedias, including electronic ones, monographs and other sources, can act as an external base. (As an example of the most common base, one can consider, for example, the information presented on the IAEA (International Atomic Energy Agency) website [11].

Information retrieval thesauri became widespread in the 1970s. The search for the necessary information is carried out automatically according to the special lexical units specified by the user - descriptors. Such thesauri usually contain semantic maps of thematic classes. This is perhaps the only niche for using neural networks in the problem of reactor design. Technical neural systems and the neural network approach in general can greatly facilitate the search for the necessary information by specifying by the user of such a neurosaurus (network) practically any, including fuzzy, semantic relations associated with a given problem.

Information from this external base is used mainly at the stage of the general statement of the problem and determination of the purpose of the decision-making. However, if necessary, an appeal to an external base is possible at any stages of decision-making by a decision-maker, at any level of the hierarchy. (For example, to correct decisions.)

The other three knowledge bases are internal. They are filled in during the design of a specific reactor, that is, they are formed in the process of consistent decision-making. They are necessary for making a decision in a specific case, for solving a specific problem and contain much less information. This volume is also decisive in making a

decision about the necessity, possibility (expediency) or unreasonableness (inexpediency) of using the neural network approach. These databases are data files containing heterogeneous information. Separate information from internal databases (files) can go to the global external knowledge base on nuclear technologies.

Depending on the convenience of use, the three internal databases can be combined into a single internal information base, which is used to solve a specific problem - the problem of optimal reactor design.

2.4. Algorithm (Procedure) for Making Decisions

The decision-making algorithm in the problems of optimal design of a safe reactor includes the following stages.

1. Statement and analysis of the problem situation, and the definition of the general goal of research and decision-making.

The stage is in the competence of the person making the decision of the upper hierarchical level, and contains mainly lexical information about some of the most significant properties of the designed object (reactor and NPP) and the main requirements for it. The initial information comes from an external knowledge base. The resources of the IAEA can be used as such a base [12, 13]. These resources are well organized and contain scientific and technical publications and other documents. A user-friendly interface and a logical clear hierarchical structure allow you to quickly search for the necessary information.

The processed information goes to the first internal database.

2. Formation of a system of quality criteria and mathematical formalization of the design problem statement.

At this stage, information from the external knowledge base on nuclear technologies is used and the first internal database is updated with information. The stage is in the competence of the decision maker, the second level of the hierarchy.

3. Reduction of the original multicriteria reactor design problem to various mathematical programming problems.

This stage is performed by the third level decision-maker. The ranking of possible criteria according to the degree of prediction is carried out on the basis of general considerations - an external knowledge base (it is customary to optimize power reactors according to one of the autonomic criteria, for example, the cost of electricity produced) and information obtained from the first internal database. The problem associated with the large dimension of the problem can also be solved on the basis of preliminary ranking of the functionals of the problem according to the degree of significance or the importance of influence on the results of solving a specific problem.

A possible way of ranking emergency situations and safety functionals according to the degree of significance was developed by the author on the basis of the maximin strategy of a cooperative game. The probabilities of accidents, safety functionals and others were chosen as criteria for a discrete multicriteria problem. Emergency modes from among ATWS and their combinations were selected as objects of the problem.

4. Solving problems of mathematical programming, including in conditions of uncertainty of the initial information.

The stage is implemented by the decision maker of the third level of the hierarchy using the basic computational and optimization software package (in this case: when designing fast reactors, it is proposed to use the “Dragon-M” code [3, 6]. The solution to the problem of mathematical programming is fully formalized. However, the obtained optimum may turn out to be local. A single (global) optimum is needed. For this reason, the problem of mathematical programming is usually solved several times, using different initial values of the control parameters. If the solutions coincide, the found optimum is global, that is, it is defined correctly.

5. Analysis of solutions to problems of mathematical programming.

If necessary, the stage includes a parameterization procedure, an analysis of uncertainties, an additional "extended" safety analysis, involving consideration of a wider set of emergency situations that were deliberately excluded from consideration at the previous stage when choosing the most significant emergency modes and functionalities characterizing these modes. The ranking of decisions according to the degree of preference is carried out with the aim of possible exclusion from consideration of uninformative or obviously unpreferable options. All results are consolidated into a single database (second internal database). This stage is performed by the decision maker of the third hierarchical level.

6. Determination of a set of additional criteria (including on the basis of internal knowledge bases) for choosing preferred options, establishing the preference of criteria, formulating a multi-criteria problem. The stage is performed by the decision maker at the second level of the hierarchy.

7. Solving the multicriteria problem posed at the previous stage using different methods.

The analysis of the stability of the solution to the chosen methods is carried out. The preferred options are

determined. The stage is implemented by the decision-maker of the third hierarchical level.

8. Additional analysis of the results is underway. It is based on high-precision (precision) calculations using the appropriate software systems and correcting the options obtained in the previous stage.

9. An analysis of the preferred options obtained in the previous steps is carried out. The ranking of options according to the degree of preference is given from the point of view of a particular set of criteria. In this case, previously excluded (less significant) information from internal knowledge bases is used. A third internal database is being formed with comments on each option and each chain of options, arranged in the order of certain priorities. The stage is performed by a second-level decision maker.

10. Transfer of the third internal database to the upper level of the hierarchy for the final decision: the choice of the only option that will be implemented.

2.5. Optimization Models

The decision-making procedure is based on the "Dragon-M" calculation and optimization code.

The search for the optimum is carried out using the method of sequential linearization [7]. This method has been successfully used for several decades to solve practical problems of optimizing fast reactors. The method of penalty functions can be considered as an alternative [14-16]. The penalty function method looks more preferable due to the possibility of solving optimization problems with functionals in which significant nonlinearities are present, and also because of the same applicability to classical and no classical problems. The main disadvantage of the penalty function method is its practical applicability only to problems of small dimension.

In the task of designing a safe reactor, several tens of control parameters and functions are commonly used. The functionals of the problem $F_i(\boldsymbol{u})$ have a complex dependence on the vector $\boldsymbol{u}$ of control parameters.

Automation of the search for optimal reactor layouts with a large dimension of the problem can be achieved using iterative methods [14, 15]. However, in multi-extreme problems, iterative methods can lead to a relative rather than an absolute optimum. Therefore, it is always useful to repeat the solution of the problem, starting with different values of the control parameters. If in this case the same controls are obtained, then it can be hoped that the iterative search has led to the absolute optimum.

Linear programming methods (in particular, the simplex method) allow solving problems with a large number of control parameters. Practical problems of reactor optimization (with nonlinear functionals) are related to nonlinear programming problems. There are various methods for solving them. The simplest of them is based on the linearization of the problem, that is, the approximation of the nonlinear dependence $F_i(\boldsymbol{u})$, where $i = 0, 1, I$, by segments of linear functionals. High accuracy of approximation is ensured by reducing the intervals of dividing by $\boldsymbol{u}$. After replacing $F_i(\boldsymbol{u})$ with a piecewise continuous dependence on $\boldsymbol{u}$, the problem is solved by one of the linear programming methods. The sequential linearization method does not require preliminary transformation and retains the non-classical nature of the problem. This method is implemented in the form of a stepwise process of searching for the optimum, which starts at some point determined by the selected value of the control vector. The change in the values of the controls at each step of the search for the optimum is carried out by solving a linear programming problem formulated using the linearization of the problem functionals.

Consider the problem of linearizing a single objective functional $F_0(\boldsymbol{u})$ under constraints in the form of nonstrict inequalities $F_i(\boldsymbol{u}) \le F_i^*$, $i = 1, 2,\ldots, I$, by the method of successive linearization. This is an iterative method, that is, the solution is found using successive iterations in u. The method is based on lining up a sequence of controls obtained as a result of iterations: $\boldsymbol{u}^{(1)}, \boldsymbol{u}^{(2)},\ldots, \boldsymbol{u}^{(j)},\ldots$ ($u_k^{min} \le u_k \le u_k^{max}$, $k = 1, 2,\ldots, K$), which improves (in this case, minimizes) the value of the objective functional.

The transition from iteration to iteration is carried out by choosing the variation $\delta\boldsymbol{u}^{(j)}$:

$$\boldsymbol{u}^{(j+1)} = \boldsymbol{u}^{(j)} + \delta\boldsymbol{u}^{(j)},\ \delta\boldsymbol{u}^{(j)} << \boldsymbol{u}^{(j)}.$$

The main condition for carrying out iterations is that the constraints

$$u_k^{min} \le (u_k^{(j)} + \delta u_k^{(j)}) \le u_k^{max} \text{ (where } k = 1, 2, \ldots, K)$$

are satisfied and the conditions

$$F_i(u_k^{(j)} + \delta u_k^{(j)}) \le F_i^*,\ i = 1, 2, \ldots, I.$$

The most laborious part of the above-considered optimal search scheme is the linearization of the problem associated with the calculation of the sensitivity factors of the functionals to the control parameters. Their calculation is accompanied by the solution of conjugate equations. The sensitivity factors are calculated using the relations of the theory of small perturbations.

The main disadvantage of the method is the problem of choosing the step of changing the control parameters. With a large step, the linearity of the problem is violated, with a small step, the time for solving the problem increases (i.e., the efficiency of solving the problem decreases). The linear approximation for the

approximation of a nonlinear function is valid only for a small neighborhood of the control vector. To eliminate this drawback, two methods are used:

- restriction of the norm of the vector $\boldsymbol{u}$;
- the penalty for large deviations must be accounted for.

In the second case, the rate of convergence of the method is higher. In this case, instead of the linear programming problem, it is necessary to solve the quadratic programming problem [16].

During the optimization process, additional information appears (about the nature of the change in the safety functional, about the shift of the maximum to the adjacent zone, etc.); therefore, it is desirable to provide for the possibility of user intervention at any stage of research.

2.6. Basic Models for Calculating the Functionals of the Problem. Neutron-physical calculation of the reactor

The calculation begins with the preparation of nuclear data. Data preparation includes several stages [17]:

- Experimental data acquisition;
- Verification of previously unprocessed ("raw") measurements;
- Comparative assessment of data quality and selection of the most preferred ones;
- Preparation of previously selected data and use in neutron-physical calculation programs;
- Data validation and development of recommendations for their use.

Four nuclear data centers operate under the auspices of the IAEA [13, 18]:

- Nuclear Data Section (Vienna);
- OECD NEA Data Bank (Paris), including the Japanese National Data Center of JAERI;
- Brookhaven Centers (USA and Canada);
- Russian Center (SSC RF - IPPE, Obninsk).

There are data libraries of Western European cooperation JEF (Joint Evaluated File Progect - the modern version of JEFF-3.3 [13, 18], coordinated by the OECD NEA (Economic Cooperation and Development Nuclear Energy Agency) working group. The NEA agency unites 28 countries in Europe, North America and the Asia-Pacific region.

In the calculations of fast reactors (without a moderator), a library of materials important for the technology of fusion reactors, EFF (European Fusion File), is sometimes used. The EAF (European Activation File) library is used to obtain the activation cross-sections. There are complex libraries. For example JEFF-3 includes JEF, EFF, and EAF. Modern versions of the following libraries are often used: JENDL-3.3 (Japanese Evaluated Nuclear Data Library [13], BROND-3.1, ABBN (Russia, State Research Center of the Russian Federation - IPPE) [13] and CENDL-3.2 (China).

All Evaluated Nuclear Data Libraries (files) use the same ENDF / B format (ENDF / B-VII.1 and VIII.0 [13, 18].

In the general case, there are three types (stages) of neutron-physical calculation [17]:

- Calculation at the stage of conceptual development,
- Detailed calculations of the reactor structure,
- Calculations for planning the operation of the reactor must be carried out.

Calculations of the first type (stage) are carried out at the initial design stage, when high accuracy is not required. The purpose of the calculations is to determine the potential advantage of a given type of reactor or the effectiveness of new reactor elements. Research of some innovative projects requires exact knowledge of nuclear constants for new materials in nuclear technology.

The main requirement for calculations of the second type (stage) is high accuracy and calculated demonstration of the safety of the developed reactor. The estimates obtained at the previous step of the calculations are replaced by new estimates, including the reactor kinetics: temperature changes in the reactivity, density and geometry of the core components, including possible changes in power, coolant flow rate, and coolant temperature at the core inlet. At this stage, accurate estimates of fuel enrichment, correct accounting of control rods are required [17].

Calculations of the third type are important for assessing the power and temperatures of each fuel assembly, fuel burnup (change in reactivity), and fuel swelling. On the basis of calculations of neutron fields and fields of γ-quanta, the development of the reactor protection is carried out.

The field of neurons and the effective multiplication factor of neutrons in the Dragon-M code are calculated based on the solution of a multi-group (26 groups by energy) diffusion equation in the approximation of a quasi-critical reactor [19, 20]. It is assumed that the cylindrical reactor consists of several radial and axial zones. The zones are homogeneous, that is, the materials in the zones are mixed. To solve the equation, a semi-direct method of iterative synthesis is used.

The neutron diffusion equation has the form (notation generally accepted in the theory of nuclear reactors: D is the diffusion coefficient, Φ is the neutron flux density, Σ is the macroscopic cross sections, k is the effective multiplication factor etc. [20]:

$$\nabla_r [D_k(r, z)\, \nabla_r \Phi_k(r, z)] + \nabla_z [D_k(r, z)\, \nabla_z \Phi_k(r, z)] -$$

$$- \Sigma_{ad}^{(k)}(r, z)\, \Phi_k(r, z) + \sum_{l=1}^{k} \Sigma_d^{(l \to k)}(r, z)\, \Phi_l(r, z) +$$

$$+ \chi_k / k \sum_{l=1}^{K} [\nu_f^{(l)}\, \Sigma_f^{(l)}(r, z)]\, \Phi_l(r, z)] = 0.$$

2.7. Calculation of changes in the nuclide composition

It is assumed that the reactor consists of I radial ($i = 1, 2, \ldots, I$) and J axial ($j = 1, 2, \ldots, J$) zones. Within each zone (i, j), the properties of the medium are constant. The change in the nuclide composition is modeled by the corresponding equation:

$$d\rho_{i,j,l}(t) = [\int_0^{Tij} \rho_{i,j,l}(t)\, dt] / T_{i,j}.$$

Where $\rho_{i,j,l}(t)$ is the concentration of the l-th nuclide in the zone (i, j), $T_{i,j}$ is the campaign of the zone.

The approximation of uniformly partial refueling is used. The diffusion equations and the equation for changing the nuclide composition are solved together iteratively.

2.8. Calculation of the Vorth of Neutrons and the Vorth of Atomic Nuclei

To determine the vorth of neutrons and the vorth of nuclei (conjugate functions of the neutron flux density and concentration of nuclei, respectively), a variation approach is used. The approach assumes the formulation of the Lagrange operator of the neutron field. On the basis of the value functions, the coefficients of sensitivity of the corresponding functionals to the control parameters are determined

2.9. Thermal Hydraulic Calculation

The thermo hydraulic calculation takes into account the release of energy in nuclear reactions of fission of heavy nuclei and capture of neutrons. It is assumed that there is no heat transfer in each zone along the fuel element axis. The average temperatures of the core components are determined through the average volumetric heat release in each design zone.

2.10. Strength Calculation

The strength calculation is carried out according to the method presented in [7].

2.11. Simulation of ATWS

Modeling of emergency modes is based on the joint solution of the equations of point neutron kinetics (six groups of delayed neutrons are used), the unsteady heat equation, the coolant energy equation and the reactivity balance equation [3]. Reactivity coefficients are calculated using the Dragon-M code or can be calculated separately using the WIMS-D5B [21] or MCU-4 [22] code.

When calculating safety functionals, it is necessary to model complex interrelated and independent dynamic processes.

2.12. Refinement of Optimization Results

The diffusion approximation gives significant errors in calculating the void effect of reactivity in a no uniform reactor. For this reason, it is necessary to refine calculations using mathematical models and codes that do not use the diffusion approximation. The most accurate (precision) models are based on solving the gas kinetic equation of neutron transport. There are two main forms of writing this equation:

- gas-kinetic equation of neutron transport - the Boltzmann equation [22, 23],
- integrated equation of neutron transport - Peierls equation [24].

The author has developed hierarchical models with adjustable accuracy based on the MCU-4 precision code [6]. The stationary state of a reactor with a continuous dependence of micro sections on the neutron energy is considered. The model is used to clarify the void and density effects of reactivity and critical parameters of the reactor.

The WIMS-D5B code is used to calculate the temperature and density coefficients of reactivity. Neutrons are grouped into 69 energy groups. S_4-approximation is used.

All the above results are new and obtained by the author personally.

3. Results

3.1. Research Novelty

The developed software made it possible to obtain new results.

1. On the basis of a systematic approach, a unified methodology for substantiating and analyzing the safety of fast reactors has been proposed and implemented, which includes the following procedures.

- Optimization of the fast reactor core layout was carried out according to a given criterion with restrictions,

including restrictions for safety functionals characterizing specified emergency modes or the entire set of emergency modes that are not deterministically excluded. The control parameters include the properties of the core materials.

● an algorithm is proposed for reducing the dimension of the problem of choosing the optimal physical characteristics of the fast reactor core through the following procedures.

a) A procedure for preliminary ranking of emergency situations and their combinations according to the degree of danger (significance for consideration in the problems of optimal design) is proposed. The procedure is based on solving an auxiliary discrete multicriteria problem by the maximin method. The objects of the auxiliary task are emergency modes and their combinations, the criteria are the relative values of the safety functionals, the probability of an accident, etc.

b) An algorithm is proposed to quickly determine the role of reactivity coefficients in complex combinations of emergency modes based on an analysis of the self-protection area.

c) A procedure for the sequential analysis of conflicts of the optimization problem, the use of effective methods of decomposition is proposed.

● An effective procedure for taking into account the uncertainties of scenarios for the development of emergency situations in the problems of optimal design and problems of safety justification is proposed [3, 6]. The author proposed a method for constructing deterministic analogs for solving optimization problems in conditions of uncertainty of scenarios for the development of emergency situations. It is based on a preliminary analysis of the time dependence of safety functional and an analysis of the aggravation and neutralization of emergency situations when they are imposed. Compared with the use of uniformly distributed sequences, the proposed procedure is much more efficient.

2. The following results were obtained for the first time.

● The results of complex optimization of the core layouts of fast reactors with various coolants (silk metals Li, Na, K, Cs and alloys, heavy metals Ga, Pb, Bi and alloys, alloys of alkali and heavy metals) were obtained with restrictions, including for functionals of safety (and in conditions of uncertainty of scenarios for the development of emergency situations).

● The ranking of different coolants of fast reactors according to the degree of preference was carried out. For high-power fast power reactors, the most preferable coolant is based on lead extracted from thorium ores.

● The results of the analysis of the influence of technical systems that determine the time of reducing the flow rate when the pumps are de-energized, the time of transporting the coolant along the primary circuit, etc., on the self-protection of fast reactors were obtained.

3. Reserves of the concepts of BN and BREST reactors of high power in terms of further safety enhancement have been identified.

● For BREST reactors, it is proposed to use a heat transfer agent based on lead and thorium ores (with a high concentration of ^{208}Pb). This contributes to a decrease in the void effect of reactivity and an increase in self-protection against accidents with acceleration on prompt neutrons. It is proposed to use tungsten coatings of the cladding of fuel elements, deposited by means of low-temperature plasma spraying.

● For BN and BREST reactors, it is proposed to use pellet oxide or mononitride fuel based on fine-grained ceramic powder and uranium metal nanopowder. A fuel based on fine-grained powder of UN-PuN (or UN) mononitride and uranium nanopowder is ideal for ensuring the safety of the reactor.

3.2. Practical Relevance of Research

The importance of research is determined by the following factors.

● The Dragon-M code developed and repeatedly modernized by the author allows solving problems of optimal design with constraints, including those characterizing the entire set of emergency situations, in a deterministic setting and in conditions of uncertainty, including the uncertainty of emergency scenarios. Code Dragon-M has no analogues.

● Proposed and implemented procedures for analyzing the uncertainties of scenarios for the development of emergency modes, determining the role of reactivity coefficients in complex combinations of emergency modes (including ATWS), ranking emergency modes according to the degree of hazard, choosing conditionally equally safe (or equally hazardous) reactor assemblies. The results obtained supplement and concretize some sections of the IAEA documents on safety substantiation of nuclear power plants [25].

● The proposed effective hierarchical systems with adjustable accuracy based on well-known high-precision computer codes (MCU) are used to conduct exploratory computational experiments, deterministic substantiation and analysis of safety (void and density reactivity effects), implementation of experimental optimization methods, post-optimization analysis (parameterization). The systems allow you to analyze any type of reactor. To carry out post-optimization analysis and search computational

experiments, the author has developed a code for operational modeling of emergency modes of the ATWS type, taking into account their various combinations and the non-simultaneity of the beginning of the processes.

● The parameters that have the greatest impact on the safety of advanced reactor types (including the BREST and BN medium and high power types) were identified, further possible ways to improve their safety were analyzed.

● A systematic comparative analysis of the possibility of using various liquid metal coolants (including unconventional) fast reactors from a wide set of initial data was carried out (alkali metals Li, Na, K, Cs and their alloys, heavy metals Ga, Pb, Bi and their alloys were considered in detail , alloys of alkali and heavy metals). Special attention is paid to alloys with adjustable properties (Na-K-Ca, Pb-Na, Pb-K, etc.). The optimal layouts of reactors with different coolants (obtained with the same formulation of the optimization problem) were compared.

● On the basis of a system analysis, the reserves of the concept of power reactors BN and BREST were identified in order to improve safety.

● the isotopic composition of the lead coolant must be monitored. (The composition of lead recovered even from different samples of the same deposit can vary greatly.) Variations in the concentration of lead isotopes in the coolant have a large impact on neutron balance and safety.

3.3. Selected Results. The Problem of Optimizing the Composition of the Lead Coolant

Research began with the selection of the preferred heat carrier. For this, a multicriteria problem was solved using the lexicographic method. Lead was chosen as the preferred coolant.

Lead contains four stable isotopes (^{204}Pb, ^{206}Pb, ^{207}Pb and ^{208}Pb). The isotopic composition of natural lead is:

1.4% ^{204}Pb - 23.6% ^{206}Pb - 22.6% ^{207}Pb - 52.4% ^{208}Pb.

It was obtained by averaging over all known lead deposits (about 1500). In reality, there are no deposits with such a lead composition in nature. Lead recovered from different deposits has different isotopic compositions. This allows you to optimize the composition of the coolant. Most preferred is lead with a high content of the doubly magic isotope ^{208}Pb. It slows down and absorbs neutrons worse. When used, the void reactivity effect is minimal.

Thus, correction of the solution is possible (optimal coolant). The shifted ideal method was used to select the preferred lead deposit. The author has solved the problem of minimizing the void effect of reactivity. Concentrations of stable lead isotopes were included in the control parameters. The concentration range corresponds to statistical data on the concentrations of different lead isotopes in different deposits.

The scope of determination of lead concentrations is based on the analysis of numerous statistical data on deposits carried out by the author. For example, thorium ores contain lead isotopic composition:

0.01 ... 0.076% ^{204}Pb - 0.89 ... 26.43% ^{206}Pb - 0.35 ... 4.11% ^{207}Pb - 69.15 ... 97.74% ^{208}Pb.

Lead and polymetallic ores contain lead isotopic composition:

1.09 ... 1.61% ^{204}Pb - 18.64 ... 25.17% ^{206}Pb - 21.36 ... 30.80% ^{207}Pb - 49.30 ... 52.49% ^{208}Pb.

Among the limitations of the optimization room, the restrictions for the security functional simulating the safe termination of ATWS processes and their various (most dangerous) combinations were considered.

It was found that for a BREST-type reactor of infinitely high power (infinite radius of the core); safety is ensured when the ^{208}Pb isotope content is more than 75 ... 80%.

3.4. The Problem of the Optimal Choice of the Fuel Composition

To solve this problem, fuel density, heat transfer capacity and heat capacity were included in the number of control parameters. The criterion of optimality and the constraints of the problem did not change.

Optimal values of density, heat transfer and heat capacity do not allow selection of real fuel material. As a result of the solution, the range of admissible values of these parameters was obtained. This area corresponds to cermets based on a mixture of mononitride micro grains (UN-PuN or UN) and uranium metal nanopowder. For the manufacture of fuel with sealed (obtained) properties, it was necessary to take into account the technological limitations.

The porosity of the ceramic fuel reaches 25%. These pores between micro grains of ceramics can be filled with uranium metal nanopowder. To ensure the safe completion of ATWS processes and their combinations, it is necessary to ensure a nanopowder content of at least 20% (by weight). Complete filling of pores corresponds to a nanopowder fraction of 39%. Thus, the use of these cermets will not only increase the safety of the reactor, but also the power of the reactor (by 39%).

3.5. The Problem of Optimal Selection of the Fuel Element Cladding Material

To solve this problem, the concentration of alloying additions to structural steel of the AISI 316SS type was included in the number of control parameters [26]. The criterion of optimality and the constraints of the problem did not change.

A wide range of possible additives were considered, including materials not used in nuclear technology. To minimize the void effect of reactivity, the additives were formulated from materials that effectively absorb fast neutrons. To increase the corrosion and erosion resistance, the appropriate materials (primarily tungsten) were included in the additives. To model the coatings, it is necessary to consider the material of the fuel element cladding, consisting of several layers. Each layer is considered separately. The composition of the control vector includes the concentration of materials for each layer of the fuel element cladding.

As a result of solving the problem, a preferred tungsten-coated steel-based material was obtained.

Tungsten coatings are attractive for the following reasons.

- Tungsten coatings minimize the rate of corrosion and erosion of liquid lead construction materials.

- Tungsten coatings exclude the chemical exothermic reaction of chromium and water vapor (analogue of steam-zirconium reaction in thermal reactors). This can be realized when the lead-water heat exchanger tubes are depressurized.

- Tungsten coatings minimize the void reactivity effect.

All the proposed innovations (coolant, fuel, structural materials) were considered comprehensively.

3.6. Two-criterion Problem of Minimizing the Void Reactivity Effect and Maximizing the Reactor Power (Optimization of the Shape of the Core of a High-Power Reactor)

The author proposed an approach to solving multicriteria continuous optimization problems. It is based on the elements of positional games: sequential decision-making strategies. The approach is implemented on the example of two-criterion optimization (maximizing the power W, minimizing the void effect R of reactivity) of a fast reactor with a lead coolant with restrictions for different functionals, including safety functionals.

The general view of Pareto-optimal solutions to such a problem is shown in Figure 1. Here W^* and R^* are the minimum allowable power value and the maximum allowable value of the void reactivity effect, *a* - cylindrical core, *b* - annular and tape core (limitation of void reactivity effect does not prevent an increase in power). The condition $R = \beta$ (where β is the effective fraction of delayed neutrons) or $R = 0$ can be considered as a criterion for the limiting level. The disadvantages of using the criterion for the limiting level and the possibility of eliminating them are analyzed.

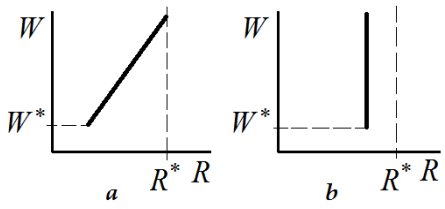

Figure 1: The Pareto set of the problem $W \rightarrow \max$, $R \rightarrow \min$

Using the innovative materials (coolant, fuel, and structural materials) discussed above, it is possible to ensure the safety of the BREST-2400 reactor with a traditional (cylindrical) core. The void reactivity effect is negative or much less than β even under the most dangerous scenario of its realization (drainage of the central part of the core). The reactor is safe in ATWS modes and in the most hazardous ATWS combinations.

3.7. Selection of Parameters that have the Greatest Impact on Safety

The problem was solved by the method of the shifted ideal. Consider a BREST-type reactor of anomalously high power (BREST-2400). The cylindrical core BREST-2400 is assembled from coverless fuel assemblies of the BREST-OD-300 reactor [4] with a square lattice of fuel elements and has three profiling zones.

The parameters w_k that have the greatest impact on safety in LOF WS mode have been identified. The most significant parameter corresponds to $| H_{i,k} | \rightarrow \max$;

$$H_{i,k} = dF_i / dw_k \cdot w_k/F_i$$

are the relative coefficients of the sensitivity of the functionals F_i to these parameters w_k. For illustration, three criteria have been selected: H_1 - relative coefficients of sensitivity of the maximum temperature of the fuel element cladding in the central profiling zone in the LOF WS transient mode; H_2 - also, in the mode of natural circulation of the coolant; H_3 - relative sensitivity coefficients of the maximum fuel temperature in the first profiling zone in the LOF WS transient mode.

The most preferable object of the problem of maximizing these three criteria can be considered the most significant from the point of view of the impact on self-protection from an accident of the LOF WS type. Among the parameters wk are effective objects: the average velocity of the lead coolant (object 1), the diameter of the fuel pellet (object 2), the height of the fuel

column (3), the relative spacing of the fuel element lattice (4), the volume fraction of the fuel (5), the time of decreasing the consumption (6). Objects 1 through 5 correspond to the center grading area.

Since the critical element of the BREST reactor is the cladding of fuel elements (in emergency modes, there are significant reserves of fuel and coolant temperatures), the most significant criteria are H_1 and H_2. Based on the method of the shifted ideal in coordinates (H_1, H_2), provided that these criteria are equivalent, the objects of the problem can be ranked according to the degree of preference as follows: 4 > 2 > 1 > 3 ~ 5 > 6. (The ">" sign means that the object is more preferable, the sign "~" means the objects are equivalent.)

Similar studies have been carried out for other types of accidents. The self-protection of BREST-2400 against LOF WS accidents is most influenced by the spacing of the fuel rod lattice; from overlapping LOF WS and TOP WS - fuel element lattice spacing and introduced reactivity; from the most dangerous combination (LOF WS + TOP WS + LOHS WS) - introduced reactivity and effective height of the natural circulation circuit.

4. The result of applying the software

The result of using the software is presented in a number of works published earlier by the author (see, for example, [3, 6] and others).

As an example of using the Dragon-M code, consider the problem of minimizing the void effect of reactivity and maximizing the power of a BREST reactor with fuel, coolant, and structural materials traditional for this reactor. Traditional UN-fuel (without uranium nanopowder), which does not contain plutonium, is used as the initial load. Natural lead is used as a coolant. There are no tungsten coatings of fuel rod cladding. The core consists of two zones of different enrichment.

The thermal power of the reactor is 5.680 GW (BREST-2300). The void effect of reactivity during drying of the central part of the reactor is negative and equals minus 1.255. This is not the most dangerous scenario. When bubbles are involved in the core (lead density decreases by 30%), the void reactivity effect is positive and exceeds the effective fraction of delayed neutrons by a factor of 6.

The optimal layout of the BREST reactor is characterized by the following values of the control parameters. Fuel enrichment in the zones is 13.0 and 16.4%, respectively. The diameter of the fuel pellet is the same in both zones and equals 7.42 mm. The relative spacing of the fuel element array is 1.46 and 1.48, respectively. The core height is 110 cm. The radial dimensions of the zones are 178.5 and 50.0 cm, respectively. The mass flow rate of the coolant is 29811 and 30091 kg m^{-2} s^{-1}, respectively.

The following values of the functionals characterizing the emergency modes of ATWS are obtained. The maximum coolant temperature in the LOF WS mode is 1010 and 1022 K, respectively, for two profiling zones. The maximum fuel temperature in TOP WS mode is 1420 and 1560 K, respectively. The steady state power of TOP WS is 13.1% higher than the nominal value.

When the processes LOF WS, TOP WS and OVC WS are superimposed, the maximum coolant temperature is 1062 and 1077 K, respectively.

The reactor cannot be considered safe due to the unacceptably high value of the void reactivity effect.

After the next upgrade of the Dragon-M code, it became possible to consider the properties of materials among the control parameters. In addition, it became possible to consider layered fuel-element cladding. It is not always possible to select materials with desired properties. Permissible density and thermal conductivity corresponds to fuel based on a mixture of ceramics and metal. However, cermets are characterized by a low melting point. The task is to find cermets fuel, the melting point of which is not lower than the melting point of ceramics.

The main result concerns the proposed innovations for fast reactors of high electric power (1.2 ... 2.5 GW) with lead coolant. This is a cermet pellet fuel based on a mixture of UN-PuN micro grains (up to 60…80% by weight) and uranium metal nanopowder (up to 20…40%). This is a coolant based on lead extracted from thorium ores. These are tungsten coatings of fuel rod claddings. Taken together, these innovations make it possible to exclude the entire set of accidents (from among ATWS). At the same time, there is no need for passive safety systems provided for in the designs of the BREST reactors [4].

It is assumed that fuel assemblies of the BREST-OD-300 reactor are used in the core [4]. The fuel rod claddings consist of three layers. The inner layer with a thickness of 0.1 mm consists of tungsten. The central layer 0.3 mm thick consists of corrosion-resistant steel of the BREST-OD-300 reactor. The outer layer is 0.1 mm thick and consists of tungsten.

In any combination of ATWS-type emergency modes, the maximum fuel temperatures do not exceed the allowable value (1350 K), the maximum fuel cladding temperatures do not exceed the allowable value (1150 K), there is a large margin for coolant boiling (about 1000 K). The most dangerous scenario for the implementation of the void effect of reactivity is associated with the

depressurization of the tubes of the heat exchanger "lead - water vapor of the secondary circuit" and the involvement of bubbles in the central part of the core. The most dangerous decrease in the average density of lead by 30 ... 40%. In this case, the void effect of reactivity is negative.

For comparison, in the BREST-OD-300 reactor under construction, it is possible to “pick up” a combination of emergency modes when the operation of passive safety systems is required. Under the most dangerous implementation scenario, the void effect is positive [4]. Calculations using the MCU code show that when the reactor power is increased (project BREST-1200), the void effect of reactivity exceeds the effective fraction of delayed neutrons by about 6 times. This takes the BREST reactor project beyond the concept of "natural safety".

5. Discussion

The module for modeling ATWS emergency modes and calculating sensitivity coefficients as part of the Dracon-M code was developed by the author taking into account the experience of researching emergency modes accumulated by the world community. These are the published results of experimental modeling of ATWS emergency modes at the EBR-II reactor [5]; results of experiments on BN-600, BOR-60 and "Rapsodie" reactors, FFTF and BFS facilities.

Experimental simulations of ATWS modes are costly and difficult. (Similar experiments were carried out in the USA at the EBR-II reactor in the late 1980s [5]). Comparison of the results of mathematical modeling of ATWS emergency modes in BN-800 and BREST-OD-300 reactors, carried out by the author, with the results of similar studies, confirm the possibility of using the author's code. For example, the results of modeling the LOF WS mode in BN-800, carried out according to different programs in Germany, France, Japan, Russia, India, predict the beginning of sodium boiling in 16.72 ... 18.96 s after the main circulation pumps of the primary circuit are de-energized [27]. Similar calculations carried out by the author give a value of 17 s.

The proposed algorithm, which increases the efficiency of decision-making in the problems of the initial stage of reactor design, is in good agreement with the well-known methods of system analysis (Golubkov's method [28]), approaches of the theory of decision-making. The author's approach to taking into account the uncertainties of scenarios for the development of emergency modes is based on the well-known fact that the minimization of subjective interference is possible by obtaining additional information when solving the problem. Such information appears during a preliminary analysis of the possibility of aggravating and neutralizing emergency modes when they are superimposed, carried out using the method of modeling emergency modes.

When carrying out informal procedures, intuitive concepts are used. To combine mathematical theories and informal procedures into a single methodology, it was necessary to formalize intuitive concepts (one of the main tasks of game theory): a conservative approach to calculating security functionals, conditionally equally safe and equally dangerous layouts; when emergency modes are imposed - dominant, competing, equivalent processes, neutralization and aggravation of emergency modes.

The safety of the BREST-OD-300 reactor under construction and the BREST-1200 conceptual design is higher than the requirements of the Russian regulatory and technical documentation (Standard of the State Corporation Rosatom "Basic Rules for Nuclear Safety in the Production, Use, Processing, Storage and Transportation of Nuclear Fissile Materials", 2016. Federal Norms and rules in the field of the use of atomic energy "General provisions for ensuring the safety of nuclear power plants", 2015.) The safety of the reactor when using the proposed innovations regarding fuel, coolant and structural materials (coatings of fuel cladding) is even higher. The results obtained supplement and specify some sections of the IAEA documents on NPP safety analysis (for example, the document "Accident Analysis for Nuclear Power Plants. Safety Reports Series no. 23, IAEA, Vienna, 2002").

Field experiments, similar to those carried out at the EBR-II reactor [5], are practically impossible due to the high risk and cost of such experiments. Separate experiments (including thermal-hydraulic ones) were carried out on the lead loop of the pilot BOR-60 reactor (NIIAR, Dimitrovgrad, Russia). The author did not participate in these experiments.

6. Conclusion

The research carried out is based on a comprehensive and correct use of well-known scientific approaches and methods related to operations research. The studies carried out constitute applications of operations research to solving the problem of ensuring safety at the initial stage of reactor design.

In the research, the computational and optimization complex Dragon-M, which has no analogues, was used. The optimization results can only be compared with the variant calculations carried out by the designers of the new generation reactors. The parameters of the BN-800 reactor core configurations obtained using the Dragon-M complex when solving various optimization problems and tasks without an optimality criterion are in good

agreement with the accepted values for BN-800 (including for the version with mononitride fuel [27]). The main difference between the results obtained by the author consists in taking into account the restrictions for the security functionals. In most cases, such restrictions significantly affect the choice of the core layout.

The author proposes and implements an effective procedure for solving problems with constraints for safety functionals under conditions of uncertainty of scenarios for the development of emergency situations, based on obtaining additional information and the possibility of abandoning the use of the traditional approach (criteria of the theory of games for choosing rational decisions).

An algorithm that increases the efficiency of decision-making in the tasks of the initial design stage, substantiation and analysis of the safety of fast reactors was developed and implemented. The proposed and implemented methods, models, approaches and procedures are combined into a single methodology, which is an application of operations research to solving a practical problem associated with the development of new generation reactors.

Optimal design problems with constraints for reliability and safety functionals in a deterministic formulation and under conditions of initial data uncertainty, including the uncertainty of emergency scenarios, as well as practically important auxiliary multicriteria problems were solved.

The solution to the problem of choosing the optimal characteristics of the fast reactor core and particular problems, including the choice of the preferred coolant and others, is based on a systematic approach. Similar tasks of system analysis are solved on the basis of operations research methods.

Elements of operations research (mathematical programming, multicriteria optimization, Markov decision-making models, decision-making procedures under conditions of risk and uncertainty, game theory, etc.) are used to solve the problem of choosing the optimal physical characteristics of a liquid-cooled fast reactor core that satisfies the series given requirements (including self-protection against the entire set of severe accidents, not deterministically excluded).

At the stage of validation of the Dragon-M and FRISS codes, the results were compared with the known results obtained earlier.

The calculation and optimization results for the Dragon-M code were compared with the results obtained for much simpler codes developed much earlier [7]. These codes do not consider functionals that characterize emergency situations. The results of ATWS accident simulations were compared with the full-scale results of experiments conducted in the USA at the EBR-II reactor [5]. A comparison was made of the results of simulation of individual emergency modes with the results of experiments carried out in different countries on fast reactors and stands.

When designing a new generation reactor, the characteristics of emergency modes are not exactly known in advance. For this reason, an analysis of the uncertainties of the initial data was carried out, including an analysis of the uncertainties of scenarios for the development of emergency situations [29]. This procedure includes several steps. At the first stage, the areas of permissible perturbations are determined by reactivity, coolant flow rate, and coolant temperature at the core inlet. (All emergency modes are modeled using a combination of these perturbations.) At the second stage, individual emergency modes from among the ATWS were identified and studied. As uncertain data, the values of the disturbances that initiated the emergency mode, the time of introduction of the disturbance, the law according to which the disturbance is introduced (linear, hyperbolic, and others) were considered. At the next stage, the possibility of neutralizing and aggravating emergency situations when they were imposed was considered. This made it possible to obtain additional data for analysis. These additional data made it possible to abandon the well-known methods for selecting points in the space of uncertain data, in which it is necessary to formulate deterministic analogues (LPτ-sequences, the max-min principle). As a result, a more efficient procedure for choosing points at which it is necessary to formulate deterministic analogs has been obtained. In addition, the number of points was reduced by approximately 10 times with the same accuracy [29].

The decision-making model in such a problem has such a large dimension and a large number of internal connections that it complicates the possibility of its practical implementation. A rationalization of the decision-making procedure was required, connected, first of all, with an increase in its efficiency in the presence of heterogeneous and uncertain information. The developed software makes it possible to design new generation reactors, in which accidents with unacceptable releases of radioactive substances outside the nuclear power plant are excluded.

The problem is considered on the example of one of the types of nuclear reactors of the new generation. The ideas are quite applicable to the study of industrial facilities that pose an increased danger.

Conflict of Interest

The author declared no conflict of interest.

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VIACHESLAV SERGEEVICH OKUNEV graduated from MEPhI in 1988. The author graduated from the Moscow Engineering Physics Institute (Russia) in 1988. In 1995, he received a Ph.D. (candidate of technical sciences) from the Moscow Engineering Physics Institute. V.S. Okunev is currently an Associate Professor at the Bauman Moscow State Technical University.

He is the author of five monographs, five textbooks and over 220 publications in the field of optimal design and safety of nuclear reactors, operations research, nuclear physics and technology.

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Machine Learning Aided Depression Detection in Community Dwellers

Vijay Kumar, Muskan Khajuria *, Anshu Singh

Department of Computer Science and Engineering, National Institute of Technology Hamirpur, Hamirpur, 177005, India

*Corresponding author: Muskan Khajuria, NIT Hamirpur, 185005@nith.ac.in

ABSTRACT: Depression is a mental condition that can have serious negative effects on an individual's thoughts and behavior. It paves way to anxiety and health problems that could lead to grave heart diseases. Depression detection has become necessary in community dwellers considering the lifestyle being followed. Here we use NHANES dataset to compare the performance of various machine learning algorithms in depression detection. The 2015 dataset was used to train the models and testing was done on data from 2017 to analyze the robustness of the model. Feature extraction was also performed on the dataset to observe relevant features. It was found that ADABoost used with Synthetic Minority Oversampling Technique (SMOTE) gave the best test results in terms of F1 score.

KEYWORDS Depression, Machine Learning, mental health, SMOTE, ADABoost, SelectKBest

1. Introduction

Depression is a psychological disorder that can be characterized by the existence of persistent sadness for at least two weeks. It creates an inability to perform daily activities, the depressed persons lose their interests and pleasures in doing those things that they usually enjoy. Nowadays a large number of youth and adults around the world suffer from depression. Depression can cause severe problems in case of failing to detect it at an early stage or failing to ensure the timely counseling of a depressed person. It is one of the major reasons to raise suicidal cases. During COVID-19 pandemic situation, depression has become a major health concern in the world and 322 million people all over the world are living with depression.

Every year about 0.8 million suicide cases take place worldwide. Among them, half of the cases occur due to depression. Over 700,000 people die due to suicide every year. Suicide is the fourth leading cause of death in 15-29 year age range. Major depressive disorder is a treatable mental disorder that appears when the individual is too stressed out. Globally, it is estimated that 5.0% of adults suffer from depression.

The effort to shun the stigma associated with mental illness like depression calls for greater awareness as these problems tend to be brushed aside. Another solution is mass screening, which requires a great amount of resources and time. However, this screening has the potential to reduce to few people. There may be people in certain demographics that may be more prone to depression because of genetic, health, medicinal, financial and social conditions. If those groups can be identified, special attention can be provided as an aid to prevent depression and also monitor them closely, and look at the contributing and affecting factors regarding depression.

Machine learning has the capability to automatically identify the patterns in the data and make predictions accordingly. This technology is being applied to different disciplines and has proved to emerge as a significant aid in the medical field as well.

Therefore, the aim is to make the use of machine learning models to predict if given community dweller may be depressed or not. The machine learning models are then trained on the relevant features of the data and their accuracy is compared by using different metrics.

Machine learning will help predict disease accurately which would enable medical teams to do the treatment.

This study utilizes datasets available at National Health and Nutrition Examination Survey (NHANES) [1] for building a model to predict depression using data from the year 2015 and 2017. The performance of various classification algorithms with different combinations of SMOTE [2], SMOTE with undersampling and SelectKBest algorithms were compared.

The parameter for evaluation of results are accuracy, F1 score and ROC AUC score. ADABoost paired with SMOTE with undersampling gave the best F1 score. XGBoost paired with SMOTE with undersampling provided the highest ROC AUC score. The highest accuracy [3] was seen in Random Forest. XGBoost with undersampling gave the best F1 [4] and ROC AUC [5] score in the dataset formed using SelectKBest algorithm, and LR gave the best accuracy.

We develop a model to predict depression in a community dweller. It would help predict dwellers at a risk.

The major contributions of this study are:

1. Identifying the most important socio-demographic factors responsible for depression.

2. Using health conditions and psychosocial information of the persons to predict depression.
3. Using machine learning and feature selection algorithms to predict existence of depression efficiently.
4. Simple questions make procedure to collect information easier, as suspected depressed person are not required to answer authentic depression screening scales.
5. Comparing different algorithms to observe the best performing algorithms.
6. Using dataset from different years to make model more robust.

2. Literature Review

There have been studies to apply Machine Learning to predict depression in communities to identify the vulnerable groups.

1. A study in China used machine learning to predict depression in the elderly. The data was collected in the form of a questionnaire with information about demographics, health related risk factors and chronic disease factors. K Nearest Neighbour (KNN) was used to fill in the missing data. The machine learning models used were linear regression, linear regression with LASSO regularisation, gradient-boosted decision tree (GBDT), Support Vector Machines (SVM) and Deep Neural Network (DNN). Linear regression (AUC=0.63) and DNN performed comparable to LSTM (reference) using AUC, one of the reasons could be their ability to deal with nonlinear relationships between variables [6].
2. This study used Novel Assessment of Nutrition and Ageing(NANA) to predict depression by using LASSO and k-fold cross validation.The model produced an area under the ROC curve of value 0.88 [7].
3. It was found that model-based policy can save approximately 50% to 60% of provider resources as compared to mass screening but will not identify 30% of patients with depression. Patient Health Questionnaire (PHQ) was taken as measure and 20 candidate predictors were identified from the combined DCAT-MDDP data. Using 10-fold cross-validation results, LR outperformed the other 3 models in AUROC (LR = 81%, multilayer perceptron = 80%, SVM = 73%, random forest = 0.78). The LR model also had the highest percentage of correctly classified instances of depression (LR = 74.0%, multilayer perceptron = 73.5%, SVM = 71.6%, random forest = 72.6%) and sensitivity (LR = 0.65, multilayer perceptron = 0.55, SVM = 0.61, random forest = 0.65), and the second highest specificity (LR = 0.81, multilayer perceptron = 0.88, SVM = 0.80, random forest = 0.79) among the 4 models. [8]
4. A study in Kerala was proposed to detect using ANN. Various sociodemographic variables like age and gender were taken into consideration to develop the model. The ANN Model that was designed with seven interconnected neurons in one hidden layer had prediction accuracy of 97.2% [9].
5. XGBoost model used on a set of 28 biomarkers from the Lifelines Database that related to immune functioning, cell metabolism, etc. Multiple samples were created using under sampling, over sampling and over-under sampling to balance the dataset. Overall score of more than 0.90 were obtained [10].
6. This study is done on the dataset for the KHANES for the year 2014 and 2016, where 2014 data was taken as training set while 2016 as test set to see the efficiency of the model with future dataset. LASSO technique was used for feature reduction and classifiers in the final model. For controlling class imbalances between the two groups in the 2014 dataset SMOTE was used [11].
7. The classification models were trained on 365 exams using a binary cross-entropy loss function and an independent set of 91 exams were left for a testing phase. A regularization method was used to avoid overfitting the training data. Accuracy of 69.23)% was achieved for the model. This model uses a multimodal deep learning model that used video data, audio data, and word content from participants' responses, as well as demographics and other metadata [12].
8. NHANES data set was used to identify the medical conditions associated with people in depression. They first identified the clusters with high depression rate using SOM. Traditional binary LR was also used for their identification.A boosted regression machine learning algorithm was used to provide a relative importance percentage for each medical symptom for each of the five key significant clusters, allowing the easy grouping of symptoms into medical categories. The machine learning boosted regression algorithm was able to untangle the array of medical symptoms. [13]

   For a brief comparison with other studies, this study predicts if an individual is having depression while other similar studies have focused on predicting depression among a certain age group, occupation or health, this study has extracted for professions, health conditions and socioeconomic backgrounds. Different studies achieved accuracy in a range of 60-80%, this study gives accuracy of 0.92 with Random-forest using techniques like ADA Boost, SMOTE, Random Forest classifier with 25 attributes varying in health status, income status, social status, mental condition and behavior of past few days [14], [15].

   From the review of literature about machine learning application in mental health, it was found that machine learning algorithms are useful in predicting depression cases. In most of the research papers, the sample size was small hence it creates a doubt that the powerful machine learning algorithms like SVM, random forest, kNN etc. may overfit the data and will give high variance output when model is applied on

new data. It should also be taken into consideration that the dataset is taken from clinical studies and trials and real life scenarios do not always support balanced proportions of target variable classes.

3. Materials and Methods

In this section, the dataset and techniques used for depression prediction are briefly described.

3.1. Data Set

The National Health and Nutrition Examination Survey releases data in two-year groupings. This paper used 2015 datasets as training data with 152 variables and 2017 for testing for 152 variables. The data consisted of various segments, out of which the following were selected for this study :

1. **AccultrationDF:** Acculturation section provides personal interview data on language use in the home. Questions asked and response categories used were customized, based on self-identified race and Hispanic origin.
2. **AlcoholDF:** Alcohol Use Questionnaire (variable name prefix ALQ) focuses on lifetime and current use (past 12 months). Questions are not specific to type of alcohol used.
3. **AudiometryDF:** Audiometry questionnaire section (variable name prefix AUQ) provides interview data on self-reported hearing status, tinnitus (ringing in the ears), hearing screening history, the use of hearing aids, the use of assistive devices for hearing, and risk factors for hearing loss.
4. **BPCholDF:** Blood Pressure/Cholesterol section (variable name prefix BPQ) provides personal interview data on awareness, treatment, and control of high blood pressure and high cholesterol.
5. **CardiocDF:** Cardiovascular Disease and Health section (variable name prefix CDQ) provides participant level interview data on evaluating cardiovascular health and includes questions to assess the presence of angina pectoris as defined by the Rose1 questionnaire.
6. **ConsumerDF:** Consumer Behavior questionnaire (variable name prefix CBQ) section provides interview data on food expenditures at the family level as part of the Flexible Consumer Behavior Survey (FCBS) module.
7. **Curr_healthDF:** Current Health Status section (variable name prefix HSQ) provides personal interview data on overall health assessment, recent illness (past 30 days), blood donation, and HIV testing.
8. **Mental_HealthDF:** A nine-item depression screening instrument (variable name prefix DPQ), also called the Patient Health Questionnaire was administered to determine the frequency of depression symptoms over the past 2 weeks. A follow-up question assessed the overall impairment of the symptoms. Response categories for the nine-item instrument "not at all," "several days," "more than half the days," and "nearly every day" were given a point ranging from 0 to 3. The instrument incorporates DSM-IV depression diagnostic criteria.
9. **DermaDF:** Dermatology questionnaire section (variable name prefix DEQ) provides personal interview data on sun exposure and sun protective behavior.
10. **DiabetesDF:** Diabetes section (variable name prefix DIQ) provides personal interview data on diabetes, prediabetes, use of insulin or oral hypoglycemic medications, and diabetic retinopathy. It also provides self-reported information on awareness of risk factors for diabetes, general knowledge of diabetic complications, and medical or personal cares associated with diabetes.
11. **DietDF:** Diet Behavior and Nutrition questionnaire (variable name prefix DBQ) provides personal interview data on various dietary behavior and nutrition related topics. Many of the questions were included in NHANES II (1976-80).
12. **DisabilityDF:** Disability questionnaire (variable name prefix DLQ) provides respondent-level interview data on serious difficulty hearing, seeing, concentrating, walking, dressing, and running errands.
13. **DrugDF:** Drug Use Questionnaire (variable name prefix DUQ) focuses on lifetime and current use of marijuana or hashish, cocaine, heroin, and methamphetamine, as well as intravenous use of these and other drugs.
14. **EarlyChildDF:** Early Childhood questionnaire (variable name prefix ECQ) section of the Sample Person Questionnaire provides personal interview data for children, including the age of the biological mother when the child participant was born, smoking habits of the mother while she was pregnant with the participant, birth weight and the proxy's assessment of the participant's current weight.
15. **FoodSecDF:** Food Security section (variable name prefix FSQ) provides individual and household-level interview data on the following topics - Household food security, Supplemental Nutrition Assistance Program (SNAP)/Food Stamp program benefits and Women, Infants and Children (WIC) program benefits
16. **HealthInsDF:** Health Insurance questionnaire (variable name prefix HIQ) provides respondent-level interview data on insurance coverage, type of insurance coverage, coverage of prescription drugs, and uninsured status during the past 12 months.
17. **HospitalDF:** Hospital Utilization and Access to Care questionnaire (variable name prefix HUQ) provides respondent-level interview data on self-reported health status and access to health care topics.

18. **HousingDF:** Housing Characteristics section (variable name prefixes HOQ or HOD) provides family-level interview data on the number of rooms in home and whether the home is owned or rented. Note: The variables HOQ.040 (age of home), HOQ.060 (time lived in home), HOQ.070 (source of tap water for home), and HOQ.080 and HOQ.085 (water treatment device use and type, respectively) were dropped from the questionnaire in 2011-12.

19. **ImmunizationDF:** Immunization section (variable name prefix IMQ) provides respondent-level data on immunizations, including the hepatitis A vaccine, the hepatitis B vaccine, and the human papillomavirus (HPV) vaccine. The number of doses received is also obtained since all vaccines are multi-dose.

20. **IncomeDF:** Income section (variable name prefix INQ) provides family level information on income sources, monthly income, family cash assets, and mode of transportation to grocery store(s). Information on family's annual income was also collected in this section and was released as part of the Demographics file (DEMO_I).

21. **MedicalDF:** Medical conditions section (variable name prefix MCQ) provides self- and proxy-reported personal interview data on a broad range of health conditions and medical history for both children and adults. The NHANES MCQ questionnaire section is generally modeled on the "Medical Conditions" questionnaire section of the U.S. National Health Interview Survey.

22. **OccupationDF:** Occupation Questionnaire (variable name prefix OCQ) section (questions OCD150 to OCQ660), which is part of the household interview, contains Survey Participant interview data on employment and variables relating to the work environment.

23. **PhysicalActDF:** Physical Activity questionnaire (variable name prefix PAQ) is based on the Global Physical Activity Questionnaire (GPAQ) and provides respondent-level interview data on physical activities.

24. **PhysicanFuncDF:** Physical Functioning questionnaire (variable name prefix PFQ) provides respondent-level interview data on functional limitations caused by long-term physical, mental, and emotional problems or illness.

25. **ReproductiveDF:** Reproductive health section (variable name prefix RHQ) contains questions for females only. Questions on reproductive health include menstrual history, pregnancy history, hormone replacement therapy use, and other related reproductive conditions.

26. **SleepDF:** Sleep disorders (variable name prefix SLQ) data set provides questions on sleep habits and disorders. The number of questions was expanded to include several questions previously asked in NHANES 2007-2008 (and earlier), and two new questions about usual sleep and wake times.

27. **SmokingDF:** Smoking - cigarette use (variable name prefix SMQ) data set provides a history of cigarette use, age at initiation, past 30 day use, cigarette brand, sub-brand and other related details. Questions on ever use of cigars, smokeless tobacco, and electronic nicotine delivery systems (including e-cigarettes) are new for 2015-16 (18 years and older).

28. **WeightDF:** Weight History section of the Sample Person Questionnaire (variable name prefix WHQ) provides personal interview data on several topics related to body weight, including self-perception of weight, self-reported weight over the participant's lifetime, attempted weight loss during the past 12 months, and methods used to try to lose weight and to keep from gaining weight.

An inner join of all these separate tables was performed using the sequence number, and the null values were dropped as they constituted only a small part of the dataset. The final training dataset consisted of 3540 rows. The final testing dataset consisted of 3381 rows. Nine-item version of the Patient Health Questionnaire (PHQ-9) was used to measure depression. The features were added and a threshold value (here, 10) was selected. A score of greater than or equal to that of the threshold was marked as depressed. This procedure was followed for both the training and the testing dataset.

3.2. Techniques Used

3.2.1. Machine Learning Models

The performances of the following machine learning algorithms were compared:

1. Logistic Regression (LR)
2. Decision Tree
3. Random Forest
4. ADABoost
5. XGBoost

3.2.2. Feature Extraction

The SelectKBest algorithm was used to extract the top 25 relevant features and a dataset comprising of only these features was created.

3.2.3. Data Augmentation

SMOTE and SMOTE with undersampling were applied on the two dataset - one with all the features present and one comprising on only the features extracted using SelectKBest algorithm.

3.3. Methodology used for depression detection

The proposed methodology consists of four main modules. These are data preparation, feature extraction, data augmentation, and model building. These modules are briefly described in the preceding subsections.

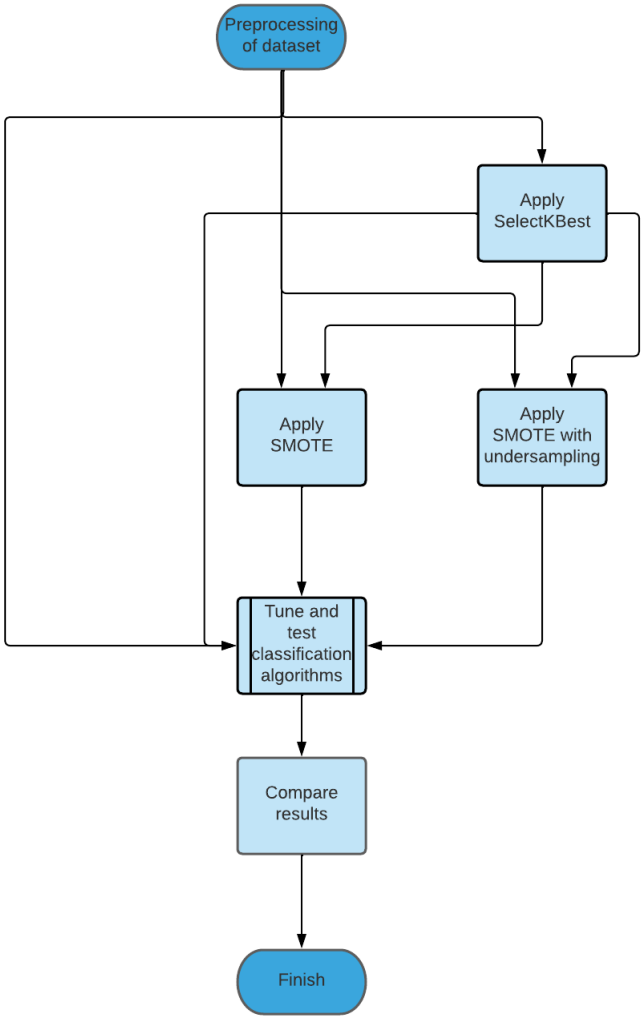

Figure 1: Proposed methodology for predicting the depression

3.3.1. Preparing the data

Data preparation module consists of two main phases namely identification of relavant variables and handling the null values present in the dataset.

1. **Selecting relevant variables :** Since the dataset consisted of a large number of variables, the ones that could prove to be most suited were selected and used.
2. **Null value handling :** Since the percentage of null values in the dataset was small, they were removed.

3.3.2. Using Feature Extraction

SelectKBest was used to extract the top 25 relevant features from the given features present. There were two datasets now - the one with the original features and the one with the features extracted using SelectKBest.

3.3.3. Using Data Augmentation

Two techniques - SMOTE and SMOTE with undersampling were then applied on both the datasets obtained from the previous step.

3.3.4. Training and Testing the models

The machine learning algorithms were the trained using the datasets obtained from the previous steps. The data from 2015 was used for this purpose. Following the training, the models were then tested using data from 2017. The results were then compiled.

4. Results and Discussion

In this section, the performance evaluation of machine learning models is evaluated.

4.1. Performance measure

Three different metrics are used to perform comparison of the different machine learning models.

1. **F1 score:** F1 score is the harmonic mean of precision and recall. It is considered a good metric to evaluate binary classification systems, particularly when dataset is imbalanced, such as when the number of people not depressed outweighs the number of depressed people.

$$F1 = 2*Precision*Recall/(Precision+Recall) \quad (1.0)$$

2. **Accuracy:** Accuracy is the measure that is the fraction of the correct classifications to the total number of classifications made. A huge number of studies use this metric to evaluate their models and it makes comparison to models in different studies easier, though it is more relevant to studies that have a balanced dataset.

$$Accuracy = TP + TN/(TP + TN + FP + FN) \quad (2.0)$$

Where TP stands for true positive, TN stands for true negative, FP stands for false positive and FN stands for false negative.

3. **AUC-ROC value:** AUC stands for area under curve and ROC stands for Receiver Operating Characteristics. Hence this metric is a measure of area under the ROC curve. A higher AUC signifies a better model, as it tells the capability of the model to separate the classes.

4.2. Validation Scores

Tables 1-3 show the top 5 performing machine learning algorithms in terms of F1 score, accuracy and AUC-ROC value while performing the validation. They were trained on the 2015 dataset. It can be seen that Random Forest using SMOTE with undersampling has the highest F1 score, XGBoost using SMOTE with undersampling has the highest AUC-ROC value and LR has the highest accuracy.

Table 1: The top 5 algorithm validation F1 scores

Algorithm	F1 Score
Random Forest SMOTE (undersampling)	0.5306
XGBoost SMOTE (undersampling)	0.5306
LR SMOTE (undersampling KBest)	0.5110
ADABoost SMOTE (KBest)	0.4867
Decision Tree SMOTE	0.3855

Table 2: The top 5 algorithm validation AUC-ROC value

Algorithm	AUC-ROC
XGBoost SMOTE (undersampling)	0.8282
LR SMOTE KBest	0.8203
Random Forest SMOTE (undersampling)	0.7879
Decision Tree SMOTE (undersampling KBest)	0.7842
ADABoost SMOTE (undersampling KBest)	0.7743

Table 3: The top 5 algorithm validation accuracy

Algorithm	Accuracy
LR	0.9300
XGBoost	0.9279
ADABoost	0.9237
Random Forest	0.9237
Decision Tree	0.9201

4.3. Testing Scores

Tables 4-6 show the top 5 performing machine learning algorithms in terms of F1 score, accuracy and AUC-ROC value while performing the testing. They were trained on the 2015 dataset and testing was done using 2017 dataset. It can be seen that ADABoost using SMOTE with undersampling has the highest F1 score, XGBoost using SMOTE with undersampling has the highest AUC-ROC value and Random Forest has the highest accuracy.

Table 4: The top 5 algorithm testing F1 scores

Algorithm	F1 Score
ADABoost SMOTE (undersampling)	0.5006
Random Forest SMOTE (undersampling)	0.5000
XGBoost SMOTE (undersampling)	0.4893
LR SMOTE (undersampling)	0.4631
Decision Tree SMOTE (undersampling)	0.4541

Table 5: The top 5 algorithm testing AUC-ROC value

Algorithm	AUC-ROC
XGBoost SMOTE (undersampling)	0.7996
LR SMOTE (KBest)	0.7938
Random Forest SMOTE (undersampling)	0.7934
ADABoost SMOTE (undersampling)	0.7796
Decision Tree SMOTE (undersampling)	0.7664

Table 6: The top 5 algorithm testing accuracy

Algorithm	Accuracy
Random Forest	0.9210
ADABoost	0.9201
XGBoost	0.9174
LR	0.9162
Decision Tree (KBest)	0.9136

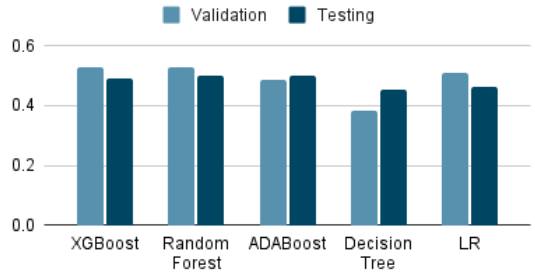

Figure 2: Bar chart for validation and testing F1 score

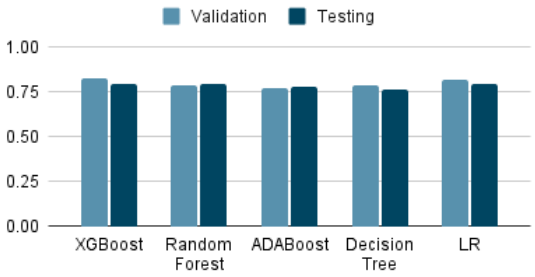

Figure 3: Bar chart for validation and testing AUC-ROC score

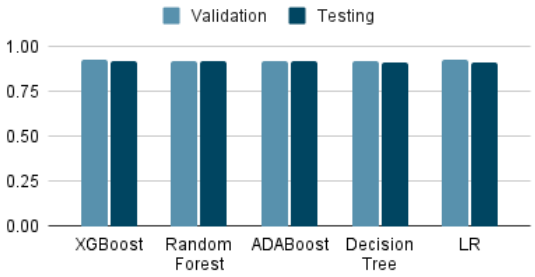

Figure 4: Bar chart for validation and testing Accuracy

The 25 relevant features as chosen by SelectKBest:

1. PFQ090 :Require special healthcare equipment
2. INQ060 :Income from other disability pension
3. DBQ197 :Past 30 day milk product consumption
4. CBD071 :Money spent at supermarket/grocery store
5. WHQ225 :Times lost 10 lbs or more to lose weight
6. CBQ596 :Heard of My Plate
7. MCQ300C :Close relative had diabetes?

8. MCQ160F :Ever told you had a stroke
9. INQ150 :Income from other sources
10. DMDMARTL :Marital status
11. SDMVSTRA :Masked variance pseudo-stratum
12. AUQ054 :General condition of hearing
13. CBD091 :Money spent on nonfood items
14. HUQ071 :Overnight hospital patient in last year
15. DLQ150 :Take medication for depression?
16. HSAQUEX :Source of Health Status Data
17. HUQ010 :General health condition
18. INQ140 :Income from interest/dividends or rental
19. DLQ020 :Have serious difficulty seeing?
20. MCQ160L :Informed of liver condition
21. FSD032B :HH Food didn't last
22. MIALANG :Language of MEC Interview
23. DLQ140 :How often do you feel depressed?
24. RIDRETH1 :Race/Hispanic origin
25. DBD910 :Previous month number of frozen meals

4.4. Discussion

In the testing and validation score tables, if the algorithm is applied alongside SMOTE, it is mentioned. It is also mentioned separately if it is SMOTE or SMOTE with undersampling. If KBest has been mentioned, then it implies that the model was trained and tested using the features that were extracted by applying the SelectKBest feature extraction.
Here different techniques were used on dataset like SMOTE, SMOTE with undersampling and SelectKBest feature extraction. The performances of models were then compared with metrics using F1 score, AUC ROC score and accuracy. It was found that the highest testing accuracy comes out to be 92% by random forest and ADABoost, closely followed by XGBoost. XGBoost outperforms all others in terms of AUC-ROC value with a value of 0.79, when it used SMOTE with undersampling along with SelectKBest. When looking at F1 score, the highest F1 score of 50 was achieved by ADABoost and Random Forest, however here too, XGBoost was not far behind.
The SelectKBest selected features like income, marital status and general health condition as contributing factors to depression, which are in tune with general intuition as to which factors might play a contributing role. Not only this, it selected race as a predictor too.
For the possibility of creation of actual predictor to be deployed in use, it would be beneficial to train on a wider range of features and with a bigger dataset, also while considering the data from different time ranges. It would be better to include the community specific features and train them, ass different communities may have different standards of living.

5. Conclusion

The paper compared various machine learning algorithms to predict depression in community dwellers. Different techniques such as SMOTE and SelectKBest were used on dataset. Machine learning models like XGBoost and ADABoost were used further. The algorithms were then ranked according to the metrics like F1 score, AUR-ROC value and accuracy.
This study can further be improved by considering a larger dataset and using a wider range of features in order to train and test the models. Further, data from different years can be used, to make the model more robust to time.

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Vijay Kumar is Assistant Professor in Computer Science and Engineering Department, NIT Hamirpur. He received his Ph.D. degree from NIT Kuruksherta. Previously, he received M.Tech. and B.Tech. degrees from GJUST, Hisar and M.M. Engineering College, Mullana, respectively.

He has 4 years of teaching and research experience in the Thapar Institute of Engineering & Technology, Patiala. Prior, he has 8 years of teaching experience in various reputed institutes. He completed 2 DST SERB sponsored research projects. Presently, he is working on 1 CSIR sponsored research project. He has published more than 100 research papers in International Journals/Conferences.

Muskan Khajuria is pursuing bachelors degree from National Institute of Technology in Computer Science and Engineering (expected may 2022).

Anshu Singh is pursuing bachelors degree from National Institute of Technology in Computer Science and Engineering (expected may 2022).

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A Deep Reinforcement Learning Approach to Eco-driving of Autonomous Vehicles Crossing a Signalized Intersection

Joshua Ogbebor[1], **Xiangyu Meng**[*,1], **Xihai Zhang**[2]

[1]Division of Electrical and Computer Engineering, Louisiana State University, Baton Rouge, 70803, United States of America

[2] College of Electronic and Information, Northeast Agricultural University, Harbin, 150000, China

[*]Corresponding author: Xiangyu Meng, Room 3325 Patrick F. Taylor Hall, Baton Rouge, LA 70803, +1(225)-578-8961 & xmeng5@lsu.edu

ORCID Joshua Ogbebor: 0000-0001-6996-6493, ORCID Xiangyu Meng: 0000-0003-3381-6690, ORCID Xihai Zhang: 0000-0001-6370-6279

ABSTRACT: This paper outlines a method for obtaining the optimal control policy for an autonomous vehicle approaching a traffic signal head. It is assumed that traffic signal phase and timing information can be made available to the autonomous vehicle as the vehicle approaches the traffic signal. Constraints on the vehicle's speed and acceleration are considered and a microscopic fuel consumption model is considered. The objective is to minimize a weighted sum of the travel time and the fuel consumption. The problem is solved using the Deep Deterministic Policy Gradient algorithm under the reinforcement learning framework. First, the vehicle model, system constraints, and fuel consumption model are translated to the reinforcement learning framework, and the reward function is designed to guide the agent away from the system constraints and towards the optimum as defined by the objective function. The agent is then trained for different relative weights on the travel time and the fuel consumption, and the results are presented. Several considerations for deploying such reinforcement learning-based agents are also discussed.

KEYWORDS reinforcement learning, eco-driving, connected vehicles, autonomous vehicles

1. Introduction

Connected and autonomous vehicle (CAV) technology is increasingly being considered in research and development and is already being assimilated into real-world transport systems due to potential benefits in traffic throughput and energy consumption management [1, 2]. In connected vehicles (CVs), real-time information about the environment, including other road users and traffic signals is made available to the vehicle's operator through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. Environment information may also be directly sensed, but can be limited to the immediate vicinity of vehicles and may require high processing power. In autonomous vehicles (AVs), the driver is not in the loop. Hence, there is a great chance of efficient use of shared or sensed information and the diminution of human errors.

In this paper, our focus is on the utilization of the reinforcement learning (RL) framework for solving the eco-driving problem of an AV approaching a signalized intersection. As a vehicle enters within some range of a traffic signal, using V2X communication, it receives the traffic signal phase and timing (SPaT) information. The vehicle then seeks to minimize energy consumption as it approaches the signalized intersection. As shown in literature, the eco-driving problem can be approximately solved by regulating advisory speed limits which, if followed, will minimize engine idle time as the vehicle approaches the traffic stop [3, 4, 5]. The problem can also be formulated as an optimal control problem that deals with finding a control policy to minimize a specified objective function [6, 7, 8].

Traditional methods for solving optimal control problems are based on the calculus of variations and the Pontryagin minimum principle to identify necessary conditions for optimal controls. Then, iterative numerical techniques are used to solve the two-point boundary-value problem to find the optimal controls [9]. In general, the eco-driving optimization problem is non-convex due to the nature of the traffic light constraints. Due to the complexity of fuel consumption models, the eco-driving optimization problem can be formulated to indirectly minimize the energy through other performance metrics, such as the acceleration [7]. In [10] it is shown that such alternatives may not yield a true energy optimum. Assuming the model of the problem is known, dynamic programming can also be used to simplify the problem into simpler, nested sub-problems, and then recursively solve the sub-problems [11, 12]. Generally, real-world vehicle systems are non-linear and highly complex. The RL framework provides a model-free approach to optimal control.

In RL, an agent interacts with its environment, observes the state of the environment, takes an action that may change

the state, and observes the new state. Some supervisory signal is provided to the agent in the form of a reward to guide it towards the desired goal [13]. The agent exploits the knowledge from its exploration in making informed decisions. Using this framework, control policies with acceptable levels of optimality can be obtained even with system constraints, provided that a proper reward structure is designed. When the states of the system are not entirely known, or the representation of the states in a table is prohibitively cumbersome, a function approximator may further be employed to augment learning as the agent explores. Given a mapping of a set of inputs to some outputs, assuming that there is an unknown underlying function that consistently maps the inputs to outputs, a function approximator seeks to approximate this function. If the function to be estimated is continuous, the universal approximation theorem [14] provides a basis for the estimation of such a function using a weighted sum of non-linear functions. Artificial neural networks are a typical class of such a weighted sum. Thus, using a supervised-learning framework, the value function can be approximated. In traditional supervised machine learning, a neural network is presented with a data set and some supervisory labels to guide the learning process. In training, the neural network adjusts its weights based on the deviation of its prediction from the true value as measured by a loss function. The loss is regarded as a measure of how close the prediction is to the true value and is minimized by adjusting the weights in the network. This process continues until an acceptable set of weights is achieved [15]. When a machine learning network has multiple layers, it is referred to as a deep-learning network [16]. The fusion of deep learning and RL is generally referred to as deep RL [17] and has inspired many successful artificial intelligent systems [18].

In this paper, we consider a direct fuel minimization problem, and propose a deep RL framework for solving it. For the eco-driving problem, we are concerned with the vehicle energy optimization as it approaches a signalized intersection, given the traffic signal phase information. In contrast to existing works, we do not assume any structure of the solution, discretize the action set, or indirectly minimize the fuel consumption, but attempt to tackle the eco-driving problem without the aforementioned simplification [19, 20, 21]. In addition, only the current signal information is available and future SPaT is unknown to autonomous vehicles. The problem is solved based on deep neural networks in the RL framework.

2. Problem Formulation

The task is to optimally control an autonomous vehicle approaching a signalized intersection. At time t_0, the vehicle starts at a point $x_0 = 0$ with an initial speed v_0. The traffic signal head is l meters away from the vehicle. The eco-driving problem is illustrated in Fig. 1.

2.1. System Model

To simplify the model, let us approximate the vehicle by a unit point mass that can be accelerated by using the throttle or decelerated by using the brake. The dynamics of the vehicle are modeled by a double integrator given by

$$\begin{bmatrix} \dot{x}(t) \\ \dot{v}(t) \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} x(t) \\ v(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u(t) \tag{1}$$

where $x(t)$ and $v(t)$ are the position and velocity, respectively.

2.2. Constraints

The next step is to define the physical constraints on the state and control values. For the state constraints, if t_0 is the starting time, and t_f is the time of arrival at the traffic signal head, then clearly,

$$\begin{bmatrix} x(t_0) \\ v(t_0) \end{bmatrix} = \begin{bmatrix} 0 \\ v_0 \end{bmatrix}, \tag{2}$$

and

$$x(t_f) = l. \tag{3}$$

If we assume that the vehicle does not back up, then additional constraints

$$0 \le x(t) \le l,$$
$$0 \le v_{\min} \le v(t) \le v_{\max}$$

are also imposed, where $v_{\max}$ is the road speed limit or the physical velocity constraint of the vehicle. With $v_{\min}$, the vehicle can be constrained not to come to a full stop, and can be adjusted to decrease queue-length build-up. The acceleration is constrained by the engine capacity of the vehicle, and the maximum deceleration is limited by the braking system parameters. If the maximum acceleration is $u_{\max} > 0$ and the maximum deceleration is

$$u_{\min} < 0,$$

then the controls must satisfy

$$u_{\min} \le u(t) \le u_{\max}. \tag{4}$$

The traffic light signal at the intersection switches between the green light and the red light consecutively, and is represented by a rectangular pulse signal

$$f(t) = \begin{cases} 1 & \text{for} \quad t \in T_G \\ 0 & \text{for} \quad t \in T_R \end{cases} \tag{5}$$

where T_G are T_R are the time intervals in which the traffic signal is green and red, respectively. The vehicle can only cross the intersection during the green interval, that is, $t_f \in T_G$.

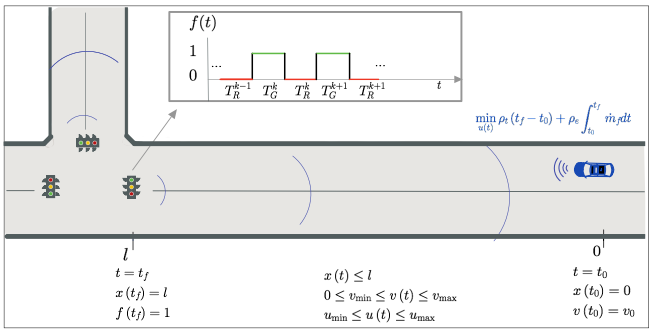

Figure 1: The eco-driving problem of a single vehicle approaching a signalized intersection

2.3. Objective function

The objective function to be minimized includes a term for the duration of travel and a fuel consumption term. The following fuel consumption model is derived from the estimation in [22], with an additional assumption of fuel consumption during deceleration:

$$\dot{m}_f = \begin{cases} m_\alpha + m_\beta u(t), & u(t) \geq 0, \\ \alpha_0, & u(t) < 0, \end{cases} \tag{6}$$

where

$$m_\alpha = \alpha_0 + \alpha_1 v(t) + \alpha_2 v(t)^2 + \alpha_3 v(t)^3 \tag{7}$$

$$m_\beta = \beta_0 + \beta_1 v(t) + \beta_2 v(t)^2 \tag{8}$$

and $\alpha_0, \alpha_1, \alpha_2, \alpha_3, \beta_0, \beta_1$ and β_2, are approximated through a curve fitting process. The performance measure is given by

$$J = \min_{u(t)} \rho_t (t_f - t_0) + \rho_e \int_{t_0}^{t_f} \dot{m}_f \, dt \tag{9}$$

where ρ_t and ρ_e are two weight parameters. When $\rho_e = 0$, it is a minimum time problem; when $\rho_t = 0$, it is a minimum energy problem.

3. Reinforcement Learning Approach

3.1. Brief Review of Reinforcement Learning

The schematic of the RL framework is depicted in Fig. 2. RL involves the interaction between an agent and environment. At each time step, the agent observes some state, s of the environment from the set of states $\mathcal{S}$, and on that basis selects an action, a from the set of actions $\mathcal{A}$, according to a policy $\pi(s)$. After one step, in part as a consequence of performing its action, the environment transitions to a new state, s'. The action also fetches the agent an immediate reward, $r(s, a)$ from the set of rewards $\mathcal{R}$.

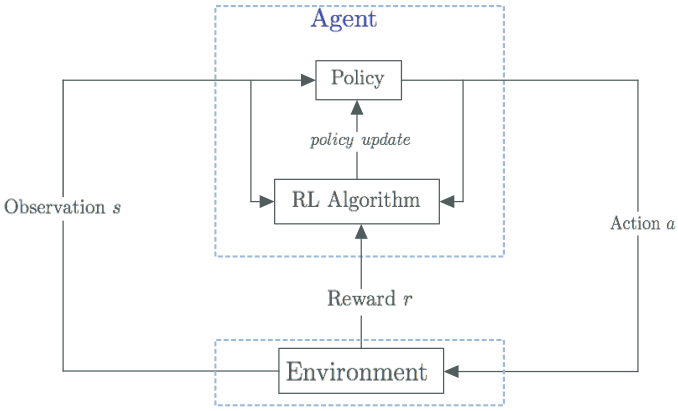

Figure 2: The reinforcement learning framework.

The action-value function or Q-value function $Q(s, a)$ maps each state-action pair to a value that represents the expected total long-term reward starting from the given state s, taking action a, and following the policy $\pi(s)$ onwards. The Q-learning algorithm is a value-based RL algorithm that tries to learn the Q-value function [23]. For any given state s observed by a Q-learner, the policy $\pi(s)$ selects the action that maximizes the action-value function $Q(s, a)$:

$$\pi(s) = \arg\max_a Q(s, a).$$

The Q-vlaue function is mostly estimated using the recursive Bellman equation [24]

$$Q(s, a) \leftarrow (1 - \eta) Q(s, a) + \eta \left(r(s, a) + \gamma \left[\max_{a'} Q(s', a') \right] \right).$$

The learning rate η determines to what extent the new information overrides the old while the discount factor γ helps to discount the future rewards in the current consideration. The deep Q-network (DQN) learner is a Q-learner with a function approximator – $Q(s, a|\phi)$, parameterized by ϕ. DQN is applicable to environments with continuous states, but the action set is discrete. For stable training, a set of previous experiences, $e = (s, a, r, s')$ is sampled from an experience replay buffer of size $\mathcal{D}$ according to a specified mini-batch size $\mathcal{B}$ and fed into the neural network [25]. The DQN-learner has its number of inputs and outputs equal to the size of the state vector and discrete action space, respectively. Because every training step updates the weights, and by extension, the Q-values of entire state-action pairs, a target network is created to keep the weights constant until after n_τ steps. Let the target network be parameterized by ϕ_t. The target network is updated according to

$$\phi_t \leftarrow \tau \phi + (1 - \tau) \phi_t$$

for some $\tau \ll 1$ [26].

When the number of possible actions is infinitely large, such as in continuous action space, it becomes difficult to calculate the Q-values for actions and compare all of them. It is also computationally intensive to solve $\max_a Q(s, a)$ at every decision step. The Deep Deterministic Policy Gradient (DDPG) approach was introduced to solve this problem and extend Q-learning to environments with continuous action spaces [26]. DDPG combines both deep Q-learning and deep policy gradients (PG) approaches by concurrently learning a Q-function and a policy. The PG approach to RL was originally proposed in [24] to handle discontinuities in the value function approximation that impact convergence assurances. The deep PG method aims to model and optimize the policy $\pi(s|\theta)$ directly using an actor-critic model: the critic updates the value function parameters ϕ for $Q(s, a|\phi)$ and the actor updates the policy parameters θ for $\pi(s|\theta)$, guided by the critic. As with critic networks, an actor target network – $\pi(s|\theta_t)$, parameterized by θ_t – is also employed to ensure the stability of the optimization. DDPG models the policy as a deterministic decision $\mu(s|\theta)$, rather than a probability distribution over actions $\pi(s|\theta)$ [27].

The critic network has an input layer size equal to the addition of the sizes of the observation vector and the action, and a single output to represent the action-value function mapping. The actor network has an input layer size equal to the size of the observation vector s, and an output layer equal to the size of the action to represent the policy [17]. Mini-batch sampling from experience replay buffer and soft target updates are also extended to the actor network. Being

an off-policy approach, DDPG does not require full trajectories and can generate samples by following a behavior policy different from the target policy $\mu(s|\theta)$. Noise $\mathcal{Z}$ is added to actions for expansive exploration during training, with variance $\sigma^2_{\mathcal{Z}}$ and variance decay $\varsigma^2_{\mathcal{Z}}$. The noise added is typically uncorrelated, and zero-mean Gaussian.

3.2. Reinforcement Learning Approach to Eco-driving Problems

To implement RL algorithms in a digital computer numerically, the system differential equation must be discretized. The acceleration $u(t)$ is generated by a digital computer followed by a zero-order holder (ZOH), then $u(t)$ will be piece-wise constant. Let h be a very small sampling period, and

$$u(t) = u(nh) \triangleq a(n)$$

for $nh \leq t < (n+1)h$. The acceleration changes values only at discrete-time instants. For this input, where

$$\xi(n) = x(nh)$$

and

$$v(n) = v(nh),$$

the discrete-time model becomes

$$\begin{bmatrix} \xi(n+1) \\ v(n+1) \end{bmatrix} = \begin{bmatrix} 1 & h \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \xi(n) \\ v(n) \end{bmatrix} + \begin{bmatrix} \frac{h^2}{2} \\ h \end{bmatrix} a(n).$$

In the following paragraphs, we will define the sets of states, actions, and rewards ($\mathcal{S}$, $\mathcal{A}$ and $\mathcal{R}$).

3.2.1. State Set $\mathcal{S}$

The agent is placed in the vehicle. The agent observes the traffic signal, $f(t)$, the position $x(t)$ and the velocity $v(t)$ at each sampling instance nh. The observation vector at the time instant $t = nh$ is thus the augmented state vector

$$s_n = \begin{bmatrix} \xi(n) & v(n) & f(nh) & n \end{bmatrix}^T \in \mathcal{S} \tag{10}$$

that includes the traffic signal and the instant at which the traffic signal is observed, and $\mathcal{S}$ is the set of all states. The initial state is $[\,0 \;\; v(0) \;\; f(0) \;\; 0\,]^T$. A state s_n is a terminal state whenever $v(n) \leq v_{\min}$, or $v(n) \geq v_{\max}$, or

$$\xi(n) \geq l.$$

We let $\mathcal{S}_T \subset \mathcal{S}$ denote the set of terminal states. After a terminal state, the agent resets to the initial state.

3.2.2. Action Set $\mathcal{A}$

It is assumed that the admissible acceleration at any step, $a(n)$, is constrained to a closed interval

$$\mathcal{A} = [u_{\min} \; u_{\max}]. \tag{11}$$

At each time instant nh, the agent selects an action

$$a(n) = \mu(s_n|\theta) \in \mathcal{A}.$$

The goal is to find the optimal $\mu^*(s_n|\theta)$ at each instant n based on the environment state s_n.

3.2.3. Reward Set $\mathcal{R}$

To design the reward system to minimize time and fuel consumption, events of success and failure are defined. In the context of the problem, success is only achieved by the agent once it crosses the traffic signal within the green time interval and all constraints are satisfied from the beginning to the end. Failure occurs when the system constraints are violated. Once success or failure is encountered, the state is a terminal state and exploration stops. For the eco-driving problem formulated in Section 2, the long-term reward can be expressed as

$$J_r = -\sum_{n=0}^{N} [\rho_t h + \rho_e h \, M_n]$$

where N is such that $s_N \in \mathcal{S}_T$ and

$$M_n = \frac{1}{h} \int_{nh}^{(n+1)h} \dot{m}_f dt.$$

The term

$$M_n = \alpha_0 + \max\left\{\text{sgn}\left(a(n)\right), 0\right\} \left(\alpha_1\psi_1 + \alpha_2\psi_2 + \alpha_3\psi_3 + (\beta_0 + \beta_1\psi_1 + \beta_2\psi_2)\, a(n)\right)$$

where

$$\psi_1(v(n), a(n), h) = v(n) + \frac{a(n)h}{2},$$

$$\psi_2(v(n), a(n), h) = v(n)^2 + v(n)a(n) + \frac{a(n)^2h^2}{3},$$

$$\psi_3(v(n), a(n), h) = v(n)^3 + v(n)a(n)^2h^2 + \frac{3v(n)^2a(n)h}{2} + \frac{a(n)^3h^3}{4}.$$

The reward function has three components:

$$R\,(n) = r_1\,(n) + r_2\,(n) + r_3\,(n)$$

where

$$r_1\,(n) = -\rho_t h - \rho_e h \, M_n,$$

$$r_2\,(n) = \begin{cases} 0 & \text{if } v_{\min} \leq v(n) \leq v_{\max}, \\ -p_2 & \text{otherwise,} \end{cases}$$

$$r_3\,(n) = \begin{cases} -p_3 & \text{if } f(N) = 0, \\ 0 & \text{otherwise.} \end{cases}$$

The first component is related to the objective function. If all constraints are satisfied from the beginning to the end, $R(n) = J_r$. The second component is related to the velocity constraint. If it is violated, a penalty $p_2 > 0$ is given. The third constant is related to the traffic signal constraint. If it is violated, a large penalty $p_3 > 0$ is given. The actions leading to constraint violations are thus discouraged. To guide the agent to a true optimum, and avoid getting stuck in local optima when the state constraints are violated, we ensure $-p_2 \ll -p_3 \ll J_r$. The discrete reward signals help avoid undesirable states, while the continuous reward signal provides a smooth manifold for improving convergence.

4. DDPG Algorithm

The algorithm applied here is based on the DDPG algorithm. We refer the interested reader to [26] for a comprehensive explanation of the DDPG algorithm. The pseudo-code applied to solve the eco-driving problem is outlined in Algorithm 1.

Algorithm 1: Deep Deterministic Policy Gradient

Randomly initialize $Q(s,a|\phi)$ and $\mu(s|\theta)$ with weights ϕ and θ;
Set target networks $Q(s,a|\phi_t)$ and $\mu(s|\theta_t)$ with weights: $\phi_t \leftarrow \phi$ and $\theta_t \leftarrow \theta$;
Initialize experience buffer;
repeat
  Initialize a random process $\mathcal{Z}$ for action exploration;
  Receive initial observation state s;
  repeat
    Select action $a = \mu(s|\theta) + \mathcal{Z}$;
    Execute a and observe both reward r and new state s';
    If s' is a terminal state ($s' \in \mathcal{S}_T$), reset environment to initial state;
    Set $d_T = 0$ if s' is a terminal state, else $d_T = 1$;
    Store experience $e = (s,a,r,s',d_T)$;
    if *number of stored experiences in buffer* $\mathcal{D} \geq$ *mini-batch size* $\mathcal{B}$ **then**
      Sample a random set of $\mathcal{B}$ experiences from replay buffer;
      Set $y = r + \gamma(d_T)Q(s', \mu(s'|\theta_t)|\phi_t)$;
      Update critic by minimizing loss L;
      $L = \frac{1}{\mathcal{B}} \sum_{e\in\mathcal{B}} (y - Q(s,a|\phi))^2$;
      Update actor network to maximize $J = Q(s, \mu(s|\theta)|\phi)$ by gradient $\nabla_\theta J$;
      $\nabla_\theta J \approx \frac{1}{\mathcal{B}} \sum_{e\in\mathcal{B}} \left(\nabla_{\mu(s|\theta)} Q(s, \mu(s|\theta)|\phi)\right) \nabla_\theta \mu(s|\theta)$;
      Update target networks: $\phi_t \leftarrow \tau\phi + (1-\tau)\phi_t$ and $\theta_t \leftarrow \tau\theta + (1-\tau)\theta_t$;
    end
  until *episode ends* ($s' \in \mathcal{S}_T$);
until *convergence*;

5. Simulation

The eco-driving problem is simulated using the parameters in the following sub-sections.

5.1. Agent environment parameters

For simulation, the upper limit of the distance observation is chosen as

$$0 \leq \xi(n) \leq l + \Delta$$

where $\Delta = hv_{\max}$ so that for a sampled distance very close to l, a maximum acceleration input is still admissible. The traffic signal for training the agent is delayed by a time-gap of t_g seconds so that there is a buffer time between the start of the green time interval and when the vehicle will cross the intersection after training. A high number of training samples has been found to improve the learning processes where the reward function is discontinuous [28]. Hence the mini-batch size is chosen to be 120. All other parameters of the agent are chosen as shown in Table 1. The fuel consumption model coefficients are borrowed from the fuel consumption model used in [22].

5.2. Neural Network Parameters

The actor and critic neural network parameters are shown in Fig. 3 and Fig. 4 respectively. The actor neural network is composed of an input layer with four inputs and three fully connected (FC) layers, each of 48 neurons with rectified linear unit (ReLU) activation. An FC layer consisting of a single neuron with a tanh function activation follows sequentially, and the result is passed to a scaling layer with a bias of −0.5 and a scaling factor of 2.5 for the resulting output layer.

The critic neural network gets inputs from both observation and action and concatenates them. Before concatenation, the observation is passed through a 48 neuron ReLU FC layer and a 48 neuron FC layer, while the action is passed through a 48 neuron FC layer. The concatenation is an element-wise addition of the two 48×1 resulting vectors, and its output is fed through a 48 neuron RELU FC layer to the network output, a single neuron FC layer. The results of the simulation are presented next.

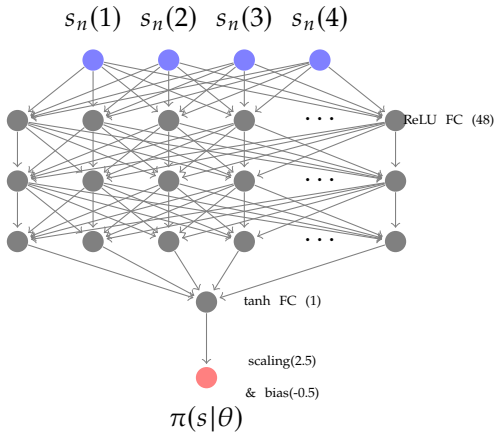

Figure 3: actor neural network

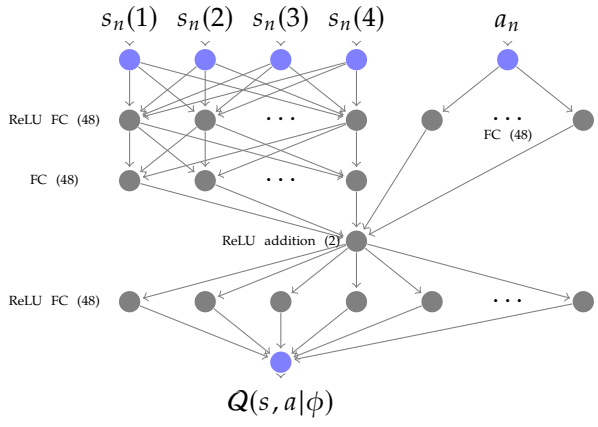

Figure 4: critic neural network

Table 1: Training parameters for eco-driving with reinforcement learning

Parameters	Symbol	Value	Unit	Symbol	Value	Unit
Environment variables						
	v_0	20	m/s	l	100	m
	$v_{\min}$	3	m/s	$v_{\max}$	50	m/s
	T_R	$\{[2.5\ 7.5], [12.5\ 17.5]\ldots\}$	s	T_G	$\{[0\ 2.5], [7.5\ 12.5]\ldots\}$	s
	a	$[-3\ 3]$	m/s^2	t_g	0.1	s
Agent hyper-parameters						
	h	0.1	s	γ	0.99	–
	n_τ	10	–	τ	5×10^{-2}	–
	$\mathcal{D}$	1×10^4	–	$\mathcal{B}$	120	–
	$\sigma^2_{\mathcal{Z}}$	1.0	–	$\varsigma^2_{\mathcal{Z}}$	1×10^{-4}	
Fuel consumption model [22]						
	α_0	0.1569	$\frac{mL}{s}$	β_0	0.07224	$\frac{mLs}{m}$
	α_1	2.450×10^{-2}	$\frac{mL}{m}$	β_1	9.681×10^{-2}	$\frac{mLs^2}{m^2}$
	α_2	-7.415×10^{-4}	$\frac{mLs}{m^2}$	β_2	1.075×10^{-3}	$\frac{mLs^3}{m^3}$
	α_3	5.975×10^{-5}	$\frac{mLs^2}{m^3}$			
Reward function variables						
	p_2	200	–	p_3	100	–

Table 2: Training results for different DDPG-based eco-driving cases

		Coefficients		Number of	Results	
Case	$v_0(m/s)$	ρ_t	ρ_e	training episodes	$t_f - t_0\ (s)$	$\int_{t_0}^{t_f} \dot{m}_f\, dt\ (ml)$
1	20	1	0	769	7.5	12.65
2	20	0.7	0.3	830	7.7	10.28
3	20	0.3	0.7	1063	9.4	4.78
4	20	0	1	1238	9.2	3.91
5	15	0	1	1157	10.5	5.91
6	10	0	1	2335	20.0	4.41

5.3. Results

The agent is trained for the cases listed in Table 2. In general, there is no guarantee that the agent will achieve an optimal solution. The training is stopped when the moving average of the reward plateaus and the difference between the critic's estimate (Episode Q_0) and the moving average of the reward is small. Episode Q_0 is the expected long-term reward estimated by the critic at the beginning of each episode, given an initial environment observation. It provides a measure of how well the critic has learned the environment. The moving average reward considered is based on the previous 10 episode rewards. After training for the number of episodes as listed in the table, the agent is simulated in the same environment from the initial state and the distance of the vehicle to the traffic signal against time is shown in Fig. 5. The velocity and input plots for the first 7.5 seconds are also shown in Fig. 5 for cases $1-4$ in Table 2. In each of these cases, the agent decelerates the vehicle for some time and then accelerates almost sharply to save time. Deceleration sacrifices previous kinetic energy, hence, the agent does not consider conserving the energy it had at the start. An approach to check this behavior is to formulate a multi-stage energy minimization problem over multiple signal stops so that the vehicle considers economizing its energy throughout the journey. Increasing the number of stages, however, can increase the complexity of the problem. An alternative approach is to directly minimize acceleration and deceleration in the current consideration.

When the initial velocity is low, as shown in Fig. 6, the optimal control may span over a longer time interval. A pattern of the training progress is shown in Fig. 7. Furthermore, decreasing the sampling time and introducing penalties on acceleration can make the optimization problem similar to the speed advisory problem [6]. Similar to speed advisory systems, the RL-based solution can be formulated to widely apply to vehicles approaching the intersection and be shared with them. Most input parameters are environment-specific, except for the input constraints and the vehicle model. By setting input parameters such as $u_{\min}$ and $u_{\max}$ to assume common values, the optimal solution can be generalized and shared with vehicles that come within the range of the intersection.

6. Discussion and Conclusion

The eco-driving problem is solved for a vehicle approaching a signalized traffic intersection. The problem is formulated as an optimization problem that explicitly minimizes fuel consumption and travel time and is a non-convex, two-point boundary value problem, thus difficult to solve analytically. A solution is obtained based on the DDPG RL framework. In general, there is no guarantee that an optimal solution can be found. The solution is, however, acceptably sub-optimal. Particularly, in the minimum-time problem, the

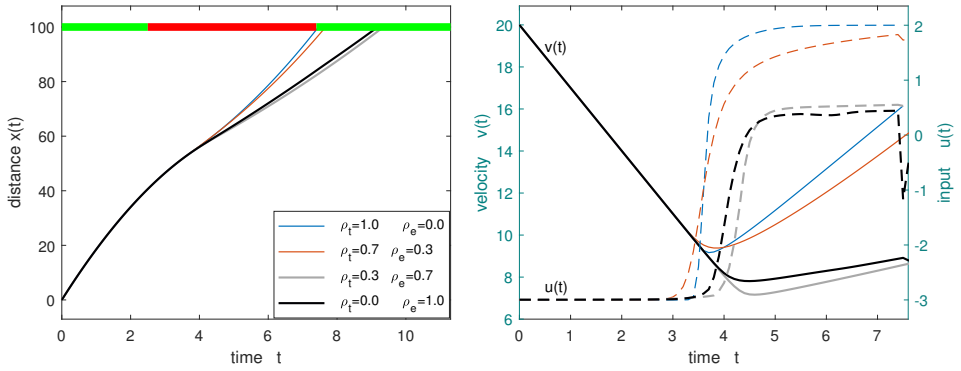

Figure 5: Distance, input and velocity plots for trained deep reinforcement learning agents

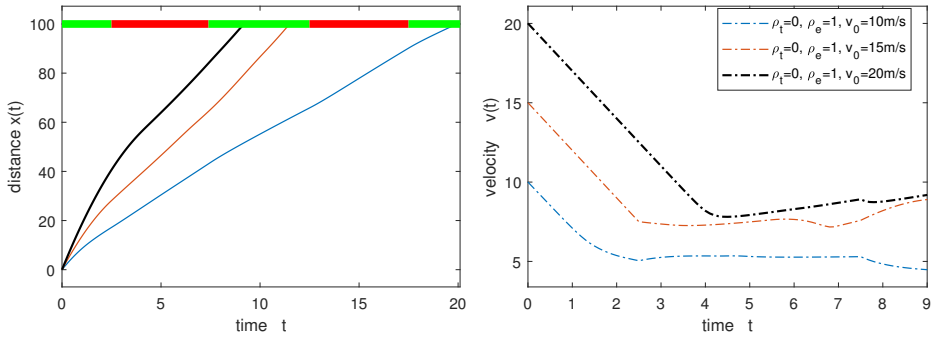

Figure 6: Comparing minimum-energy eco-driving solutions for different initial velocities

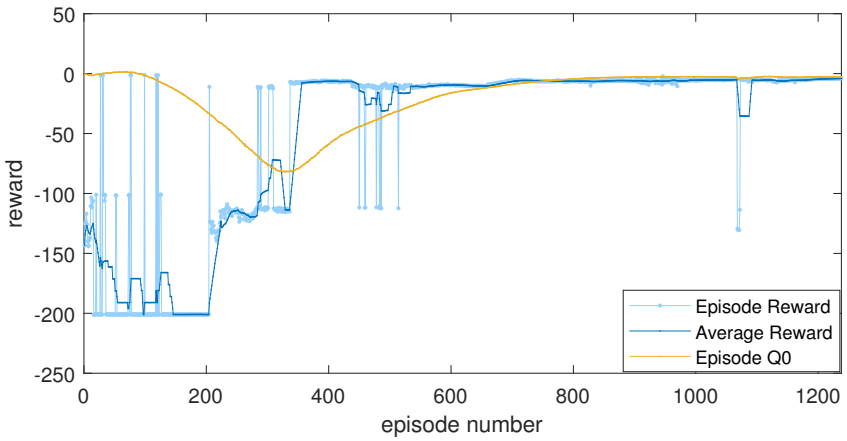

Figure 7: Training progress for case 4

vehicle reaches the intersection at the exact start of the next green signal phase.

This approach can be formulated to widely apply to vehicles over different SPaTs. The optimal solution can thus be hosted on infrastructure around the intersection and shared with vehicles that come within range of the intersection. There is an added advantage of easy assimilation of deep neural networks for computer vision to allow for dealing with obstacles in the vehicle's path during training. Furthermore, to decrease the time required for convergence, the sampling period can be chosen to be large. When the sampling period increases and the input is explicitly penalized in the objective function, the formulated eco-driving problem is similar to the speed advisory problem [6].

Presently, the agent does not consider the comfort of the occupants. Some penalty can be placed to make the agent consider the occupant's comfort so that the objective function has an additional term $\frac{da(t)}{dt}$. Another concern of the approach is whether the solution to a single-vehicle eco-driving problem can slow down the entire traffic and increase congestion. As indicated by the United States Department of Transportation, eco-driving vehicles are envisaged to be assigned to dedicated lanes – eco-lanes, similar to high-occupancy vehicle lanes [29]. Hence, the eco-driving vehicles will be somewhat isolated from the rest of the traffic. Nevertheless, an area of research that considers the integration of queue-length considerations into the solution for the eco-driving problem is a potential area of future research.

Other potential areas of research also include considerations for human-driven vehicles, and non-deterministic traffic signal patterns, including traffic signals that adapt to vehicle queue length.

Conflict of Interest The authors declare no conflict of interest.

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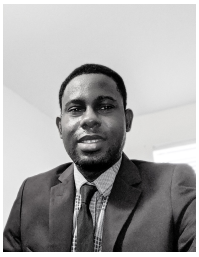
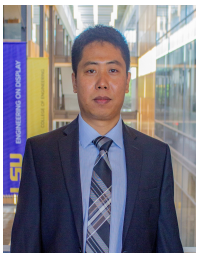


JOSHUA OGBEBOR has completed his bachelor's degree in electrical and electronics engineering at the University of Lagos, Akoka, Lagos. He is currently pursuing his master's degree with the School of Electrical and Computer Engineering, Louisiana State University, Baton Rouge, USA.

He has been involved in research projects on systems design and learning-based control systems. He is also experienced in deep-learning based computer vision. His current research interests include machine learning, deep learning, reinforcement learning, multi-agent systems, connected and autonomous vehicles.



XIANGYU MENG has done his bachelor's degree from Harbin Engineering University in 2006. He has done his master's degree from Harbin Institute of Technology in 2018. He has completed his PhD degree in Control Systems from the University of Alberta in 2014.

From June 2007 to July 2007, and from November 2007 to January 2008, he was a Research Associate with the Department of Mechanical Engineering, University of Hong Kong. From February 2009 to August 2010, he was a Research Award Recipient in the Department of Electrical and Computer Engineering, University of Alberta. From December 2014 to December 2016, he was a Research Fellow with the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore. From January 2017 to December 2018, he was a Postdoctoral Associate with the Division of Systems Engineering, Boston University, USA. Since 2019, he has been an Assistant Professor with the Division of Electrical and Computer Engineering, Louisiana State University, Baton Rouge, LA, USA. He has published over 30 refereed articles in academic journals, and contributed to one textbook and over 20 conference papers. His research interests include connected and autonomous vehicles, deep learning, and reinforcement learning.

X. H. Zhang received B. S. and M. S. degrees in electrical engineering from Northeast Agricultural University, Harbin, China, in 2002 and 2005, respectively. He received a Ph.D. degree in control science and engineering from Harbin Institute Technology, Harbin, China, in 2013. He is currently a professor in the College of Electronic and Information, Northeast Agricultural University, Harbin, China. His current research interests include Internet of Things, embedded systems, as well as deep learning and its application to computer vision.

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PWM Controlled Bidirectional Converter having Load-Independent Voltage-Gain

Muhammad Tanveer Riaz [*,1,2], **Umar Saeed** [3], **Saba Waseem** [1], **Sidra Riaz** [4], **Eman Manzoor Ahmed** [5]

[1] Department of Mechanical, Mechatronics and Manufacturing Engineering, University of Engineering and Technology Lahore, Faisalabad Campus, Faisalabad, Pakistan.

[2] Department of Electrical and Information Engineering Politecnico di Bari 70125 Bari – Italy

[3] School of Electrical Engineering, The University of Faisalabad, Faisalabad, Pakistan.

[4] Department of Aerospace and Engineering, Politecnico di Bari, Bari Italy.

[5] Department of Electrical Engineering, University of Engineering and Technology Lahore, Faisalabad Campus, Faisalabad, Pakistan

*Corresponding author: Muhammad Tanveer Riaz, uetmtr@yahoo.com ORCID: 0000-0002-4391-9821

ABSTRACT: The power balancing is the issue that creates when voltage fluctuations occur in the DC microgrid. In order to compensate for the DC bus voltages in the DC microgrid, the energy storage system is used. This system absorbs or releases the power to make the DC bus voltages is stable. In this research, a bidirectional series resonant (BSR) converter is proposed which operates at the fixed frequency for the energy storage system. A simple PWM control technique is used for the power flow regulation in the system. The gain voltage of the BSR converter depends only on the duty cycle of the applied voltage and does not change the direction and amplitude of the power flow. Theoretically, after the calculations, the gain voltage of the BSR converter changed from minimum (zero) to maximum (unlimited) which means the designed converter is a buck-boost converter as well. This property of the BSR converter will help the researcher to use a wide range of voltage applications. The operations mode i.e. forward and backward modes, and the direction of the power flow can be changed smoothly by Pulse Width Modulation control. Zero voltage switching for all the voltage ranges of the active switches is also achieved in this research.

KEYWORDS: Uninterrupted Power Supply, Inverter, PWM Control, Resonant Converter, Bidirectional Converter

1. Introduction

Gadgets such as batteries and supercapacitors which do store energy, capable of enduring or interim energy buffering has been a critical part in numerous DC microgrids. The key device to interface storage batteries or super-capacitors with a DC voltage bus in a DC microgrid is a bidirectional DC-DC converter (BDCs). Moreover, BDCs needs more voltage gain because of extensive variation of terminal voltages in the batteries and super-capacitors. So, it's a research gap was available in the last few years in order to get a high efficacy in the BDCs for the wide range of voltage gain in the applications of DC microgrid. Although, an isolated BDC is also available in the market which considered as a better form of unidirectional converter (DC-DC). It can be designed as by replacing the rectify diodes with active switches. Keeping in mind of this given principle, many varieties of remoted BDCs are designed in the years i.e. PWM controlled BDCs, resonant BDCs, phase shift DAB (Dual-Active-Bridge) BDCs etc. From these BDCs, DAB BDC has gain more attraction towards research because of its many advantages like flexibility present for controlling the Buck-Boost converter, small voltage stresses exist on the switches and turn-on losses reduce in the switching (by zero-voltage switching (ZVS)). The phase shift angle between primary and secondary switching is used to control the direction and amplitude in the power flows. However, this type of BDCs also limited due to presence of high circulating currents in the transformers and semiconductors devices that keep turn-off current losses high. Phase shift manipulation techniques also work to adjust the circulating current but, in this case, ZVS performance does not meet expectations among the whole operation. Resonant BDC (LC series-resonant tank) can be used to reduce the turn-off current losses if purely sinusoidal current finds in the resonant tank. But still problem exist in the resonant BDC i.e. exceeds circulating

current and increased turn off losses when increases the phase-shift angle.

Saving the domestic electrical energy consumed by the DC gadgets in thou- sands of AC to DC conversions by just doing one conversion in DC microgrid system. The Bidirectional DC to DC converter can be used on HVDC level because bidirectional gain independent converters promise a feasible and re- liable solution for energy conservation and sharing. This project can be marketed in future when DC microgrid will be a part of Distribution System Due to the quality of bidirectional power flow, this project can be used for power exchange between two countries on HVDC lines.

To implement a bidirectional dual active bridge DC [1] to DC converter with AC link for Galvanic isolation to meet the requirement of voltage matching and safety considerations in DC microgrids.

2. Basic Model and Operation

The basic working principle and flow chart of the project is shown in the following Figure 1.

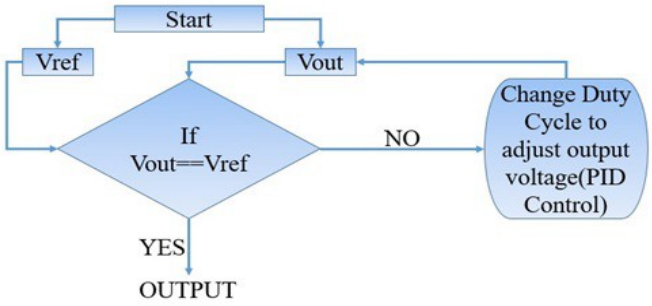

Figure 1: Flow Chart of the Project

2.1. DC Supply for the Inverter

Input DC supply for converter was to be designed from 0 to 400V and 15A ratings [2]. For this purpose, three components were used.

- Variac transformer for supplying variable AC input to the bridge Rectifier.
- Bridge Rectifier rated at 400V and 15A.
- Smoothing capacitor of 400V and 2200UF.

Variable AC input was fed to the high voltage rectifier. Then rectified pulsating DC was smoothed by using 2200UF, 400V capacitor. Hence re- quired 400V and 15A DC was fed to the inverter [3]. The following figure is showing the high voltage DC supply on the same PCB board contain the high voltage rectifier and 2200uF, 400V rating capacitor.

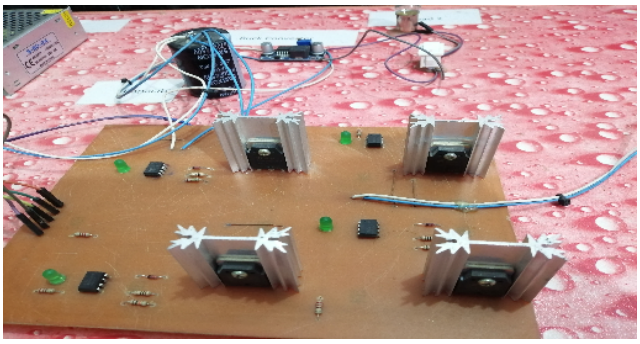

Figure 2: 5V DC Supply

2.2. Duty Cycle Range

Duty cycle range for the two inverters is 0-0.5 [4]. When primary is fixed at 0.5 secondary is varied from 0 to 0.5, while when secondary is fixed at 0.5 primary is varied from 0 to 0.5 theoretically. Best operation of the novel BSR is at Gain=1 means both duty cycles are 0.5, so BSR is designed near boundary condition [5–9]. The relationship between duty cycle range and the operation modes is shown in the following table.

Table 1: Duty cycle Control: Relationship Between Duty Cycle and Operation Mode

Operaion Mode	Voltage Gain G_b	Duty Cycle	
		D_p	D_s
Buck	<1	<0.5	=0.5
Boundary	=1	=0.5	=0.5
Boost	>1	>0.5	<0.5

2.3. H-Bridge Inverter

For H-Bridge inverter two complementary PWM signals were generated by microcontroller STM32F407VG. Dead time was included for safe and sound operation of IGBT's. H-Bridge consists of two legs each containing two IGBTs as switches. Switches in each leg turn on and off complementary to avoid short circuit of High Voltage DC supply and severe damage to circuit. Upper switch of left leg and lower switch of right leg are operated by same signal. Similarly, lower switch of left leg and upper switch of right leg are operated by same signal. When upper switch of left leg and lower switch of right leg are in the ON state then a positive DC voltage of 311V is applied at points a and b. Similarly, when upper switch of right leg and lower switch of left leg are in the ON state then a negative DC voltage of 311V is applied at points a and b. In this sense DC is converted to high frequency 100kHz square wave. In the same way another inverter is operated. The Figure 3 is showing the complete H-Bridge inverter with high voltage DC supply on the same PCB board [10].

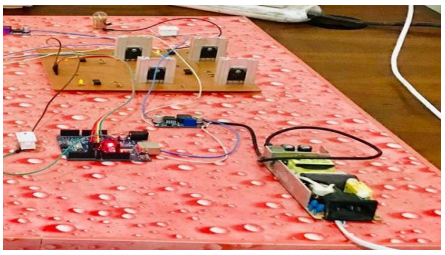

Figure 3: H-Bridge Inverter

2.4. Resonant Tank

For desired DC to DC converter LC resonant was used to couple the two inverters such that DC side of first inverter was used as input of the whole converter. Then the first inverter AC side was given as input to LC resonant tank for fixed frequency operation. Resonant tank output was given as input to AC side of second inverter [11–19]. DC side of second inverter is used as output of whole converter.

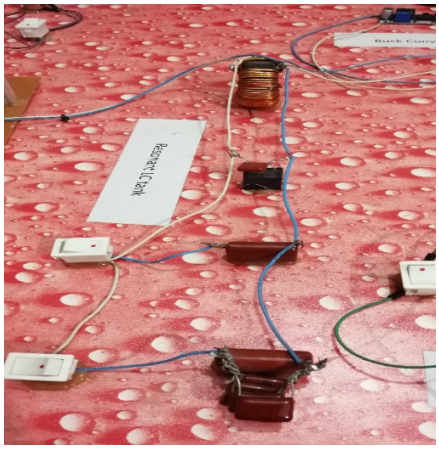

Figure 4: LC Resonant Tank

3. Proposed Method

Figure 5 shows the block diagram for the proposed solar system installed with FLC. MPPT [20–25] control in this work is achieved by FLC due to its higher speed.

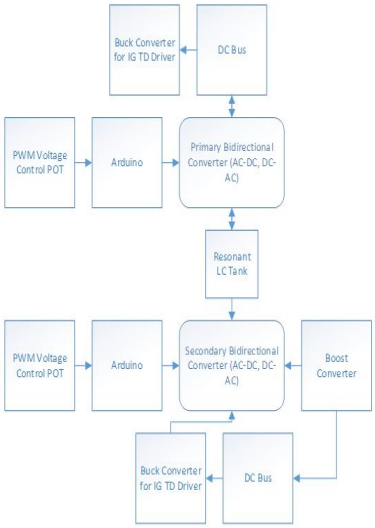

Figure 5: Complete Schematic of the Project

4. Simulation Results

4.1. Controller Outputs

The Micro-Controller [26], [27] which is used is STM32F407VG. It is based on 32-bit ARM processor. It has max frequency of 168 MHz with 192 kB of RAM and 1MB of ROM. It is selected because it is most versatile in its operation, very flexible to be programmed and has very large number of libraries available [28].

Timers are used to generate the PWM of frequency 110 kHz which can changed according to the resonant frequency of LC-Tank [29]. It is a fixed frequency system that is whatever is the frequency of LC-Tank, it is same throughout the system [30].

The controller is giving four PWM's, two for each invertor. Each PWM is given to two IGBT's of different legs of invertor. The two PWM's given to the invertor are out of phase, center aligned so that two transistors in same ladder are not conducting at once, so that short-circuit is avoided.

The output of the controller [29], [31–34] or the PWM generated from the micro- controller is shown in the Figure 6.

Figure 6: Controller Output

4.2. Optocoupler Outputs

Optocoupler is a device that is used to isolate the Controller from high power circuit such as in our case the invertor. It uses light to transfer electrical signals to required circuit, hence named Optocoupler. It is taking input from STM microcontroller and is providing signal to the gate of IGBT's [35–40].

Optocoupler actually serves two purposes, one being isolation and the other providing enough power to gate of IGBT's. STM outputs are typically 3.3V maximum which is unable to drive gate of IGBT's as they require typically 15V to conduct.

Also, STM pins cannot provide enough current to the gate, so we use Optocoupler. The output obtained from the optocoupler or the response of the optocoupler is shown in the following Figure 7.

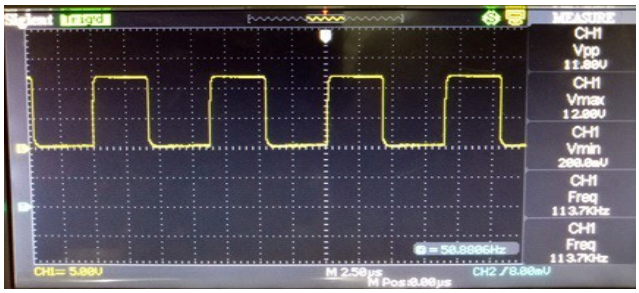

Figure 7: Optocoupler Output

4.3. Response of IGBT

IGBT stands for 'insulated-gate bipolar transistor'. It is three terminal device that is mainly used as a switch in an inverter. It combines good properties of Power MOSFET's and BJT's. It is used because it has high efficiency, so it can be used in high power circuits and it has fast switching characteristics, so it can be operated at very high frequency. As circuit involve high voltage, high current as well as high frequency, so we select IGBT's as our switching device.

As the invertor is operating at very high frequency, IGBT's were not switching off in time due to miller effect. Capacitance effect in IGBT's be- come dominant at high frequency so some remedies were employed.

Firstly, PCB was made such that it has very small paths between the components so that inductance would not pose the problem in such a condition. So, we made the shortest path between the gate of IGBT and the output terminal of the optocoupler to make the gate signal free from harmonics inclusion.

Secondly, IGBTs were soldered directly on the PCB without using connectors. Also, legs of IGBT's were made as small as possible.

Thirdly, DC power supply inductor was posing the problem, so it was removed as it was main reason behind large 'off-time' of IGBT. The waveform in the following Figure 8 showing the response of IGBT at high voltage and frequency.

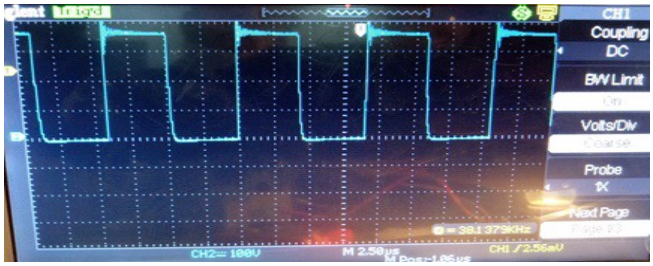

Figure 8: IGBT Response

4.4. Inclusion of Dead Time

The dead time is the time in which no part of a H-bridge is turned on. It is used when you have two out of phase PWM signals so that neither the high nor the low side of the H-bridge can be switched-on at once.

If dead time is not included in waveforms, it is very much the possibility that both IGBT's would turn on, resulting in short-circuit and damaging the DC supply and IGBT's permanently.

Dead time of 15-20 microseconds is introduce in PWMs with STM controller programming to avoid any kind of short circuiting. The following Figure 9 clearly indicates the dead time included in the two out of phase PWM signals[41].

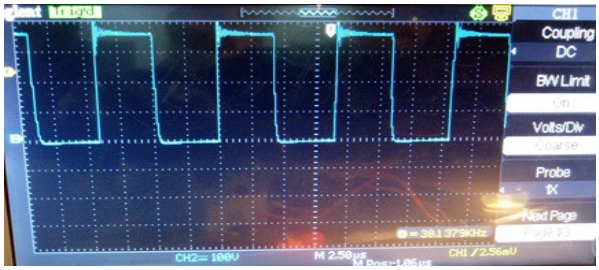

Figure 9: Inclusion of Dead Time

4.5. LC Tank Response

LC-Tank is an electric circuit, in which both inductance and capacitance are large as compared to resistance which should be ideally zero. Series resonant tank is used as it is better for voltage magnification as is required by the project.

LC-Tank acts as a band pass filter, that can allow certain frequencies and block others. As our inverters are operating at fixed frequency, it is required that this fixed frequency signal contain most of the power and other harmonics of this frequency should be diminished. So, both the invertors frequencies are made equal to the resonant frequency of LC-Tank [42–44]. The Figure 10 shown below is the response of series LC resonant tank when the frequency of the applied PWM signals is equal to the resonant frequency of the LC resonant tank.

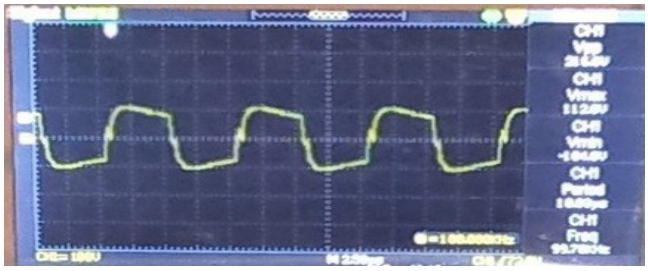

Figure 10: Inclusion of Dead Time

5. PWM Control

By controlling the PWM and changing the duty cycle of the generated PWM [45–49], we can operate the inverter in different modes of operation as discussed below.

5.1. Duty Cycle Control

As discussed earlier, the given converter is fixed frequency that means all signals involved have same frequency equal to the resonant frequency of the LC-Tank.

Voltage gain of the converter is controlled by the Duty Cycle of signals given to IGBT's. Let Dp and Ds are Duty Cycles of primary and secondary side upper IGBT's respectively. Duty Cycle of lower switches are complementary centre-aligned of each of the upper IGBT. Duty Cycle Dp and Ds have no effect on the amount and direction of power. The duty cycle control corresponding to different modes of operation is shown in the following Figure.

5.2. Buck Mode

In Buck mode, voltage gain would be less than one. In this mode, primary side Duty Cycle Dp would always be less than 0.5 and Duty Cycle of secondary side IGBT's, Ds would be constantly equal to 0.5 [50–52]. Gain can be changed by varying duty cycle Dp in the range from 0 to 0.5 but it would not cross 0.5 threshold.

5.3. Boost Mode

In Boost mode, voltage gain would be greater than one. In this mode, secondary side Duty Cycle Ds would always be less than 0.5 and Duty Cycle of primary IGBTs, Dp would be constantly equal to 0.5. Gain can be changed by varying duty cycle Ds in the range 0 to 0.5 but it would not cross 0.5 threshold.

6. Conclusion

This article has proposed a new serial bidirectional resonance converter (BSR) and its control strategies. The main features of the proposed BSR converter has obtained by theoretical analyses and experiments. Bidirectional regulation of voltage and power flow with a fixed frequency PWM control technique facilitates easily for implementing and controlling the BSR converter. The duty cycles of the primary and secondary switches are used for finding the normalized voltage gain and no change is follow with the direction and amplitude of the transmitted power. Automatic and smooth mode of transition is easily possible due to the simple control of voltage-increasing properties of this BSR converter. In order to get a wide range of voltage in case of bidirectional power conversion application, buck and boost voltage converters has capacity to work for both modes i.e. forward and reverse modes. For getting zero voltage switching of all active switches within full range of load and voltage, auxiliary inductor is used. Soft switches have low circulating energy because of converter working at series resonant frequency.

By combining the all features given in above paragraph, a highly effective bidirectional isolated converter is obtained specifically for micro DC network application. The main characteristics, probability and feasibility of this BSR converter are intended to be evaluated and verified by getting experimental results on a 1.6 kW prototype power with a voltage range of 320V to 480V and a bus voltage of 400V.

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MUHAMMAD TANVEER RIAZ received the B.Sc. degree in electrical engineering from the University of Engineering and Technology Lahore, Pakistan, in 2015, and masters of engineering degree in electrical engineering from the Chongqing University, Chongqing, China, in 2018. He is serving as Lecturer in the department of mechatronics and control engineering at the University of Engineering & Technology Lahore, Pakistan since May 2019.

His current research interests include Smart Integration of Renewable energy sources, Smart grid and micro grid security issues, HVDC grounding parameters analysis, Hybrid HVDC protection system, New electrical technologies and energy management.

SIDRA RIAZ is recently doing Ph.D. Degree from Politechnico di Bari University of Italy.

Her current research interests include aerospace engineering, plasma physics and optimal control systems.

SABA WASEEM is doing B.Sc. in Mechatronics and Control Engineering from University of Engineering and Technology Lahore (Faisalabad Campus).

Currently, she is working on a project whose title is Porosity Measurement of Woven Fabric using Light Through Methodology.

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Comparative Analysis of Scheduling Algorithms in 5G Uplink Transmission

Maryam Imran Sheik Mamode [1,*], Tulsi Pawan Fowdur [2]

[1] University of Mauritius, Reduit, Mauritius

[2] Department of Electrical & Electronic Engineering, University of Mauritius, Reduit, Mauritius

* Corresponding author: Maryam Imran Sheik Mamode, Reduit, Mauritius, maryamsheikmamode@hotmail.com

ABSTRACT: 5G is the successor to 4G technology and it has enabled a new level of user experience with much greater speeds and much lower latencies. Scheduling is the method of allocating resources for transmission of data. In this paper, three scheduling algorithms have been investigated, namely Proportional Fair, Round Robin and Best CQI. An uplink 5G system with one base station and four user equipment were used to evaluate the three algorithms by varying four sets of parameters. Simulation results showed that the Round Robin algorithm was the fairest of all three algorithms by displaying almost similar resource share percentage for the four user equipment. Proportional Fair algorithm was observed to yield a higher throughput than the Round Robin algorithm for a specific user in some cases. It offered a better trade-off between throughput and fairness. In the case where distance of user 1 from the base station was 100m, the system simulated with the proportional fair technique yielded a peak throughput 30% higher than the system simulated with Round Robin technique. On the other hand, the Best CQI algorithm displayed a peak throughput value about 35% higher than the proportional fair algorithm for the 100m distance case. The Best CQI algorithm was found to be the least fair of all three algorithms as it favored users with better channel conditions.

KEYWORDS: Scheduling, 5G, Uplink, Proportional Fair, Round Robin, Best CQI

1. Introduction

5G is the 5th generation of mobile communications which was presented in 3GPP Release 15. It enabled three key technologies namely Enhanced Mobile Broadband (eMBB), Enhanced Machine Type Communication (eMTC) and Ultra-reliable Low Latency Communication (URLLC). eMBB provides high speed internet connectivity as well as virtual reality and augmented reality media and greater bandwidth. It includes the use of Massive Multiple-Input Multiple-Output (MIMO) antennas, technology, beamforming and mmWave [1]. eMTC provides low power consumption for machine type communication with more coverage and high data rate while URLLC offered much higher Quality of Service (QoS), enabling applications such as remote surgery and intelligent transport system. eMTC also involves Internet of things (IoT) which provides connectivity between different machines without human intervention [1]. Release 16 has provided enhancements with regards to 5G satellite access, wireless convergence for 5G, Local Area Network interworking, network slicing and IoT, among others [2]. Release 17 has presented enhanced NR (New Radio) MIMO, enhanced URLLC, User Plane Function (UPF) enhancement, Network slicing phase 2 and Narrowband IoT (NB-IoT), among other improvements [3]. Release 18 has launched 5G-Advanced and works are expected to be completed by 2023 [4]. 5G has achieved peak data rates of 20 GB/s, which is about 20 times faster than 4G networks. The user experience is 10 times faster than 4G with a data rate of 100 Mbit/s. 5G has also enabled simultaneous connection for 1 million devices per square kilometre and a latency of 1m/s [5]. Cisco has predicted that 500 billion devices will have internet connectivity by 2030 while Ericsson has predicted that 29 billion devices will be connected to the internet by 2022 and 60% of that number will be related to IoT [5]. 5G has been developed for a broader range of applications compared to 4G which had primarily been developed for mobile communications [6].

Scheduling deals with the assignment of resources for transmission of data. The main objective of a scheduler is to provide an optimized allocation of resources for the User Equipment (UEs) in terms of time, frequency and power, while maintaining a satisfactory Quality of Service (QoS) level [7]. Schedulers in the Base station control the allocation of resources among users while mitigating intra-cell interference. They use different sources of information in order to assign resources and coordinate transmission.

In [8], the authors have developed a new Proportional Fair (PF) algorithm that is able to dynamically adjust for the capacity improvement of the Long Term Evolution (LTE) system. The proposed technique is compared with traditional PF downlink scheduling algorithm and Best Channel Quality Indicator (CQI) scheduler. The new method improved the average cell throughput by 31% at the expense of some degradation in the fairness level as compared with traditional PF algorithm. The authors in [9] compiled a survey of downlink scheduling algorithms. The algorithms were separated into QoS aware and QoS unaware. QoS aware makes use of the data rate, buffer status and CQI to ensure a good throughput. QoS unaware, on the other hand, utilizes the same parameters as QoS aware but in addition to those, it also uses delay constraints as well as CQI to meet the required throughput. A comparative analysis of all related scheduling algorithms had been carried out. The study has shown that QoS aware algorithms are not suitable for wireless multimedia traffic as QoS requirements are not taken into account while QoS aware algorithms do not consider the non real-time traffic. The authors in [10] proposed an enhanced PF scheduling algorithm constructed from the Latency-Rate server theory and system characteristics defined in the LTE standard. The proposed scheme was compared with PF and Modified Largest Weighted Delay First (M-LWDF) schedulers, while the rate for each user was calculated based on traffic characteristics and delay required. Simulations showed that the novel scheme outperformed the other two scheduling algorithms by meeting the delay required by users. In [11], the researchers compiled state of the art downlink scheduling algorithms and identified their challenges. An optimized solution was then developed such that the flow deadlines could be met and the solution was added to the scheduling algorithms. The buffer state for each user as well as the strict deadlines for packets were considered. Simulations have showed that the existing scheduling algorithms using the proposed solution outperformed the traditional algorithms in terms of throughput, packet loss and fairness. In [12], the authors used a Model Based Design (MBD) and Model Based Testing (MBT) method in order to investigate several scheduling algorithms which take into consideration the QoS requirements of each user and the channel conditions. Maximum Rate (MR), Round Robin (RR) and PF algorithms are evaluated as well as a new UE-based MR algorithm. Simulation results showed that the scheduling algorithms can be further enhanced using the MBD and MBT method. The authors in [13] combined the buffer status with the PF algorithm in order to generate a novel scheduling algorithm for efficient eMBB use. The efficacy of the novel algorithm was then investigated through simulations, taking into account the throughput, fairness and buffer status. In [14], a novel scheduling algorithm was developed and it considered priorities and deadlines in order to assign resources to users. The researchers in [15] proposed a novel scheduling technique which was able to choose a specific scheduling algorithm based on instantaneous scheduler states so that packet drop rates and packet delays were minimized. Reinforcement learning is used to map the scheduling algorithm to each state for real-time scheduling and also to learn when each state should be applied. In [16], the RR and PF scheduling techniques were compared for varied UE density scenarios using voice and video traffic, in order to evaluate the performance of 5G mmwave network. Simulation results showed that RR was the preferred choice for voice traffic while PF was selected for video traffic due to better throughput results.

In this paper, three scheduling algorithms have been investigated namely PF, RR and Best CQI. An uplink 5G system has been used to simulate the three algorithms. The "NR PUSCH FDD Scheduling" program in Matlab was used to carry out simulations. Four sets of parameters were identified in the program and were investigated. Thus four schemes have been implemented whereby the four sets of parameters were varied individually while keeping other relevant parameters constant. The four sets of parameters that were varied are as follows:

- Distance of the UE from the base station
- Size of packets transmitted
- Total Bucket size : Prioritized bit rate (PRB) and Bucket size duration (BSD)
- The priority of each logical channel.

The simulation results were analysed in terms of goodput, throughput, Resource Share percentage and Buffer Status. Simulation results showed that in all cases, the RR algorithm displayed almost similar resource share for all UEs. The PF algorithm, however, showed better throughput values for particular UEs by considering the scheduling factors. The Best CQI algorithm largely considered channel conditions and thus it was observed that the user with better CQI yielded much better throughput than the other users.

The rest of the paper is organized as follows. Section 2 presents scheduling in 5G. It elaborates on the scheduling

factors, processes and techniques. Section 3 deals with simulation results and analysis. Section 4 concludes the paper.

2. Scheduling in 5G

In order to allocate resources to a specific user, there are various factors to be considered such as Measurement (UE/Network), BSR (Buffer Status Report), QoS Requirement, Associated Radio Bearer, CQI and SR (Scheduling Request) among others. The CQI helps to select the appropriate Modulation and Coding Scheme (MCS) to be used on the resource block allocated to the user. The buffer status report is used by the user to inform the base station in case there is some data in its buffer in order to request a grant from the network to transmit the data. Thus, the base station is constantly informed about the buffer status of the UE. The QoS determines how a data packet is treated in the network. Web browsing packets are given lower priority than voice packets. The scheduler depends on the BSR, CQI and QoS in order to make an appropriate scheduling decision [17].

For the allocation of resources during the scheduler operation, both the UE buffer status and QoS requirements of each UE and associated radio bearers, are considered. Measurements at the base stations or made by the UE, are used to determine radio conditions at the UE. Those measurements can then also be used to allocate resources. Radio resources are assigned in a unit of slot (for example one mini-slot, one slot, or multiple slots) and the radio resources are made up of resource blocks [18].

The UE will receive a scheduling channel following a scheduling request and the resources assigned can be determined from the scheduling channel. The uplink buffer status reports form part of the measurements used for the scheduler operation. These reports are used to evaluate the data buffered in the UE's logical channel queues in order to create Qos-aware packet scheduling. There are two types of logical channels namely logical control channel and logical traffic channel. The logical control channel is used for transmitting control plane information. The control channels consist of the Broadcast Control Channel (BCCH), the Common Control Channel (CCCH) and the Dedicated Control Channel (DCCH). The logical traffic channels are used to transmit user plane information. The Dedicated Traffic Channel (DTCH) is a point-to-point channel for the transmission of a particular user's information. It can be used both in downlink and uplink.

Two categories of scheduling are defined for 5G namely Time-domain and frequency domain [19]. A resource block in 5G can be defined as a group of twelve sub-carriers which are contiguous in frequency, over one slot in time. It constitutes the smallest unit of radio resource and can be built up into radio frames, subframes, slots and mini-slots. The radio frame has a duration of 10ms and constitutes 10 subframes with each subframe of a duration of 1 ms. Each subframe contains one or more adjacent slots containing 14 OFDM symbols. A mini-slot in Release 15 contains 2, 4, and 7 OFDM symbols and the time duration of a slot depends on the sub-carrier spacing as illustrated in Figure 1 [20].

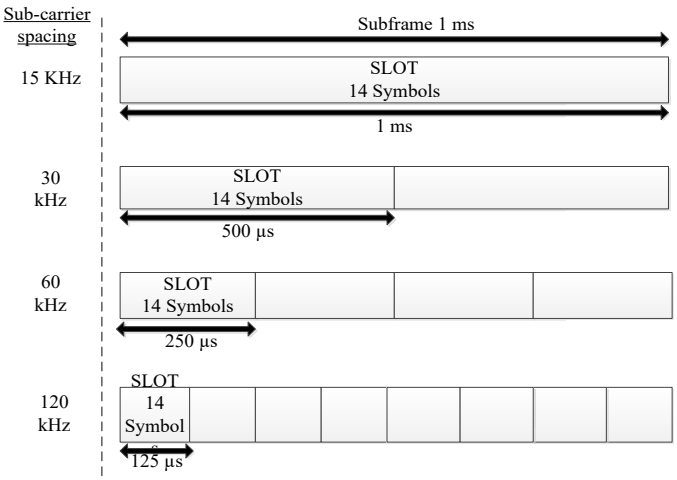

Figure 1: Frame structure 5G

The resource element mapping takes place in the Physical Downlink Shared Channel (PDSCH) for downlink transmission and in the Physical Uplink Shared Channel (PUSCH) for uplink transmission, before OFDM signal generation [21]. The Uplink scheduling strategy has the task of allocating PUSCH resources to a group of UEs related to a gNB. The schema of a scheduling system is shown in Figure 2 [22].

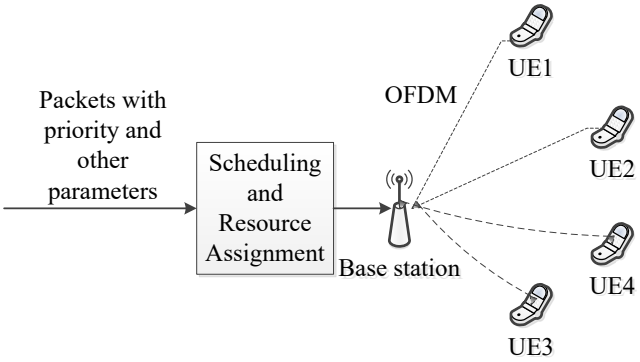

Figure 2: System architecture for scheduling

From Figure 2, it can be observed that packets are input to the scheduler of the base station. Each packet is destined for a particular user with specific characteristics in terms of priority, distance and packet size. Beamforming is used to transmit packets to the UEs and four UEs are used in the 5G system architecture simulated.

The function of the gNB is to assign uplink resources by using the scheduling algorithm. Uplink assignments are sent to the UEs and PUSCH transmission is received from the latter. The tasks of the UEs is to transmit the pending buffer status report to the gNB and collect the uplink assignments from the gNB, which is used for PUSCH transmission. The scheduler is used every p slots

to allocate resources where p denotes the periodicity of the scheduler. In each period, the periodicity p matches the number of slots scheduled. Figure 3 shows a schema of the Uplink scheduler function [22].

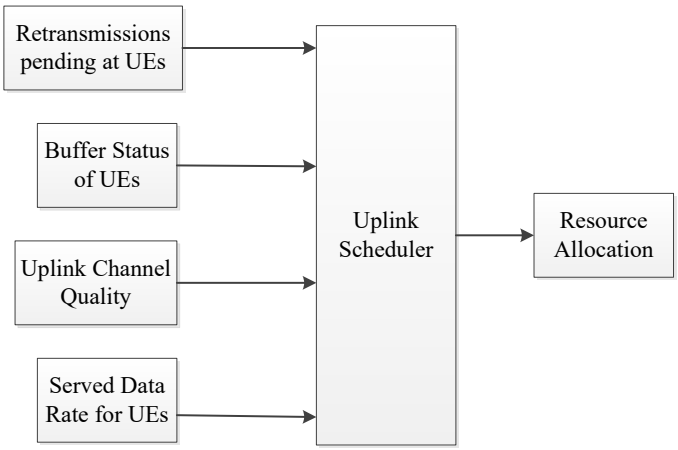

Figure 3: Uplink scheduler function

The RR algorithm is used to allocate resources equally between all users without any consideration towards the channel conditions. The RR algorithm provides fairness to all UEs and it operates by rotating the queue process. When a process ends, the next process is handled and each process is allocated the same time period. An equation is used to define the user priorities for each resource block in terms of user *i* and resource block *k* [16].

$$x_{i,k} = y_i(t - T_i) \quad (1)$$

where y_i represents the priority value for each process for user i

t represents the current time

T_i represents the last time user i was served.

The Proportional Fair (PF) algorithm has the primary objective of achieving a fair trade-off between throughput and fairness. The PF scheduler assigns resources to UEs according to the average achievable data rate and thus it also serves UEs having very low CQI values [13]. The throughput of UEs having better instantaneous achievable rate are increased compared to mean throughput. The PF algorithm does not take into account the buffer status of the UE and thus it is not optimal for real time services. It considers the ratio of the user's instantaneous transmittable data rate to average transmitted rate, in order to schedule users.

The scheduling formula for PF is represented by equations below.

$$x_i(t) = \frac{y_i(t)}{z_i(t)} \quad (2)$$

$$z_i(t+1) = \left(1 - \frac{1}{t_c}\right) z_i(t) + w_i(t+1) * \frac{1}{t_c} * y_i(t+1) \quad (3)$$

$$w_i(t+1) = \begin{cases} 1 & when\ packets\ of\ user\ i\ are\ allocated\ at\ interval\ t+1 \\ 0 & when\ packets\ of\ user\ i\ are\ not\ allocated\ at\ interval\ t+1 \end{cases} \quad (4)$$

where: $y_i(t)$ represents the momentary data rate for user i calculated during time interval t,

$z_i(t)$ indicates the mean throughput of user i during time interval t,

$w_i(t+1)$ indicates the selection of the packet for transmission during time interval t+1,

t_c denotes a time constant which can be used to capitalize on throughput and fairness with the PF algorithm.

The Best CQI algorithm selects the user who has the highest CQI. This algorithm basically schedules resources based on feedback report from the UE on the radio channel quality such as BER, CQI and SINR. The resource assignment depends essentially on the channel condition or radio signal power and thus fairness is not a priority for this algorithm. In the 5G-NR standards, CQI vs MCS (Modulation and Coding Scheme) tables are already defined. According to the CQI value reported by the UE, the different transport block sizes are selected to transmit data. In case a high CQI value is reported, a larger transport block size is used to transmit data [23]. Thus the users at edges of a cell with bad channel conditions will not get assigned any resources [24].

The following equation can be used to illustrate the Best CQI algorithm.

$$n = \max_{t=1\ to\ N} (P_i(t)) \quad (5)$$

where n is the user, $P_i(t)$ is the achievable data rate of a particular UE i at time t and N is the total number of active users.

3. Simulation Results and Analysis

Three Uplink scheduling strategies namely PF, RR and Best-CQI are evaluated in this work, in terms of throughput and fairness in frequency division duplexing (FDD) mode.

Four schemes have been simulated. Four UEs and 1 gNB, are used for simulations. For each of the schemes simulated, a set of parameters were varied and other sets were kept constant. The simulation results were displayed in terms of throughput, goodput, resource share percentage and Buffer status.

The throughput is defined as ratio of the data bits delivered successfully to the whole simulation time [13].

$$\text{Throughput} = Throughput = \frac{\sum Received\ Packet\ Size}{Total\ Simulation\ time} \quad (6)$$

The goodput illustrates the successful delivery of data packets to the UE. It does not take into consideration packet retransmissions and thus the value for goodput is

lower than for throughput [25]. The goodput can be expressed as follows [13]:

$$Goodput = \frac{Useful\ data\ transmitted}{Total\ transmission\ time} \quad (7)$$

The Buffer Status Report (BSR) provides the gNB with data about the amount of volume in the MAC entity. The following parameters are configured by the RRC to manage the BSR including periodic BSR Timer and retransmission BSR Timer [26]. The volume of UL data that can be allocated to a logical channel is determined by the MAC entity and computed based on the data volume calculation process in [27] and [28].

Fairness metric is used to illustrate the equal sharing of resources between all users in a communication system [13]. The most commonly used fairness metric is Jain's index, where the level of fairness received by each stream is the flow rate attained by each flow when the simulation ends [13]. It can be expressed as follows [13]:

$$Fairness_{index} = \frac{(\sum b_i)^2}{a \times \sum b_i^2}$$

where $b_i$is the user throughput and a denotes the active flows.

In this simulation, the resource share percentage is calculated as a percentage of the total UL resources for each UE to illustrate the fairness of scheduling [22].

$$Resource\ share\ percentage = \frac{Resource\ allocated\ for\ one\ UE}{Total\ UL\ resources} \quad (8)$$

All simulations were carried out using the 5G toolbox in Matlab.

3.1. Scheme 1

For scheme 1, the distance is varied for the 4 UEs and other parameters are kept constant. However, since the distance of a UE from the gNB is directly related to the CQI, as shown in Table 1, the CQI also changes for each UE. Table 1 has been derived from NR PUSCH FDD Scheduling function in 5G toolbox of Matlab.

Table 1: Distance vs CQI mapping

Distance	Maximum Achievable CQI value
≤200m	15
≤500	12
≤800	10
≤1000	8
≤1200	7

For each Resource block assigned, the value of CQI for a particular UE is generated randomly, limited by the maximum achievable CQI value.

The parameters used for scheme 1 is shown in Table 2.

Table 2: Parameters for scheme 1

Parameters	
Number of frames	200
Number of UEs	4
Number of Logical channels	3
UE distance from gNB	UE1: 100m UE1: 300m UE1: 600m UE1: 900m
Packet periodicity	40ms
Packet size	20000 bytes
Maximum buffer length	10240
Priority for logical channels	1
Prioritized bitrate for each logical channel	Logical channel 1: 8kb/s for all UEs Logical channel 2: 16kb/s for all UEs Logical channel 1: 32kb/s for all UEs
Bucket size duration for each logical channel	Logical channel 1: 5ms for all UEs Logical channel 2: 10ms for all UEs Logical channel 1: 20ms for all UEs
Scheduler strategy	PF, RR and Best-CQI
Bandwidth	5MHz
Subcarrier spacing	15 kHz

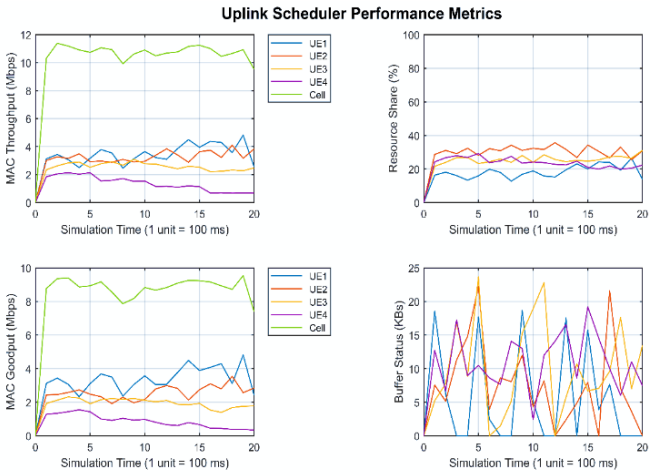

Figure 4: Uplink scheduler Performance for PF strategy – Scheme 1

In scheme 1, UE1 was assigned the nearest distance from the gNB and hence display better CQI. Figures 4,5 and 6 show the performance of PF, RR and Best-CQI algorithms respectively in terms of throughput, goodput, Resource fairness and Buffer status, for scheme 1. It is observed that the PF and RR algorithms display almost the same performance in terms of throughput and goodput while the Best CQI algorithm noticeably differentiates the performance for each UE based on the CQI value with UE1 depicting the best performance followed by UE2, UE3 and then UE4. This is due to UE1 being closest to the gNB and hence having the best CQI values compared to the other 3

UEs. Considering the resource share percentage, it is noticed that the PF and RR strategies display almost the same resource share behaviour while the Best CQI strategy display remarkably higher percentage of resource for UE1 compared to the other UEs. Moreover, the buffer status is also low for UE1 with Best CQI algorithm.

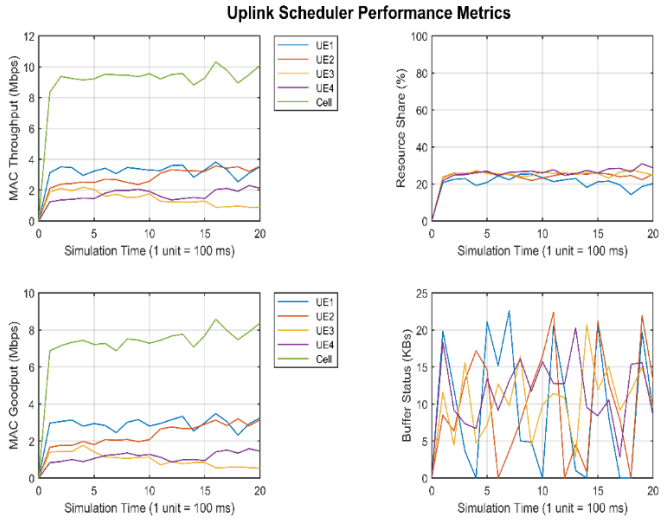

Figure 5: Uplink scheduler performance for RR strategy– Scheme 1

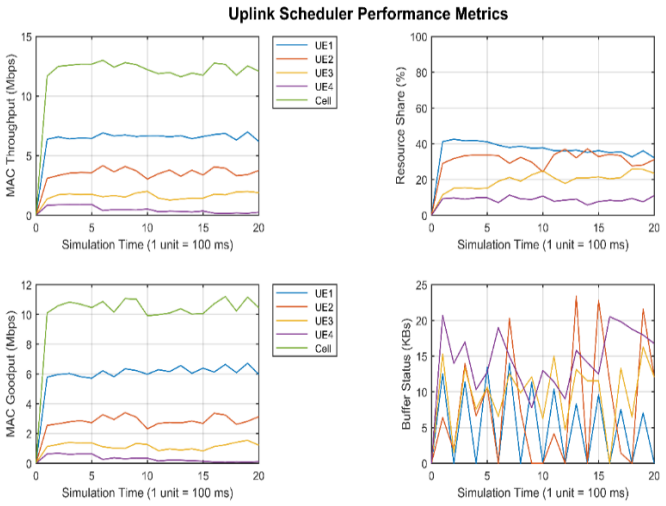

Figure 6: Uplink scheduler performance for Best CQI strategy - Scheme 1

3.2. Scheme 2

For scheme 2, the size of packets generated by the UE in each logical channel is varied and other parameters are kept constant. The parameters used for simulations are shown in Table 3.

Table 3: Parameters for Scheme 2

Parameters	
Number of frames	200
Number of UEs	4
Number of Logical channels	3
UE distance from gNB	300m for all UEs
Packet periodicity	40ms
Packet size	UE1: 20000 bytes UE2: 10000 bytes UE3: 5000 bytes UE4: 2000 bytes
Maximum buffer length	10240
Priority for logical channels	1
Prioritized bitrate for each logical channel	Logical channel 1: 8kb/s for all UEs Logical channel 2: 16kb/s for all UEs Logical channel 1: 32kb/s for all UEs
Bucket size duration for each logical channel	Logical channel 1: 5ms for all UEs Logical channel 2: 10ms for all UEs Logical channel 1: 20ms for all UEs
Scheduler strategy	PF, RR and Best-CQI
Bandwidth	5MHz
Subcarrier spacing	15 kHz

Figures 7,8 and 9 show the performance of PF, RR and Best-CQI algorithms respectively in terms of throughput, goodput, Resource fairness and Buffer status, for scheme 2. As UE1 has larger packets, it is expected that it will have higher buffer status. It is observed that the PF algorithm display the highest buffer status for UE1 with packet size 20000 bytes and lowest buffer status for UE4 with packet size 2000 bytes. However, the resource share is almost the same for all 4 UEs while UE4 has a slightly lower performance than the other UEs. RR algorithm, on the other hand display higher buffer status for UE2 and UE3 and similar buffer status for UE1 and UE4. The resource share is identical for 3 UEs except UE4 and the performance of UE1 is slightly better than the other UEs. The Best CQI algorithms shows more resources allocated to UE1 which also displays a much better performance in the first 1000ms as compared to the other UEs. Less resource is allocated to UE4 who also depicts poorer performance than all UEs. The buffer status is higher for UE2 compared to the other three UEs which display almost similar buffer status.

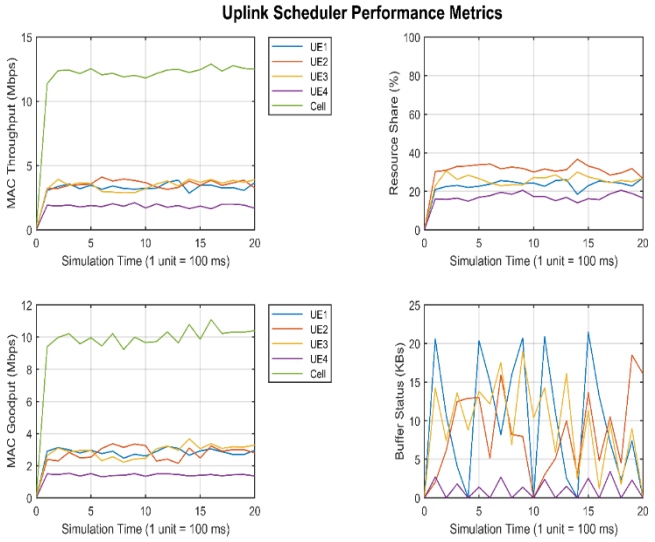

Figure 7: Uplink scheduler performance for PF strategy - Scheme 2

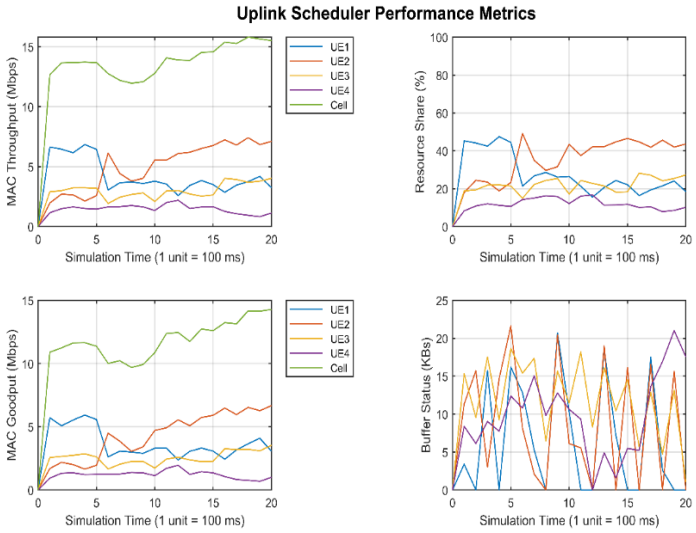

Figure 8: Uplink scheduler performance for RR strategy - Scheme 2

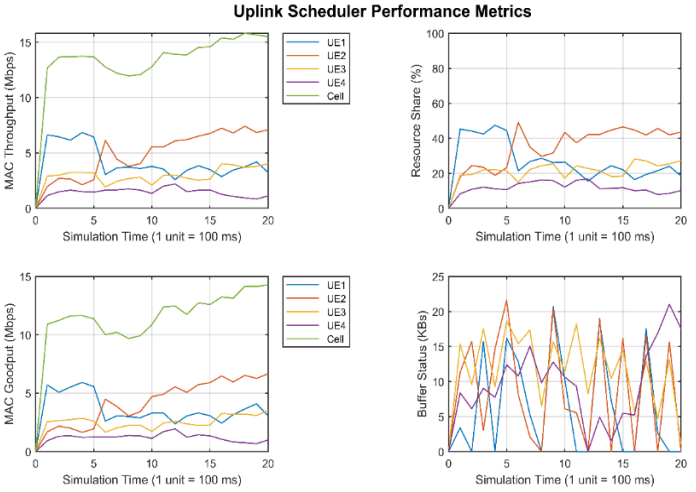

Figure 9: Uplink scheduler performance for Best CQI strategy - Scheme 2

3.3. *Scheme 3*

For scheme 3, the prioritized bit rate (PBR) and the bucket size duration (BSD) of each logical channel is varied and other parameters are kept constant. The BSD is defined as the duration during which a logical channel buffers the upper layer data according to the PBR of the logical channel. The total bucket size (buffer capacity) is defined as PBR*BSD. The bucket size is utilized to avoid starvation due to prioritized logical channel.

The parameters used for scheme 3 is shown in Table 4.

Table 4: Parameters for Scheme 3

Parameters	
Number of frames	200
Number of UEs	4
Number of Logical channels	3
UE distance from gNB	300m for all Ues
Packet periodicity	40ms
Packet size	20000 bytes
Maximum buffer length	10240
Priority for logical channels	1
Prioritized bitrate for each logical channel	UE1: 8kb/s for all logical channels UE2: 16kb/s for all logical channels UE1: 32kb/s for all logical channels UE1: 128kb/s for all logical channels
Bucket size duration for each logical channel	UE1: 5ms for all logical channels UE2: 10ms for all logical channels UE3: 20ms for all logical channels UE4: 20ms for all logical channels
Scheduler strategy	PF, RR and Best-CQI
Bandwidth	5MHz
Subcarrier spacing	15 kHz

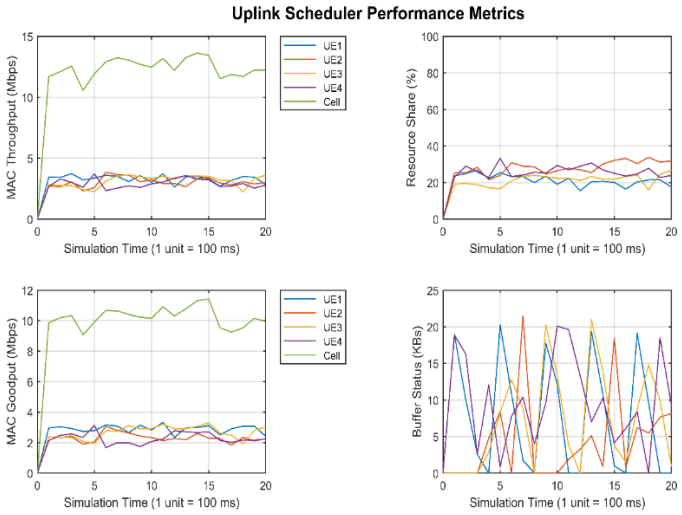

Figure 10: Uplink scheduler performance for PF strategy - Scheme 3

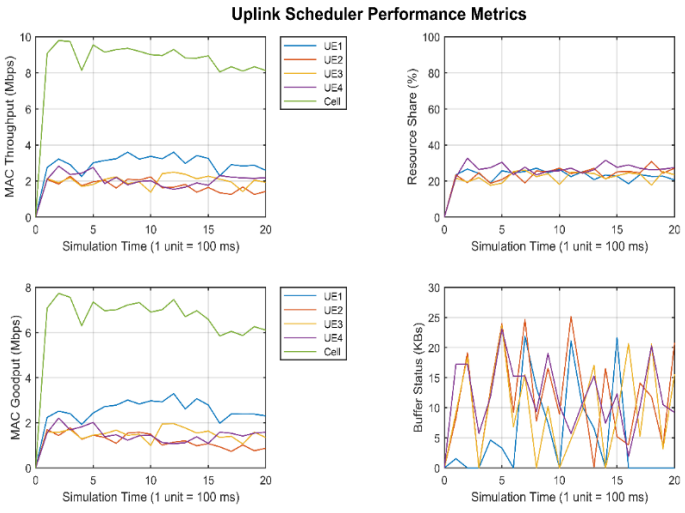

Figure 11: Uplink scheduler performance for RR strategy - Scheme 3

Figures 10, 11 and 12 show the performance of PF, RR and Best-CQI algorithms respectively in terms of throughput, goodput, Resource fairness and Buffer status, for scheme 3. As per the parameters configured, UE4 will have larger bucket size (128*0.02=2.56kb) compared to UE 1 (8*0.005=0.04 kb). The PF algorithm demonstrates almost similar performance for all UEs including similar resource

share percentage, with a slight advantage to UE4. The buffer status is also similar for all UEs. The RR strategy displays better performance for UE1 compared to other UEs, with lowest buffer status for UE1. The resource share for UE4 is slightly higher than for the other UEs. The Best CQI strategy displays noticeably better performance and resource share for UE1 followed by UE2. The buffer status is high for UE3 and UE4.

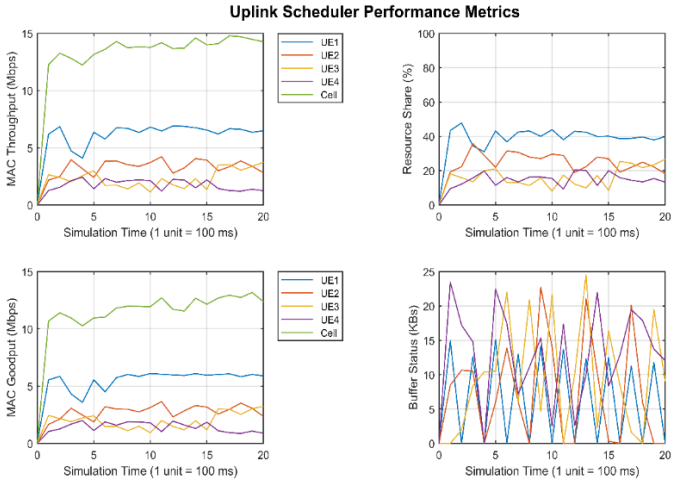

Figure 12: Uplink scheduler performance for Best CQI strategy - Scheme 3

3.4. Scheme 4

For scheme 4, the priority of each logical channel is varied and other parameters are kept constant. The data from the logical channel with the highest priority is scheduled first followed by the data from the logical channel of the next highest priority. An increasing priority value indicates a lower priority level.

The parameters used for scheme 4 is shown in Table 5.

Table 5: Parameters for Scheme 4

Parameters	
Number of frames	200
Number of UEs	4
Number of Logical channels	3
UE distance from gNB	300m for all UEs
Packet periodicity	40ms
Packet size	20000 bytes
Maximum buffer length	10240
Priority for logical channels	UE1: 1 for all 3 logical channels UE2: 10 for all 3 logical channels UE3: 10 for all 3 logical channels UE4: 10 for all 3 logical channels
Prioritized bitrate for each logical channel	Logical channel 1: 8kb/s for all UEs Logical channel 2: 16kb/s for all UEs Logical channel 1: 32kb/s for all UEs
Bucket size duration for each logical channel	Logical channel 1: 5ms for all UEs Logical channel 2: 10ms for all UEs Logical channel 1: 20ms for all UEs
Scheduler strategy	PF, RR and Best-CQI
Bandwidth	5MHz
Subcarrier spacing	15 kHz

Figures 13, 14 and 15 show the performance of PF, RR and Best-CQI algorithms respectively in terms of throughput, goodput, Resource fairness and Buffer status, for scheme 4. For the PF and RR algorithms, it is observed that although UE1 has highest priority, the performance for all 4UEs are almost the same with only a slightly better performance for UE1 while the resource share for UE1 is lower than for the other UEs. The buffer status is fairly similar for all UEs. For the Best CQI strategy, UE1 displays a noticeably better performance and resource share percentage compared to the other two algorithms. The buffer status for UE1 is also much lower than for the other UEs.

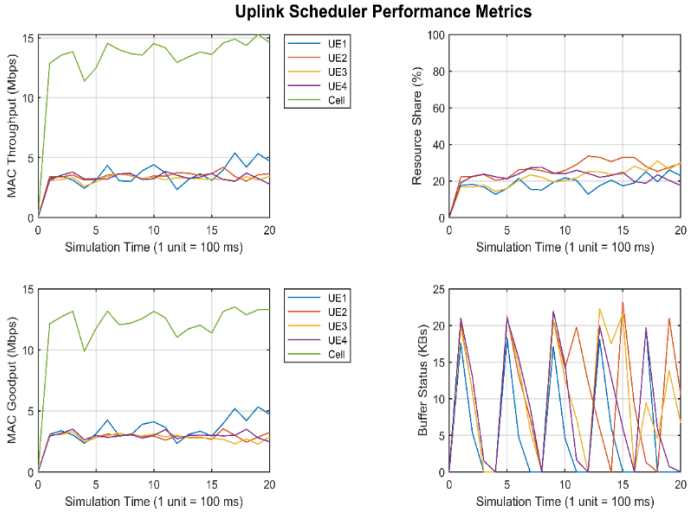

Figure 13: Uplink scheduler performance for PF strategy - Scheme 4

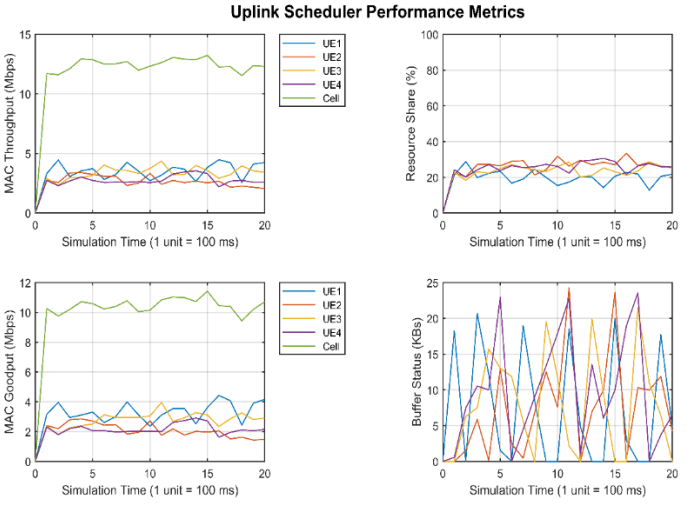

Figure 14: Uplink scheduler performance for RR strategy - Scheme 4

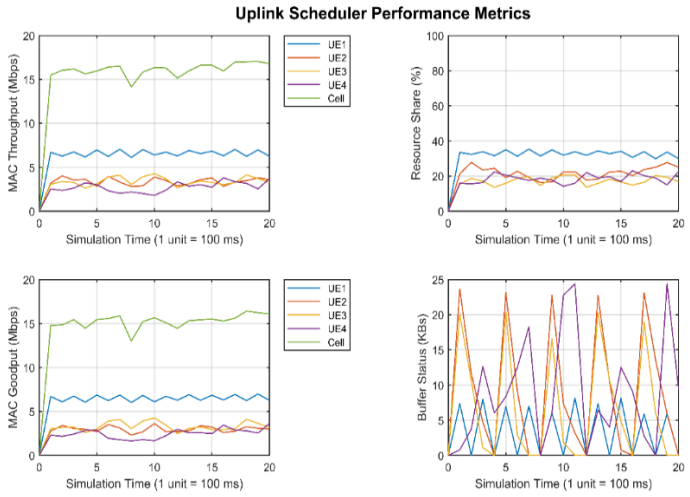

Figure 15: Uplink scheduler performance for Best CQI strategy - Scheme 4

From the simulations carried out, it has been observed that the Best CQI algorithm yielded the best performance for a particular user. This is due to the fact that this algorithm prefers the user with the most favourable conditions. Thus, data transmission with good channel conditions and good quality will lead to less retransmissions and higher throughput and goodput, which is noticed in all simulation cases.

It is observed that the RR algorithm, on the other hand, allocates a data channel for transmission, irrespective of the amount of data to be transmitted. Thus, in all simulation cases, it is observed that the throughput and goodput follow almost the same trend irrespective of the size of data packets.

The PF algorithm is observed to take into consideration the size of packets to be transmitted and the priority of each user in all simulation cases. It aims to maximize the throughput of each user and thus provides a better trade-off between fairness and performance.

For further analysis, the work carried out in this paper has been compared with a similar work carried out in [13].

In [13], a downlink wireless network with one gNB, 10 UEs and a maximum bandwidth of 100 MHz was considered. The throughput, goodput, buffer status and fairness of several scheduling algorithms were compared including the three scheduling algorithms investigated in this paper. However, the authors did not display the throughput for each user as achieved in this paper as the only the minimum and maximum values were displayed. Moreover, in our case, several parameters were varied in order to illustrate the effect of each parameter on the throughput, goodput, buffer status and resource share percentage for each scheduling algorithm.

The key parameters for both papers are illustrated in Table 6.

Table 6: Parameters for both papers

	Paper [12]	This paper
Bandwidth	100 MHz	5 MHz
Subcarrier spacing	30 kHz	15 kHz
Number of Frames	100	200
Number of UEs	10	4

The plots below show a comparison of results obtained in [13] with results obtained in this paper to illustrate whether the algorithms behave similarly in downlink and uplink, for throughput and goodput performance. In order to achieve a fair comparison, the minimum and maximum values of the users are considered for the scheme where distance was varied. There is a noticeable difference in throughput values achieved for both papers due to the different values of simulation parameters used.

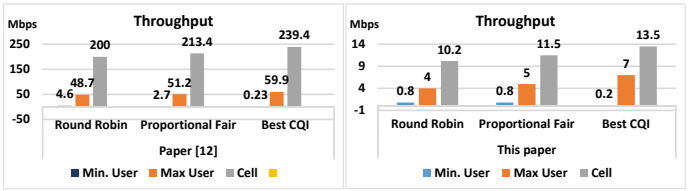

Figure 16: Throughput performance for both papers

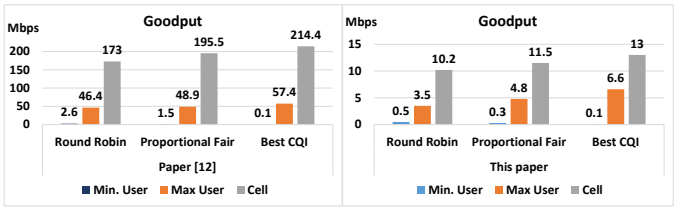

Figure 17: Goodput performance for both papers

It can be seen from the results plotted that the three scheduling algorithms follow the same trend for both downlink and uplink scheduling performance.

In [29], the authors have simulated a LTE-A system using four scheduling algorithms, including the three algorithms mentioned in this paper, in LTE downlink. The results obtained in [28] for the three scheduling algorithms follow a similar trend as observed in this paper.

It is to be noted that most of the previous works so far have been done on LTE-Advanced. The three algorithms mentioned in this paper have previously been used for LTE and are currently being used for 5G as well. This work has reconfirmed the trend observed in LTE as a similar trend has been observed with 5G. For a broader analysis, more parameters have been varied in this work as compared to other papers, hence it provides insightful results to the scientific community.

4. Conclusion

This paper considered simulations using 5G systems with three scheduling strategies namely Proportional Fair, Round Robin and Best CQI. Four sets of parameters were varied. When distance was varied, the Best CQI

algorithm displayed distinctive gaps in the throughput and resource share percentage for the four UEs compared with RR algorithm which displayed almost the same fairness percentage for all four UEs. The PF algorithm, gave a slightly better throughput than RR. When size of packets was varied, the PF algorithm provided a trade-off between fairness and throughput while RR algorithm displayed similar fairness for all four UEs. Moreover, the Best CQI algorithm showed better resource share percentage and throughput for the UE with highest packet. When the total bucket size was varied, the PF algorithm displayed slight gaps in the resource share percentage and almost the same throughput value for the four UEs. RR depicted a slight advantage in throughput for UE1 with the least total bucket size. When priority was varied, Best CQI algorithm showed a considerable advantage for the UE with the best priority, both in terms of fairness and throughput. A general observation made was that the PF algorithm provided a trade-off between throughput and fairness while the Best CQI algorithm offered the highest throughput than the other two algorithms while displaying a considerable preference for UEs with more favourable conditions and parameters. For future works, the authors are planning to implement machine learning algorithms together with existing scheduling algorithms mentioned in [30].

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgment

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Impact Analysis of Duck Curve Phenomena with Renewable Energies and Storage Technologies

Giovani Manuel Pitra , Kameswara Subrahmanya Sastry Musti *

Namibia University of Science and Technology, Department of Electrical & Computer Engineering, Windhoek West, Windhoek, 13388, Namibia

*Corresponding author: Kameswara Subrahmanya Sastry Musti, Namibia University of Science and Technology, +264-83-207-2768, mks.sastry@gmail.com

Corresponding author ORCID: 0000-0003-4384-7933

ABSTRACT: When higher quantities of solar energy is injected into power grid, then it is likely to result in what is known as "Duck curve phenomena". The net load under this phenomenon is negative and thus energy generation needs to be curtailed during the peak hours and also a part of the load during off-peak hours cannot be met. Due to several economical and technical challenges, the environmentally friendly solar energy source will be switched-off during the peak hours. Analyzing the impact of duck curve on a system can be challenging. This paper presents a novel methodology to analyze the duck curve phenomena and to mitigate its effects. The proposed methodology requires two popular, open source software tools - IRENA FlexTool and System Advisory Model (SAM). SAM is used to obtain the data for solar energy production and FlexTool is used carryout the optimal energy dispatch. A 4-bus power system is considered with base load plants, renewable energy sources and energy storage facilities. Then the proposed methodology is applied on this system to analyze the impact of duck curve to demonstrate the effectiveness of both the methodology and the open-source tools.

KEYWORDS: Solar Energy, Renewable energy technologies; Energy Storage Technologies, System Advisory Model; IRENA FlexTool; Unit commitment

1. Introduction

The phenomenal rise of renewable energy technologies (RETs) has resulted in large volumes of capacity addition in solar and wind segments, specifically due to their environmental friendliness and lower production costs [1, 2]. In addition, there are several other classes of energies such as Pumped Hydro Storage (PHS) systems, Concentrating Solar Power (CSP) plants at the grid level and also other resources such as biomass and roof-top solar systems [3, 4, 5, 6]. Though such RETs reduce stress on generating plants, these energy sources are intermittent in nature and thus create challenges with traditional load dispatch methodologies [2, 5]. Usually, optimal dispatch is done among fossil fuel based energies and hydro power stations [7, 8]. However, this has changed as it is now common to use solar energy to meet the peak demand.

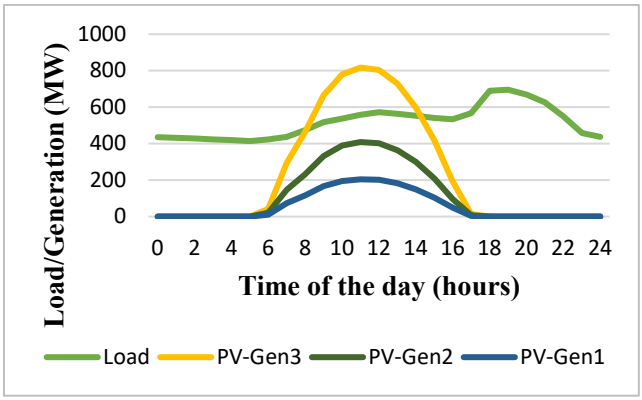

Figure 1: Load Curve with different levels of PV penetration

Higher capacities of solar power plants result in excess energy generated and this in turn results in negative load conditions since supply can be far greater than the load. This results in the formation of duck curve pattern or phenomena. This phenomenon is normally illustrated with plots of load, generation and net load over a day and

a pattern resembling a duck can be seen. Figures 1 and 2 show how the increasing solar PV generation in the grid results in the formation of the duck curve.

In figure 1, one can clearly see an ideal generation profile of a typical solar power plant and where it fits within a typical load curve [3. 6].

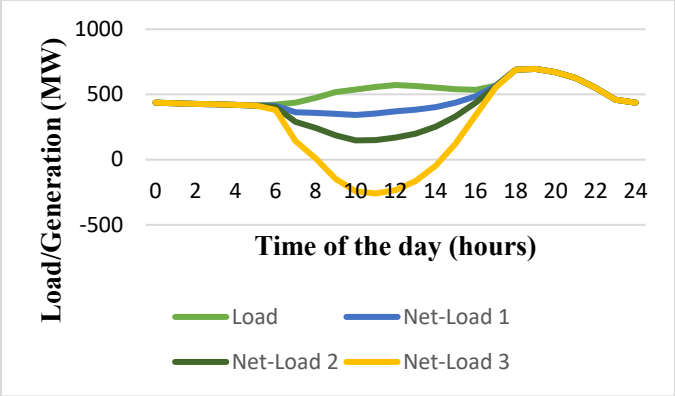

Figure 2: Duck Curve with different levels of PV penetration

At the same time, it can be observed that the solar PV generation profile is advantageous to the grid as it starts ramping up at a time adjacent to that of the first increase in demand of the day. This is beneficial to the grid as it reduces the ramping requirements and the overall power supplied by the conventional power plants at that time [8]. Figure 2 illustrates this decrease in dependency from conventional power plants to supply power during the first increase in demand of the day, as the solar PV generation increases [1, 8, 9]. Figure 2 also shows the drawbacks that come with increasing solar PV generation in the grid, in that its sun-dependent power starts ramping down at a time when demand is increasing, adding a lot of stress to the conventional power plants in the grid [1, 7]. In other words, as the PV generation increases, the ramping demand on conventional power plants increases, requiring the conventional power plants to supply more power in a shorter period of time [1, 6]. In summary, it is the plot of net load, that is referred to as the duck curve as shown in figure 2. It is clear that the excess energy region of the duck curve needs to be reduced or flattened [3, 6, 8].

As shown in the figures 1 and 2, higher capacities of solar energy decrease the net load during peak hours. This in turn requires reduction (or curtailment) of energy injection into the grid. Since conventional base load plants are designed to operate continuously, it is not possible to shut those generating units [9]. However, this excess energy can be stored for later use in PHP and/or battery storage systems [10].

Energy adequacy is essential in the operation of any power system as almost 15% to 20% energy is lost in terms of transmission and distribution losses put together. And modern smart cities on the load side and RETs on the generation do contribute to power quality issues [2, 4]. Also interconnections between RETs, main grid and consumers also increase the system complexity [4, 11] due to varying network topology and switching. This leads to several challenges with metering [11, 12], power system protection [13, 14] and even power quality [14, 15]. If such challenges are not effectively addressed, then users experience outages and this results in loss of revenue to utility [11, 12].

It is interesting to note that duck curve is the result of excess energy, but it is only temporary during peak hours. This requires a smart and flexible power system so that necessary adjustments can be done dynamically. It can be seen that duck curve phenomenon requires utility engineers to manage the energy resources differently to avoid large curtailments. Capacity planning studies may not be able to accommodate more solar energy addition beyond a point as this will pose financial risks to the IPP as the grid is not in a position to absorb their energy. To determine these aspects, a series of simulations have to be carried out to determine the possible solutions. However, there is no specific approach or methodology suggested by anyone thus far and this paper takes this up as its main objective.

2. Literature Review

Integration of high levels of solar PV power to the electric grid comes with problems other than those related to the duck curve [1, 3, 6]. Power quality for instance, is greatly affected because of the current harmonics caused by the inverters in the system, which convert the DC power from the solar panels to AC power that is supplied to the grid [2, 16]. It is illustrated design requirements of solar systems to mitigate these harmonics, with appropriate filters [16]. However, such infrastructure can incur additional costs and may not entirely address the duck curve problem [17]. Transportation of this excess energy to the region where it is more demanded, is again another challenge due to the losses involved. One of most common misunderstandings is that solar energy is cheaper and large quantities can be added to regular power grids. Duck curve phenomena is reported first time, with a lot of details by a California Independent System operator (CAISO) [2]. Then a good number of authors have presented simulations and mitigating techniques over the years [1, 6, 8, 18]. In reality, high levels of energy penetration into an existing system can lead to excessive system losses and thus thermal limits of the transmission lines can be violated and also leads to complaints from consumers [11, 12].

Due to decreasing trends of over costs, utilities have injected large amounts of solar energy into the grid over the last decade. Naturally duck curve phenomena has been observed in several places though it is first reported by the system operator from California [2]. In the case of

California, the operator was forced to curtail large volumes of solar energy as generation exceeded the load. Following this, different mitigation techniques have been reported as well, primarily addressing the issues of ramping and excess generation. These approaches included changing the tilt angles of solar panels [6, 19] and also using different types of energy storage systems [8, 10, 20, 21]; and Demand Side Management (DSM) methods [9, 22]. DSM methods generally include using alternative sources of energies, such as solar water heaters and biomass briquettes [9, 16, 20]. It should be noted that not all such options may be very well accepted by modern environments and communities from the smart cities [12, 21, 22].

Due to the popularity of renewable energies and DSM methods, policies of various states across the globe have openly encouraged consumers to add solar PV on their roof-tops and liberal incentives are given for circular economy practices [9, 18, 21]. However, the conventional energy audits may not very well capture such variations in energy consumption patterns, and this creates a disconnect between capacity addition and load estimation studies [22, 23]. Quantification of demand response needs to be done dynamically and results should be fed to capacity expansion plans [9, 22]. Some energy policy initiatives such as the Single Buyer Model (SBM) can also influence the duck curve. In [18], the authors analyzed the impact of excess energy conditions when power is traded between grid connected IPPs and SBMs. In addition to IPPs, most industrial and commercial establishments (prosumers) produce their own solar energy in smart city and/or circular economy zones during the same peak hours. These factors result in steeper duck curve and naturally, solar farms need to be disconnected, as they do not have ramping up/ down problems [24, 25].

Economic dispatch and unit commitment become challenging under excess energy conditions as fossil fuel-based energy sources cannot be stopped quickly due to ramp-up/down parameters, spinning reserves, crew constraints, fuel cost constraints etc. [1, 2, 6, 24, 25]. Since solar energy is not affected by such parameters, energy curtailment is forced on solar farms. This leads to financial losses to the IPPs that have invested in solar segment. This warrants the use of specialized computational tools for unit commitment and economic dispatch with additional constraints since dispatch is now required to be computed almost hourly basis. To accomplish this, researchers and engineers have used different software solutions such as AMPL and CPLEX [7], SAM, PLEXOS [5, 18], BEopt [15, 17] and MATLAB [3, 5, 22, 24].

Now it is clear that there are different software solutions to deal with energy dispatch with solar energy injections. However, input data requirements of these tools vary widely. The most common data input being the load and generation profiles, local weather conditions with forecasts. However, load data estimation can be challenging. Firstly, load is continuously changing over the day and is so over the months in a year. Load also changes over the years due to natural growth of the dwellings. Though several studies and field projects point to the need for using the information systems [26], typical system simulations need to be carefully adjusted based on assumptions and projections about the load.

Although a good number of works have analyzed the duck curve phenomena, reduction of energy curtailment and cost effectiveness are not very well treated, specifically with CSP and a PHS plant [7, 8, 10, 18, 24, 27]. Though these storage technologies have their own pros and cons, scientific investigations need to be carried out in a systematic manner. Basically, such investigations need to determine how flexible is the overall system, how well the load is met without having to curtail the load or generation [15, 28]. In reality, the generation resources are in different locations geographically, but connected to the grid [29]. Thus far research on the duck curve did not take the distance parameter into consideration. However, such consideration requires GIS based tools [29].

Another challenge is the availability of simple and cost-effective software tools. Analysis of duck curve requires appropriate software tools that can support varying scenarios of energy productions and load profiles. A few works have used commercial software tools to simulate duck curve phenomenon [3, 18]. This paper addresses these gaps by undertaking a series of simulations with CSP and PHS facilities added to the grid under higher levels of solar penetration, with open-source software tools SAM and IRENA FlexTool.

To accomplish this, the reminder of this paper is divided into five sections. Proposed methodology is provided in section 3. Four different case studies and results are provided in sections 4, 5, 6 and 7. Section 8 presents the discussions and finally section 9 provides the conclusion.

3. Proposed Methodology

3.1. Simulation Process

Given that an electric utility intended to integrate high levels of PV power in a grid dominated by conventional power plants, a study would have to be conducted in the following manner:

1) Identification of the sites available – exposed to the highest global horizontal irradiance (GHI), and closest to the regions with the greatest demand of electrical power, to minimize transmission losses.

2) Design and modelling of the prospective PV plants in the respective sites identified, with the relevant

weather data, using a software of choice. This needs to be done to extract the possible electrical power generation data necessary to model the electric grid including the PV plants to be integrated.

3) Gathering of information regarding the conventional power plants connected to the grid – their generation capacity, ramping capacity, minimum-up time, and minimum-down time, as well as all associated costs of interest. This information is particularly important during the modelling process as it will show how the grid will react after the integration of PV power plants in the system, that is, how much PV power it would be able to accommodate and how much would have to be curtailed.

4) After obtaining the data from steps 2 and 3, one can proceed to the modelling stage, where the data obtained in the stages mentioned above is used to create a model or representation of the electric grid including the PV plants, using a software of choice. With this model, one would be able to predict how the electric grid would react with the addition of PV plants and decide whether duck curve solutions would need to be implemented or not. Given that the integration of the PV plants would result in duck curve problems, another study would have to be conducted to find out the duck curve solutions that would be feasible within that area. As it is known, solutions such as the addition of battery storage technology may be implemented anywhere, but PHS is limited by geographical features [10, 8]. The execution of this process may be possible but not limited to the utilization of tools such as System Advisor Model and IRENA FlexTool. Subsections 3.2 and 3.3 explain how these individual software tools were utilized, the inputs and outputs, and why these tools were needed to meet the objectives of this work. Steps 5 to 8 describe the process of obtaining the most suitable solution to minimize or irradicate all duck problems.

5) Development of a list of feasible duck curve solutions based on the geographical characteristics of the power system.

6) Modelling of the feasible solutions, whether energy storage technology based, or DSM based, considering all the necessary investment cost, as well as the social and environmental aspects.

7) Simulation of the power system including the PV plants and duck curve solution, to observed how the solution considered affects the curtailed energy and unserved load due to ramping requirements.

8) Repeat step 7 for all feasible solutions, then choose the one that best suits the utility goals.

3.2. IRENA FlexTool

IRENA FlexTool is a spreadsheet based solution developed by the International Renewable Energy Agency (IRENA) to aid energy planners, utility engineers, and policy makers simulate various scenarios of future power systems, when planning to implement new power plants and/or transmission lines or increase the capacity of the same. Unlike other tools used by the same entities to perform the same simulations, FlexTool is open-source and its results have been benchmarked with highly recognized tools such as PLEXOS [2, 6, 20].

In this work, IRENA FlexTool was used to simulate the unit commitment of all the plants in the system considered, to obtain the resultant operational costs, CO_2 emissions, unserved demand due to ramping requirements, and curtailed energy. Data such as minimum load capacity, minimum-up time, minimum-down time, ramp-up and ramp-down capacity per unit per minute, forecasted load and RET generation data, are provided as inputs to the tool.

3.3. System Advisor Model

System Advisor Model (SAM) is software developed by the National Renewable Energy Laboratory (NREL). SAM is used to design or model renewable energy based electric systems such as solar PV, Concentrating Solar Power, Wind, Geothermal, and Biomass plants just to mention a few. The software supports various performance and financial models. It takes as input various design parameters which are system specific as well as the relevant weather data which is typical for RETs. In this work, SAM was used to model the solar PV power plants.

Modelling the solar PV power plants in SAM was necessary to obtain the generation profile data of that plant. This data was purposefully obtained to simulate the effect of integrating high levels of PV power in the system. Similarly, SAM could have also been used to model the concentrating solar power plant so as to obtain the generation profile data of that plant, but that was not necessary a that data was already available.

To demonstrate how the proposed methodology may be applied, this work considers four case scenarios, where the first one involves analyzing the behavior of the power system considered before the integration of RETs, the second one involves studying how the addition of PV power results in duck curve problems, and the third and fourth case studies analyze the effectiveness of using PHS and CSP plants respectively, as a solution to the duck curve problems in case 2.

4. Case Scenario 1

A description of the power system considered for analysis is given in this section. This includes the specifications of each plant in the system, that is, the minimum load capacity, minimum-up time, minimum-down time, ramp-up and ramp-down capacity per unit

per minute of each plant, the interconnections of the system on a regional basis, and the capacity of the transmission lines. Simulations were performed to obtain the parameters of interest before implementing RETs.

This case was used to evaluate the performance of the power system before the possible integration of RETs. Figure 3 illustrates the power system considered. This figure also shows the nodes that refer to the different regions in any specific country. For clarity, the notation in this paper is same as that is normally used in IRENA FlexTool. Thus it will provide seamless learning for the prospective users of our approach and the IRENA FlexTool [22]. Each transmission line has maximum capacity of 350 MW, which limits the flow of power between the different regions to that value. Although only the maximum load in each node shown in figure 3, the daily load data for each node is available for a period of one year in intervals of one hour and was supplied to IRENA FlexTool for simulation purpose [9, 22]. Figure 3 also shows the capacity of each power plant connected to the power system.

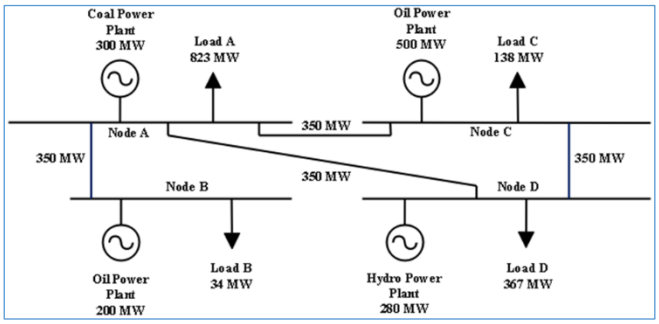

Figure 3: Power system before RET integration

Table 1 contains the specifications of each power plant shown in figure 3. Quantities such as efficiency and minimum load are given in per unit. The ramping demand is given in per unit per minute, the minimum up/down time is given in hours, and the storage capacity in MWh. These parameters are used by FlexTool to compute the optimum commitment of all the units in the system.

Table 1: Power Plant Parameters

Unit	Efficiency	Minimum Load	Ramping	O&M Costs /MWh	Start-up Cost	Minimum Up/Down Time	Storage
ST-Coal	0.28	0.4	0.02	4.0	2.0	12	0
CC-Oil	0.40	0.5	0.05	2.5	1.0	5	0
Hydro-ROR	1.0	0.0	0.20	0.0	0.0	0	0
Hydro-RES	1.0	0.0	0.20	0.0	0.0	0	26880
PV	1.0	0.0	1.00	0.0	0.0	0	0

In this system, the coal-fired plant operates as the base load power plant, while the oil-fired and hydro run-of-river (ROR) plants operate as intermediate, and the hydro reservoir (RES) operates as a peaker plant.

Additionally, the fuel costs for the coal and oil are given as 10 USD/MWh and 45 USD/MWh respectively. FlexTool utilizes these costs to calculate the total cost for running these plants, in addition to the maintenance and startup costs. The simulations performed in FlexTool resulted in the following annual per cent utilization: 92.31% ST-Coal, 70.71% CC-Oil, 62.05% Hydro-ROR, and 73.14% Hydro-RES.

This led to a total cost of USD 1996.98 million per year (including operational and penalty costs), and a total carbon dioxide (CO_2) emission of 4.632 million tons. The annualized unserved demand was 136.494 GWh where only 52.577 MWh were caused by the upward ramp limitations. The total cost added up to USD 1996.98 million. Figure 4 shows how each plant was committed to supply the demanded power in a day.

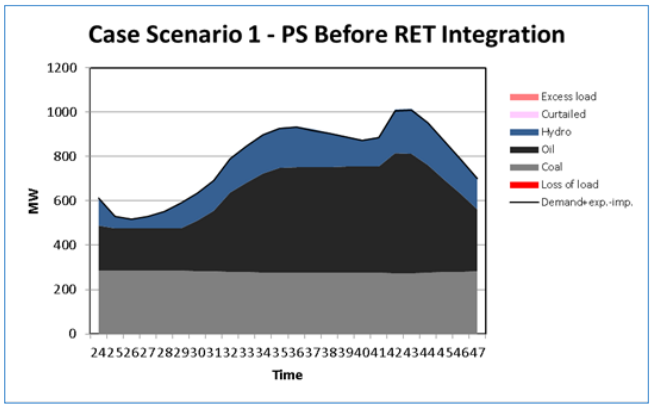

Figure 4: Daily generation profile before RET integration

5. Case Scenario 2

Figure 5 illustrates how the system changes after the integration of solar PV plants. The figure shows that these PV plants are connected to nodes A, C, and D, and have capacities of 550 MW, 400 MW, and 500 MW respectively. It is assumed that these plants are added to the system to reduce the amount of unserved demand and the CO_2 emissions.

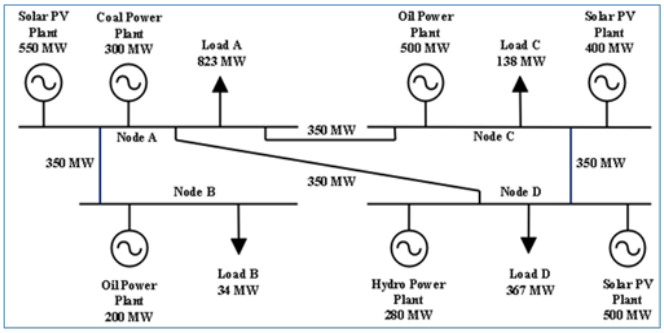

Figure 5: Power system after PV integration

Simulations were conducted to find out how the addition of these plants influence the operation of the other plants in the system. The output power of a solar PV

plant is location dependent, thus, SAM was used to model this system. In SAM, the performance model Photovoltaic-PVWatts with no financial consideration was chosen, then the following steps were taken to design the system:

a) The weather file of a random location in the southern hemisphere was chosen and input in the location and resource page.

b) The system nameplate capacity, type of module, dc-to-ac ratio, rated inverter size, and inverter efficiency were input in the system parameter section under the system design page.

c) Still in the system design page, an azimuth of zero was chosen so that the panels face true north, and a tilt angle of 35 degrees was selected for maximum energy production. Also, a typical ground coverage value of 0.4 was inserted. Next, the systems losses, which added up to 14%, were allocated.

Lastly, the simulation was run, and the system generated power output was copied to an excel file then input to IRENA FlexTool. The results obtained from FlexTool showed a decrease in CO2 emissions from 4.632 million tons to 3.622 million tons after the integration of solar energy into the system. This is due to the fact that fossil fuel-based power plant usage has reduced significantly in this case. With ST-Coal reducing by 10.47% and CC-Oil reducing by 30.59%. In figures 6, it can be seen how the addition of solar PV plants in the grid changed the system generation profile in a daily basis.

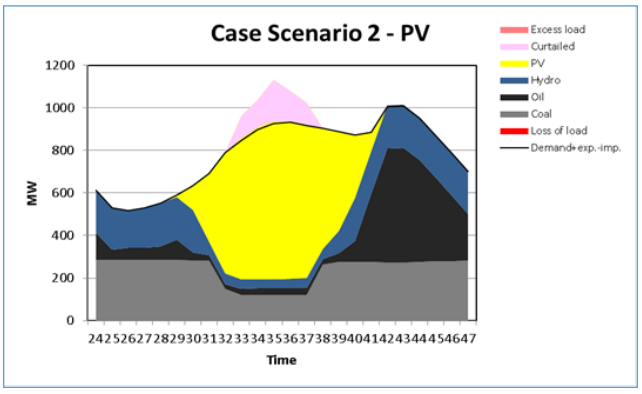

Figure 6: Daily generation profile after PV integration

No significant change was observed from the Hydro-ROR and Hydro-RES plants results in terms of percent utilization. The total cost reduced to USD 1005.55 million, that is due to the reduction in penalty and operational costs. as the share of unserved energy decreased from 136.494 GWh to 65.210 GWh and the operation of Solar PV plants is less costly compared to the fossil fuel counterparts.

From the simulation results in FlexTool it was observed that the integration of the solar PV plants led to a annualized energy curtailment of 326.444 GWh, about 12.522 GWh were curtailed to decrease downward ramp so that rest of the system manages to ramp up, and 6.119 GWh were unserved because of the upward ramp limitations. These features show the effects of the duck curve when higher quantities of solar power are added to the grid.

6. Case Scenario 3

The application of PHS technology as a solution to the duck curve is explained in this section. Background is given on the significance of the technology today as compared to when it was first implemented, then the modelling process and simulation results pertaining this work are explained. PHS plants are not a new technology, they have been used since 1907 and their application today is not so different to their application back then. They are now gaining more attention as the world aims to reduce greenhouse gas emissions because they can store large quantities of power which is needed to compensate for the intermittent nature of RETs.

Unlike shifting the load through DSM which requires that the consumer actively participate in the transition from fossil-fuel based to RET, PHS allows this transition to happen without the consumer even noticing. It is well known that before the need for transitioning to RETs, PHS technologies would mostly be charged (or store water at the upper reservoir) using low-cost excess energy available during low demand periods and that this excess energy would be supplied from fossil-fuel-based power plants, but with the addition of solar PV plants in the grid the excess energy come from the PV plant, allowing the charging process of the PHS plant to be environmentally friendly. This paper aims to analyze the performance of the PHS plant as a solution to the duck curve, when compared to the other solutions considered.

Modelling process for the PHS plant was all done on the IRENA FlexTool so that it can be utilized in simulation process of the duck curve. FlexTool caters for all the parameters of interest for this project, thus its sole utilization for the modelling and simulation was enough. Simply to deal with the amount of energy curtailed, it would be necessary that the capacity of the power plant would be as large as the amount of energy curtailed plus the energy losses in the system.

$$E_{capacity} = 9.81 \cdot \eta \cdot \rho \cdot V \cdot H \quad (1)$$

From equation (1) the basic parameters of interest which are the efficiency of energy conversion (η), density of water (ϱ), volume of reservoir (V), and the difference in height between the upper and lower reservoir (H) are used to calculate the capacity of the power plant ($E_{CAPACITY}$). From this list of parameters FlexTool only takes the efficiency of energy conversion (η). The other parameters are geographically dependent; hence they are not part of the scope of this project.

The results obtained from the simulations showed that the CO2 emissions were somewhat higher than those obtained in the second case study (section 5), as it only increased from 3.622 to 3.676 million tones. Similarly, this increase is because of the raise in the utilization of the coal-fired plant from 81.84% to 87.03%. Compared to the previous case studies (sections 5 and 6), a significant reduction in cost is observed when the PHS was implemented as a solution to the duck curve – up to USD 327.049 million. The annualized energy curtailment reduced to 90.078 GWh, and 3.042 GWh were curtailed to decrease downward ramp so that rest of the system manages to ramp up. PHS also resulted in 0 GWh of unserved demand because of the upward ramp limitations. Figure 7 shows generation profile with PHS in order to mitigate the impact of duck curve.

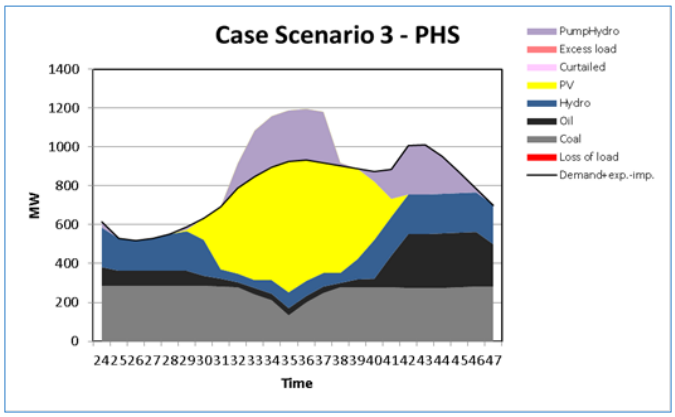

Figure 7: Daily generation profile after simulating PHS as solution to the duck curve

7. Case Scenario 4

In this section the 4th and last case study is discussed. This case study considers the integration of a CSP plant as a solution to the duck curve. Details such as its application, modelling, simulation, and results analysis are provided.

CSP plants are sometimes considered as the more convenient to harness the energy from the sun at large scale because of their ability to generate electricity and store the same in the form of heat. Compared to PHS plants, CSP plants have an advantage as they do not rely on the excess energy from other plants on the grid to store its energy. CSP plants may play different roles on the grid. In Namibia for instance, it has been estimated that CSP plants can mainly work as peakers during the rainy season, and in winter they can also support the base load power plants. Figure 9 shows generation profile with a CPS plant in order to mitigate the impact of duck curve.

Because its energy storage works independently from the other plants in the grid, when dealing with the duck curve CSP plants do not cater for the curtailed energy caused by the minimum base load plant capacity. However, it still plays an important role because of its rapid ramping capacity, which is needed to meet the high ramping requirements left by the solar PV plant when its supply is decreasing. Thus, this rapid ramping capacity takes care of the unserved load due to ramping requirements. In this case, a 260 MW plant with a storage capacity of 2080 MWh was connected to node A as shown in figure 8. It is assumed that that region at Node A has highest Direct Normal Irradiance (DNI), hence the ideal site of installing the plant.

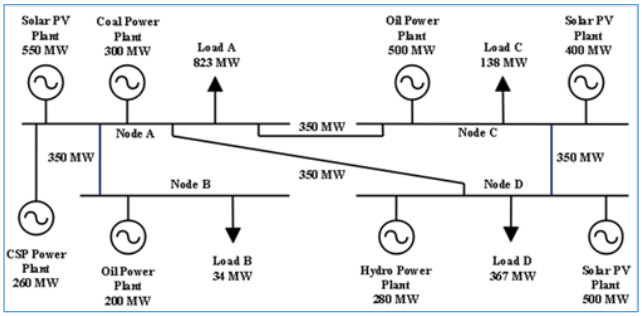

Figure 8: Power system after integration of CSP plant

The simulation results indicate that the integration of the CSP plant resulted in 3.482 million tons of CO2 emissions, thus it is the case scenario with smallest amount of CO2 emissions amongst the other case scenarios. This case scenario also resulted in the lowest total cost, which was equivalent to USD 299.517 million. As expected, the annualized energy curtailed and the amount of energy needed to decrease downward ramp so that rest of the system manages to ramp up, did not change significantly compared to case scenario 2, but just like case scenario 4, this case also resulted in zero GWh of unserved demand because of the upward ramp limitations.

The effect of a typical of a typical CSP plant on the power system is illustrated in figure 9. From the same figure, one can also see that the CSP plant mainly supplies power in the second peak, hence it aids the system ramping up as the solar PV power decreases.

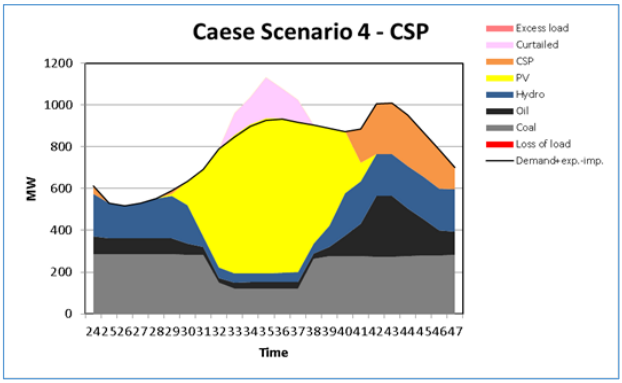

Figure 9: Daily generation profile after simulating CSP as solution to the duck curve

8. Discussion

Previous sections considered four different case studies. These studies have been carried out based on the proposed methodology using the open-source tools SAM and IRENA Flex. Thus, it is possible to use open-source tools effectively to study the duck curve phenomena. Table 2 presents the overall summary of the results

obtained from these simulations. On this table only those parameters that are relevant in selecting the most suitable solution to the duck curve were presented. As it can be expected the choice of selection of the most suitable solution may be motivated by different aspects. For instance, if one were to consider the cost and the CO_2 emissions as the driving factor behind the choice of selection of the best solution then, case scenario 5, where a CSP plant was implemented as a solution to the duck curve would have been the best option.

For this work, it can be observed that the choice of selecting the most suitable duck curve solution is driven by the reduction in CO_2 emissions, annualized unserved energy, and annualized unserved demand due to upward ramp limitation. However, this assumes that there is a feasible site for the implementation of a PHS plant. Thus, case scenario 3 is chosen as the most suitable solution to the duck curve problem of the grid considered. Further, it can be seen that open-source tools SAM and Flex tools can be used to study duck curve phenomenon. Table 2 lists the four different cases.

Table 2: Summary of results

Case	A	B	C	D	E	F
1	4.63	1996.9	136.5	0	52.57	0
2	3.62	1005.6	65.21	326.44	46.70	12.52
3	3.68	327.05	0	90.078	0	3.042
4	3.48	299.52	0	327.19	0	12.59

The 5 variables considered: A is CO_2 Emissions (M Tons), B is Total Costs (M USD), C is Annualized Unserved Energy (GWh), D is Annualized Curtailed Energy (GWh), E is Annualized unserved demand due to upward ramp limitation (MWh)and F is Curtailed energy due to downward ramp limitations (GWh).

9. Conclusion

The overall concept of a typical duck curve phenomena and the circumstances surrounding the same have been introduced. Importantly, this paper first proposes a novel methodology using open-source software tools to simulate the duck curve and then to analyze its impact. Typical load curves have been generated with SAM to incorporate location specific load data and also solar energy generation data. This ensures that the suggested approach takes field operating conditions into consideration. Integration of CSP and PHS plants can mitigate the impact of duck curve phenomena and these cases were simulated analyzed separately on a 4-bus system. Results show that it is possible to mitigate and even eliminate solar energy curtailment with careful planning. The proposed methodology can be further used to study the duck curve in-depth with different scenarios.

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Mr. Giovani Manuel Pitra has obtained his bachelor's degree in Electrical and Computer Engineering Namibia University of Science and Technology, Windhoek, Namibia in 2022. Mr. Pitra's research interests are in the extended areas of Electrical power systems and renewable energy technologies.

KS Sastry, Musti has obtained his masters and doctoral degrees in Electrical Power Systems and Engineering from National Institute of Technology, Warangal, India in 1996 and 2002 respectively. Presently, he is with the Namibia University of Science and Technology. He is a senior member of IEEE (USA) and IET (UK). His research interests are in the extended areas of Electrical power systems, renewable energy technologies and energy economics.

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Optimization of Proportional Solenoid for Flow Control Valve using Recursive Method in OCTAVE and FEMM

Tom Thampy, Emmanuel Gospel Raj Rivington *, Rajath Chandrashekar

Additive and Smart Manufacturing Processes, Central Manufacturing Technology Institute, Bangalore, 560022, India
*Corresponding author: Emmanuel Gospel Raj Rivington, Contact No:9442330252 & Email: empelraj@gmail.com

ABSTRACT: Proportional solenoid valves are used in various applications that require smooth control of flow or pressure. Manufacturing such valves would involve design of valve component, solenoid core and the coil for specific input and output ratings. Materials for each component of the solenoid valve need to be selected for their magnetic properties, application specific requirements such as medical grade, temperature compatibility, etc. With proportional control as the primary objective, the proportional solenoid valve must exhibit linear characteristics between the control input and the output. Optimization of the magnetic core plays a vital role in achieving these requirements. Optimizing the core geometry of the proportional solenoid is crucial in achieving necessary linearity in the plunger movement without compromising the actuating force on the plunger for a given size of the solenoid. A proportional solenoid valve for mass flow control in low pressure application such as medical oxygen ventilators is developed based on the performance requirements such as flow rate, pressure and control requirements such as the solenoid voltage and current ratings. The materials used for manufacturing the valve components such as medical grade stainless steel with required magnetic properties are selected based on the application requirements. An optimization technique based on recursive method is used to determine the efficient core geometry for a proportional solenoid valve. The experimental results obtained from the proportional solenoid valve manufactured based on optimization results closely matched with the calculated values of plunger displacements from different offsets of 0 mm, 1 mm and 2 mm from the reference position in a total stroke length of 5 mm, which is presented in this paper.

KEYWORDS: Flow control valve, Proportional solenoid, Recursive method, Optimization

1. Introduction

Proportional solenoid valves provide linear variation in the output flow or pressure for change in the input current or voltage. They are widely used in flow control applications, where the amount of a gas or liquid can be precisely controlled for a metered flow. Proportional solenoids are different from latching solenoids in their core geometry. Latching Solenoid valves can either be fully open or fully shut based on the control input to the solenoid coil. Therefore, they allow either full flow or no-flow during their operation. Proportional solenoids on the other hand, are used in applications that require smooth movement of its plunger rather than step movement between on and off positions as in the latching type. A well-designed proportional solenoid produces a linear displacement of the plunger to achieve linear variation in valve output in terms of output flow or output pressure. The effective volume of the proportional solenoid, material and the geometry of the solenoid core are the crucial factors determining the accuracy in the performance of the proportional solenoids for automatic valve control applications [1], [2]. Achieving linearity in the design of proportional solenoid valve is a huge challenge that paved opportunity for many researchers to adopt and suggest various elaborate techniques to optimize the construction of the proportional solenoid for valve applications [1], [3]-[8]. Conventional force equations [3], [9] available for calculating the force on plunger for solenoids is suitable for the simple geometries of ON/OFF (or) latching solenoid. The complex geometry of proportional solenoids cannot be analyzed with these equations [4], [9]. This paper illustrates the design and development of a direct acting proportional solenoid valve for gas flow control application and examines the

various factors such as magnetic material selection, core geometry, spring selection, valve geometry, and control involved. It is valuable in the way it sums up our understanding of the various aspects of designing and developing a proportional solenoid and its optimization through practical approach using recursive method. The influence of individual dimensions of the magnetic core and the step by step optimization of the core geometry using the combined powerful features of FEMM and OCTAVE applications is illustrated graphically. Finite Element Method (FEM) based analysis is performed to assess the performance of the proportional solenoid with various geometries and obtain an optimal geometry. Hardware prototype of the proportional solenoid valve is developed and tested to validate the results

2. Basic Components of The Proportional Flow Control Valve

Figure 1 shows the cross-section view of the various components of the proportional solenoid valve.

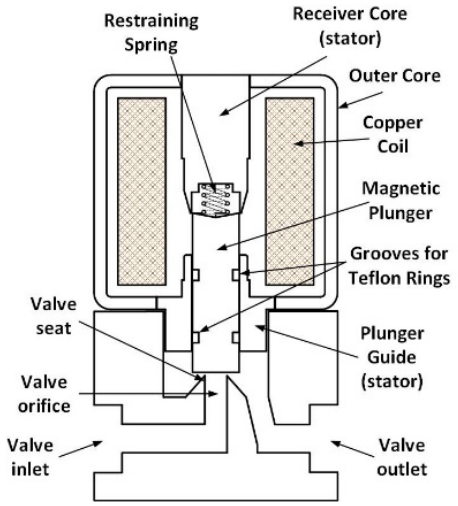


Figure 1: Cross section view of the proportional solenoid valve

Proportional valves have the following functional components: a solenoid that produces a variable magnetic field when excited by a variable Direct Current (DC), a magnetic core that provides a low reluctance path for the magnetic field, a magnetic plunger that moves when the solenoid is excited, a valve body with a valve closure mechanism that is actuated by the solenoid and a spring that helps to keep the valve closed when the solenoid is unexcited.

The cylindrical plunger inside the hollow stator core moves towards the stator receiver core that has a tapered cross section at the inner end in the axial direction [1], [2], [4]. Two circumferential grooves are provided on the plunger at suitable locations to accommodate two Teflon rings [1] to reduce the friction between the metal plunger and the plunger guide.

Specifications of proportional solenoid valves include maximum flow rate, rated pressure and power. Design of the solenoid involves winding design, core material selection and optimization of the proportional core geometry, while that of valve involves the design of orifice and valve seat.

2.1. Winding Design

The winding of the proportional solenoid, is designed in such a way that it produces the required flux to generate force that is sufficient to create displacement of the plunger and the opening of the valve. As the proportional solenoid does not latch during its operation unlike an ON/OFF solenoid, it is important to ensure that the attractive force between the plunger and the stator is sufficient and moderated throughout its entire stroke length.

The power consumed by the solenoid is calculated as

$$P = I^2R \text{ (or) } VI \text{ (watt)} \quad (1)$$

where,

I – Solenoid Current (A)
R – Resistance of the solenoid (Ω)
V – Voltage across the solenoid (V)

Force produced by the solenoid on the plunger[1], [9]

$$F = \frac{(NI)_g{}^2 \mu_0 A_g}{2g^2} \quad (2)$$

where,

$(NI)_g$ – Ampere turns required (A)
μ_0 – Magnetic permeability of free space or vacuum (H/m) or (N/A^2)
A_g – Area of the plunger surface (m2)
g – Length of the air gap (m)

$$8 = \frac{(NI)_g{}^2 4\pi \text{ x}10^{-7} \text{x } \pi \text{ x } (5.5 \text{ x}10^{-3})^2}{2 \text{ x}(1 \text{ x}10^{-3})^2}$$

$$(NI)_g = \sqrt{\frac{8 \text{ x } 2 \text{ x } (1 \text{ x}10^{-3})^2}{4\pi \text{ x } 10^{-7} \text{ x } \pi \text{ x } (5.5 \text{ x}10^{-3})^2}}$$

$$(NI)_g = 366 \text{ ampere turns(AT)}$$

Magnetic field intensity across the air gap

$$H_g = \frac{(NI)_g}{g} \quad (3)$$

$$= \frac{366}{1\text{x}10^{-3}}$$

$$H_g = 366\text{x}10^3 \text{A/m}$$

Magnetic Flux density in the air gap,

$$B_g = \mu_0 \text{ x } H_g \quad (4)$$

$$= 4\pi \text{ x} 10^{-7} \text{x } 366\text{x} 10^3$$

$$B_g = 0.46 \text{ tesla(or) weber/sq. meter}$$

Total flux in the air gap,

$$\varphi_g = B_g \text{ x } A_g \quad (5)$$

$$= 0.46 \text{ x } \pi \text{ x } (5.5\text{x} 10^{-3})^2$$

$$= 0.46 \text{ x } \pi \text{ x } (5.5\text{x} 10^{-3})^2$$

$$\varphi_g = 43.7 \text{ weber}$$

To produce the same flux throughout a magnetic core of same area Ag and a length of 200 mm:

Ignoring the fringing effect, the flux density in the core, $B_c = B_g = 0.46$ tesla

Magnetic field intensity across the core

$$H_c = \frac{B_c}{\mu_c} \quad (6)$$

$$= \frac{0.46}{1000\text{x}4\pi\text{x}10^{-7}}$$

$$H_c = 366.1 \text{A/m}$$

MMF required

$$(NI)_c = H_c \text{x length} \quad (7)$$

$$= 366.1\text{x } 200\text{x} 10^{-3}$$

$$(NI)_c = 73.2 \text{ AT}$$

Total Ampere turns required:

$$(NI)_{total} = (NI)_c + (NI)_g \quad (8)$$

$$= 73.2 + 366$$

$$(NI)_{total} = 439.2 \text{ AT}$$

Considering additional 25 % for losses,

$$(NI)_{total} = 549 \text{ AT}$$

Having a control current of 0.2 A (or) 200 mA would require number of turns

$$N = \frac{549}{0.2} \quad (9)$$

$$N = 2745 \text{ turns}$$

2.2. Geometry of the Magnetic Core

Proportional solenoids are required to produce a constant force throughout its full stroke length for a constant current. The geometry of the central core and the plunger of the solenoid plays a crucial role in achieving this. Figure 2 shows the cross-sectional geometry of the proportional solenoid with the control parameter D, t and P that have to be optimized for the solenoid to exhibit linearity and repeatability of the control movements of the plunger [2]. D represents the corner point on the outer edge of the cone, t represents the corner point on the top of the cone and P represents the depth of the conical top of the plunger.

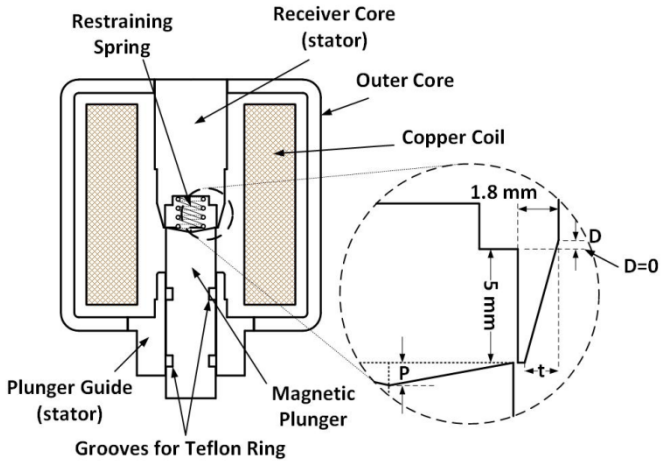


Figure 2: Cross section of the proportional solenoid depicting the cone design parameters

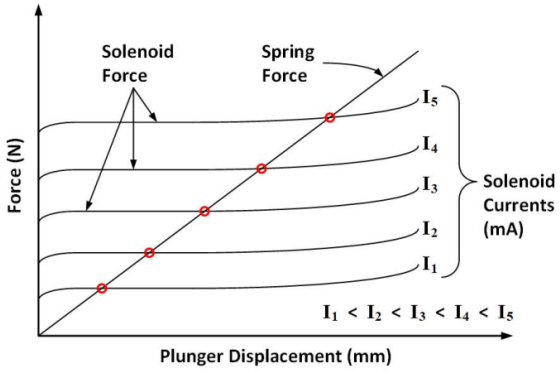
The typical Force-Displacement characteristic of a proportional solenoid is shown in Figure 3 (a). Ideally, the solenoid exhibits a constant force for a constant current for plunger displacement throughout the stroke length [3], [6]. This force increases proportional to the solenoid current. The restraining spring placed between the plunger and the receiver core produces a linear force with slope proportional to the spring constant. The intersections of the spring force with the solenoid force curves are the equilibrium points to which the plunger moves for various values of current through the solenoid [2], [6]. This in turn yields the relationship between the solenoid current and the plunger displacement as shown in Figure 3 (b).

3. Recursive Optimization of the Control Cone

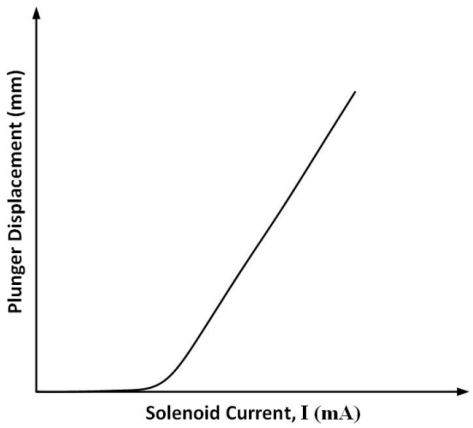
Optimization of the control cone parameters such as D, t, and P is important to achieve consistent linear characteristics of the plunger movement with respect to the control input given to the solenoid. Analysis of various designs for the computation of force on the plunger is performed by Finite Element Method Magnetics (FEMM) software application [2], [7], [10] The details of mesh settings are as shown below

- Mesh Type: Triangular Mesh
- Mesh Size: Adaptive

Recursive method provides a simple approach towards optimizing the design parameters and also requires only two iterations in arriving at the optimum results. Even though design of proportional solenoids with different configurations is possible with multiple parameters that can be optimized, the given solenoid is designed with the configuration as shown in Fig 2, and optimized for the three independent variables namely D, t and P. Each step in the recursive method finds the optimal location of an individual parameter in coarse search that narrows down to a fine search in the subsequent iterations.



a. Force-Displacement characteristics



b. Displacement-Current characteristics

Figure 3: Typical characteristics of a proportional solenoid

The optimization of the cone parameters of the proportional solenoid is based on minimizing the objective function f(s) [2], [6], [10] shown below:

$$f(s) = \sqrt{\frac{\sum_{n=1}^{x}(F(n) - F_{avg})}{x}} \quad (10)$$

where,

f(s) – Objective function (N)
x – Number of plunger steps
F(n) – Force on plunger on n^{th} step (N)
F_{avg} – Average force on plunger across the full stroke length (N)

3.1. First iteration

Every iteration in the optimization of the proportional solenoid geometry by recursive algorithm is a sequence of multiple steps of finding the near optimal value of the parameters, one at a step, in the order D, t and P. For each position of D at equal intervals between the constraints of -5 mm to +5 mm as shown in Figure 4, the plunger is moved for a stroke length of 4 mm from the tip of the cone with a step size of 0.5 mm to obtain the Force vs Displacement curves. The Force vs Displacement curves for various positions of D is shown in Figure 5. Having the corner point D near -5 mm show high force near the tip of the stationary core due to wide area made available by virtue of the position of D, which then reduces when the plunger moves deep inside the core due to increased area of low reluctance core appearing in the radial direction rather than axial. As the point D moves upwards making the shape of the receiver cone sharp and conical, the force on the plunger across its full stroke becomes moderate. It could be seen in Figure 6 that the values of the objective function are high for extreme values of D, which reduces to a lowest value of around 0.6 when D is at 1 mm above the reference point.

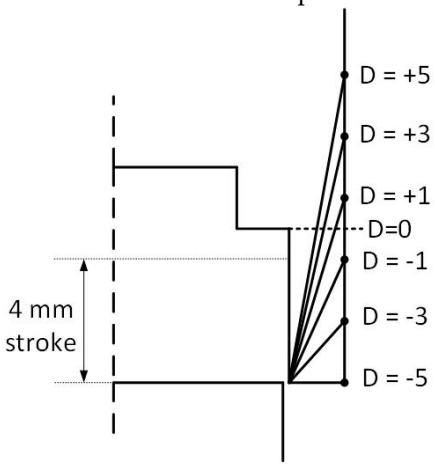


Figure 4: Optimization of D in the first iteration

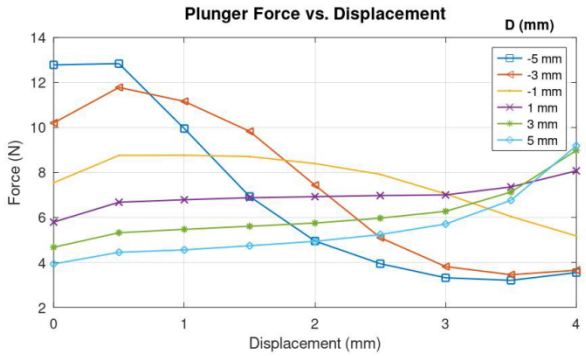


Figure 5: Plunger Force vs. Plunger Displacement characteristics for various positions of D in the first iteration

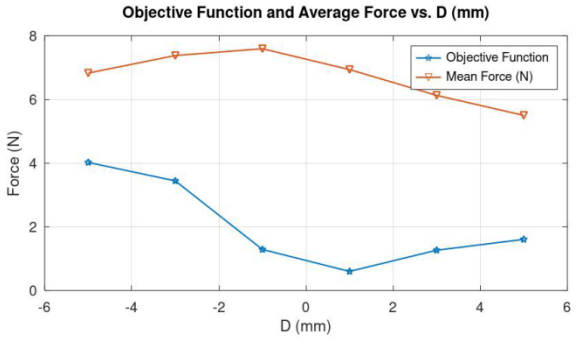


Figure 6: Objective function and Average force at various positions of D in the first iteration

The optimal value of D = 1 mm obtained from the previous step is fixed for the optimization of t between the constrains of 0 mm to 1.8 mm in the next recursive step. With D = 1 mm, the position of t is varied from 0 to 1.8 in steps of 0.36 mm as shown in Figure 7. From the various Force vs Plunger Displacement curves in Figure 8, it could be seen that that the curve corresponding to t=1.8 appears to be flatter than the other curves. Figure 9 shows that the Objective function is also minimum for the same position of t, which is 1.8 mm.

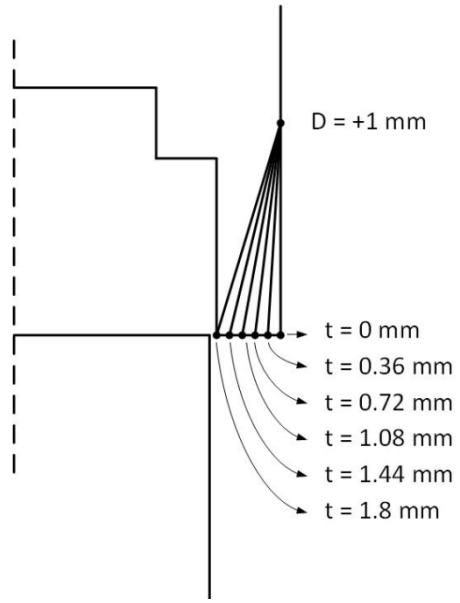


Figure 7: Optimization of t in the first iteration

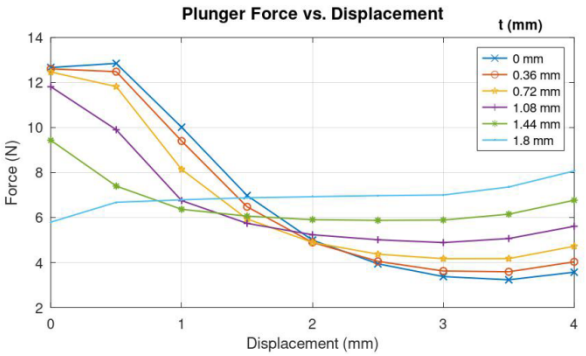


Figure 8: Plunger Force vs. Plunger Displacement characteristics for various positions of t in the first iteration

The positions of D and t are fixed at 1 mm and 1.8 mm respectively from their references and the parameter P is next optimized.

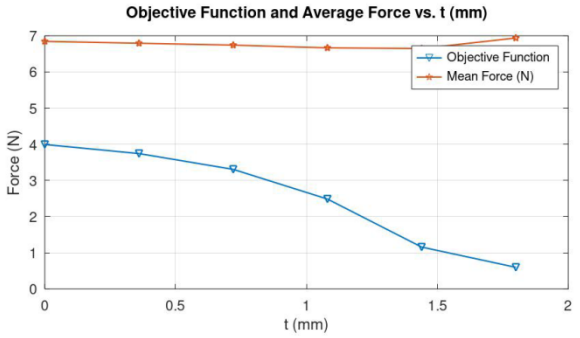


Figure 9: Objective function and Average force at various positions of t in the first iteration

Point P is at the axis of the cylindrical plunger and therefore moving P within the cylindrical structure of the plunger would create a hollow conical structure on the surface of the plunger facing the receiver core. Figure 10 shows the variation of P from -5 mm to 0 mm in 1 mm steps.

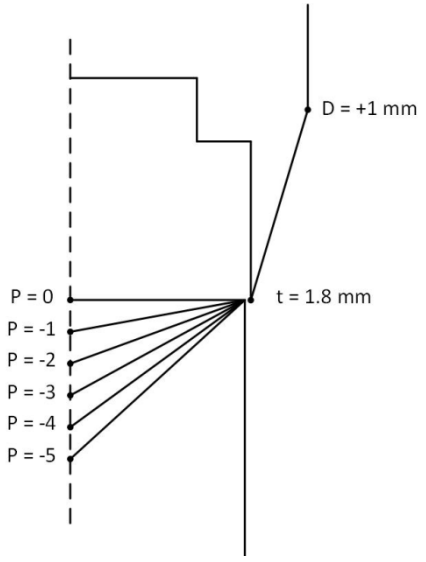


Figure 10: Optimization of P in the first iteration

The force characteristics for various positions of P can be seen in Figure 11 and the objective function characteristics in Figure 12. The optimization of P would

have considerable impact in reducing the latching tendency of the plunger when it moves closer towards the stationary receiver core beyond 3.5 mm.

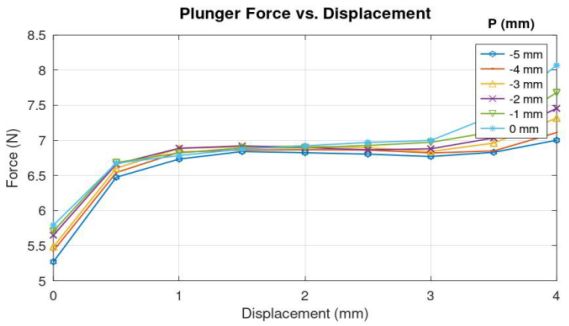


Figure 11: Plunger Force vs. Plunger Displacement characteristics for various positions of P in the first iteration

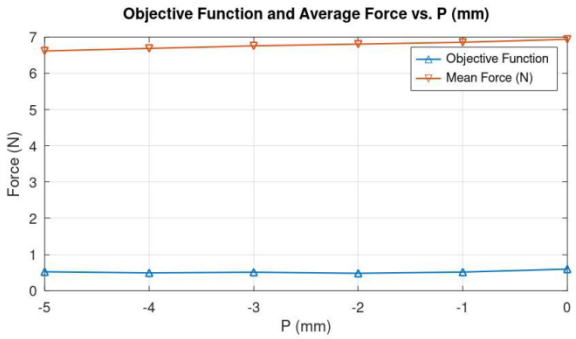


Figure 12: Objective function and Average force at various positions of P in the first iteration

The summary of parameters, constraints and the optimization results from the first iteration of the recursive method is shown in TABLE 1. The geometry obtained at the end of the First iteration is shown in Figure 13.

Table 1: Optimization results obtained from the First Iteration of the recursive method

Parameter	Min	Max	Step size (mm)	Optimal	Min. F(s)	Average force at Min. F(s)
D	-5	5	2	1	0.59828	6.9384
t	0	1.8	0.36	1.8	0.59828	6.9384
P	-5	0	1	-2	0.48351	6.8065

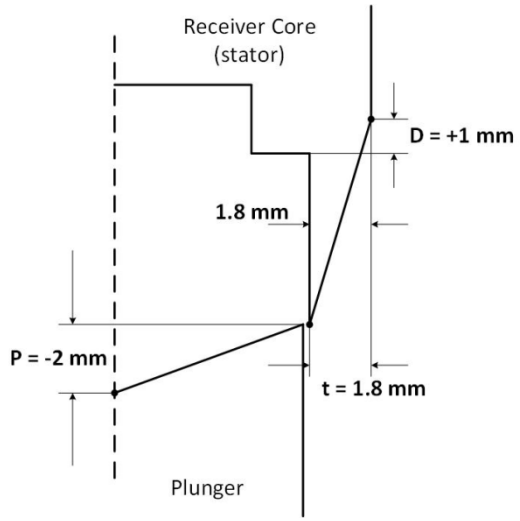


Figure 13: Geometry of proportional solenoid core obtained from First iteration of recursive optimization.

3.2. Second Iteration

The first iteration of the recursive method has given a rough idea of the optimal locations of the geometrical parameters. A second iteration is essentially required to obtain accurate results of the optimization parameters. TABLE 2 shows the details of the new parameter constraints, optimal values and the corresponding objective function. The new parameter constraints with narrow step sizes are set near the previously obtained optimal results in such a way that a detailed search is performed for finding the accurate locations of the parameters. It could be seen that the value of Minimal Objective Function has reduced from around 0.59 to 0.15 from the first row of TABLE 1 to the last row of table 2.

Table 2: Optimization results obtained from the Second Iteration of the recursive method

Parameter	Min	Max	Step size (mm)	Optimal	Min. F(s)	Average force at Min. F(s)
D	0	2	0.4	0.4	0.40518	7.131
t	1.3	1.8	0.1	1.7	0.18655	6.9748
P	-3	-1	0.2	-1	0.14875	7.0161

Figure 14 to Figure 19 show the force curves and the objective function curves obtained during the second iteration in the recursive optimization of D, t and P. The optimal values of the parameters are obtained as P = + 0.4 mm, t = + 1.7 mm and P = -1 mm. The optimal geometry of the proportional core of the solenoid is shown in Figure 20.

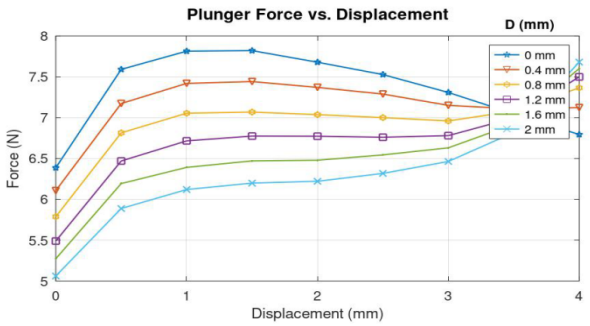


Figure 14: Plunger Force vs. Plunger Displacement characteristics for various positions of D in the second iteration

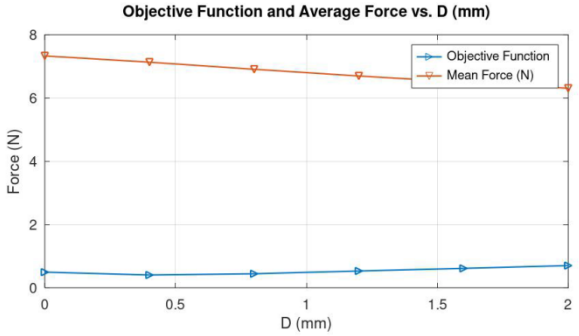


Figure 15: Objective function and Average force at various positions of D in the second iteration

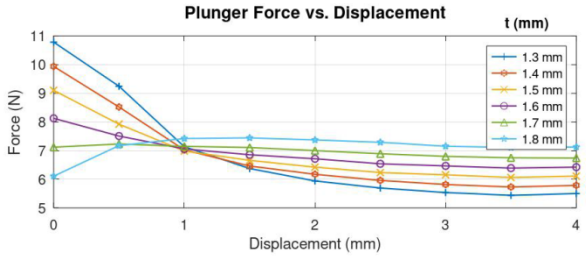


Figure 16: Plunger Force vs. Plunger Displacement characteristics for various positions of t in the second iteration

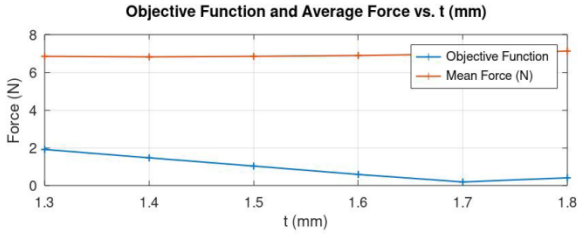


Figure 17: Objective function and Average force at various positions of t in the second iteration

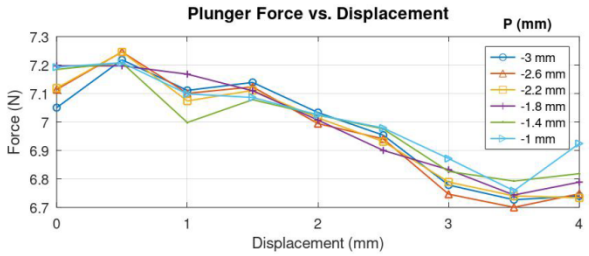


Figure 18: Plunger Force vs. Plunger Displacement characteristics for various positions of P in the second iteration

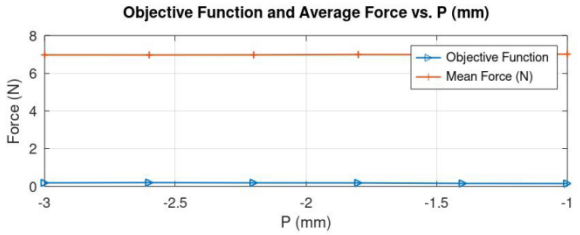


Figure 19: Objective function and Average force at various positions of P in the second iteration

Figure 21 shows the proportional solenoid valve that is developed with the optimized core geometry for gas flow at a maximum pressure of 3 Bar.

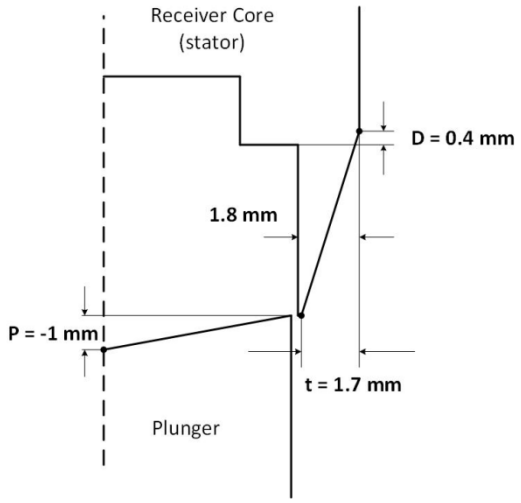


Figure 20: Geometry of the optimized proportional solenoid core obtained from second iteration of recursive method.

4. Performance testing and results

The optimized geometry of the proportional solenoid has to be checked for its optimal performance. Optimization of the proportional solenoid geometry has helped to achieve constant force for constant current through the solenoid winding regardless of the position of the plunger within the span of the 4 mm stroke length where the solenoid is intended to operate.

Force curves of the optimized solenoid for various values of constant currents and the force generated by the restraining compression-spring with a spring constant of 3.6 N/mm represented as the load line are shown in Figure 23.

Figure 21: The developed proportional solenoid valve for flow control

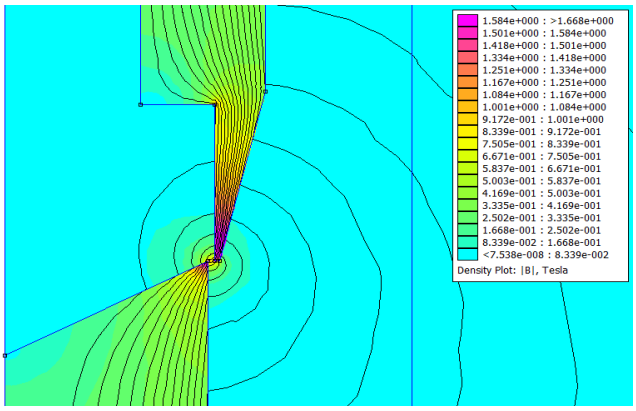


Figure 22: Magnetic flux density plot of the optimized proportional solenoid geometry in FEMM

The intersections between the load line and the force curves are obtained and the characteristics between solenoid current and the plunger displacement is drawn as shown in Figure 24.

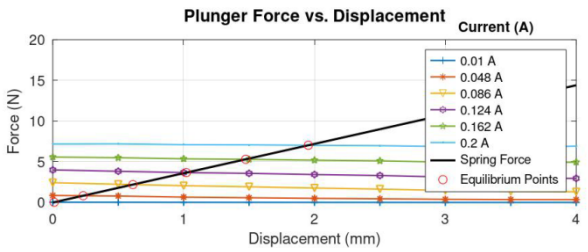


Figure 23: Force vs Displacement characteristics of the Proportional Solenoid and the restraining spring (0 mm offset)

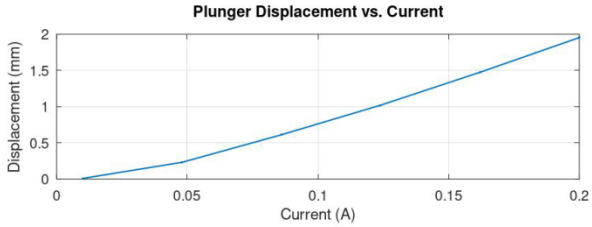


Figure 24: Plunger displacement vs solenoid current characteristics with 0 mm offset of the restraining spring

For an optimized proportional solenoid, the relationship between the control current and the plunger displacement remains same in the stroke length of the plunger regardless of the initial offset of the spring or the initial position of the plunger.

The load line of the spring that is offset by 1 mm along with the force curves of the proportional solenoid is shown in Figure 25. The characteristics between the control current of the solenoid and the plunger displacement is shown in Figure 26. It may be noted that the displacement of the plunger starts from the initial offset position of the spring at 1 mm.

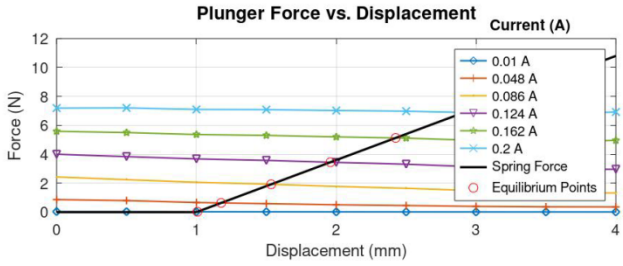


Figure 25: Force vs Displacement characteristics of the Proportional Solenoid and the restraining spring (1 mm offset)

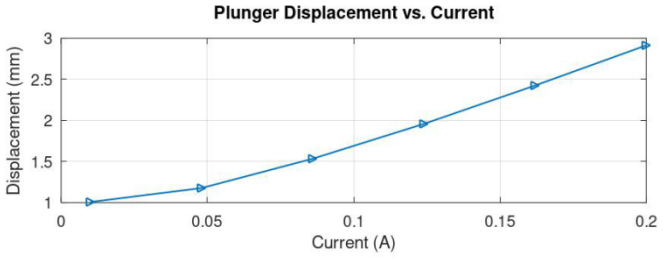


Figure 26: Plunger displacement vs solenoid current characteristics with 1 mm offset of the restraining spring

The load line of the spring that is offset by 2 mm along with the force curves of the proportional solenoid is shown in Figure 27. The characteristics between the control current of the solenoid and the plunger displacement is shown in Figure 28. It may be noted that the displacement of the plunger starts from the initial offset position of the spring at 2 mm.

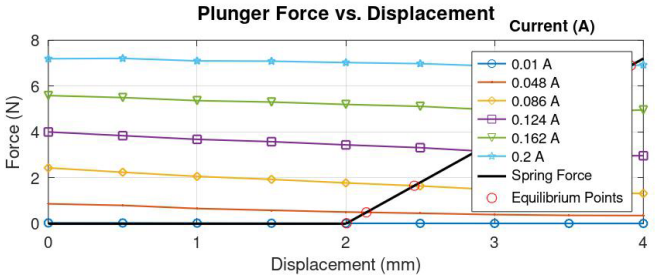


Figure 27: Force vs Displacement characteristics of the Proportional Solenoid and the restraining spring (2 mm offset)

The effective displacement of the plunger in the optimized model of the proportional solenoid with three different offsets such as 0 mm, 1 mm and 2 mm is shown in Figure 29. It can be seen that the characteristics are close to each other. It should be noted that the desirable ideal characteristics is to have all curves straight and aligned with each other.

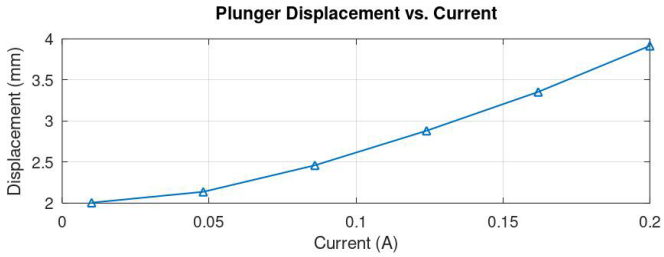


Figure 28: Plunger displacement vs solenoid current characteristics with 2 mm offset of the restraining spring

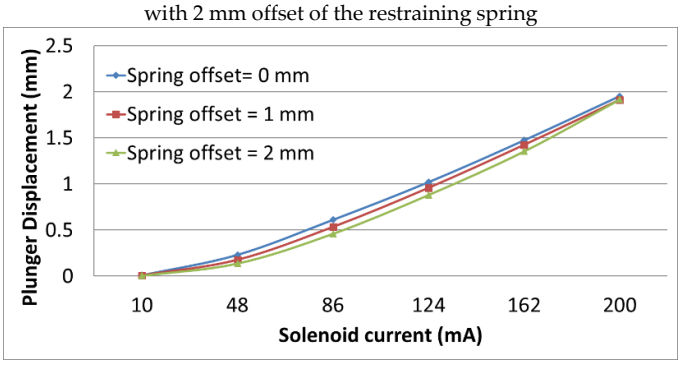


Figure 29: Effective plunger displacement vs solenoid current characteristics of the optimal design with various offsets

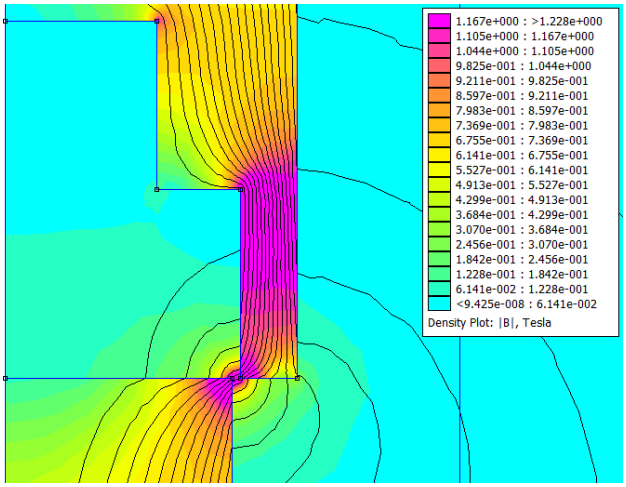


Figure 30: Magnetic flux density plot of the flat non-optimal geometryin FEMM

For a non-optimal design, the control characteristics may not be straight and aligned as it may be expected. Figure 30 and Figure 32 show two non-optimal designs featuring flatter than optimal design and sharper than the optimal design respectively.

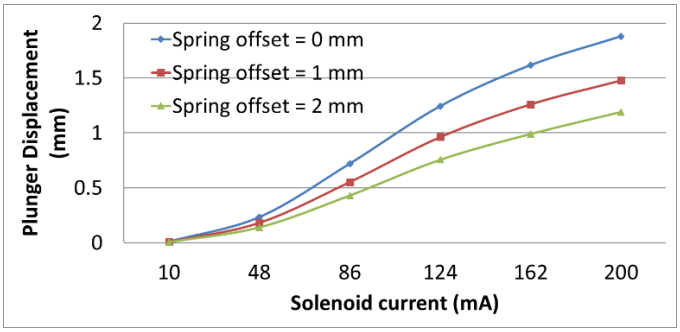


Figure 31: Effective plunger displacement vs solenoid current characteristics of the flat non-optimal design with various offsets

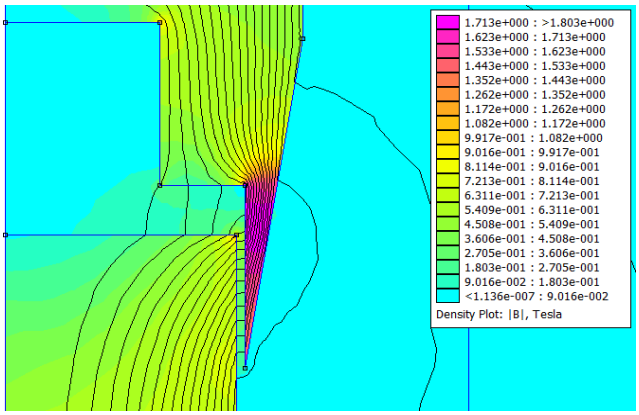


Figure 32: Magnetic flux density plot of the sharp non-optimal geometry in FEMM

The characteristics of the two non-optimal designs are shown in Figure 31 and Figure 33. An undesirable widening in characteristics can be seen in Figure 31 corresponding to a flat non-optimal geometry. It can be seen in Figure 33 that two of the curves are close to each other with lesser displacement than optimal and the third curve is deviating.

The Plunger displacement vs current characteristics is experimentally obtained from the manufactured proportional solenoid and compared with the computed characteristic of the optimized geometry as shown in Fig 34.

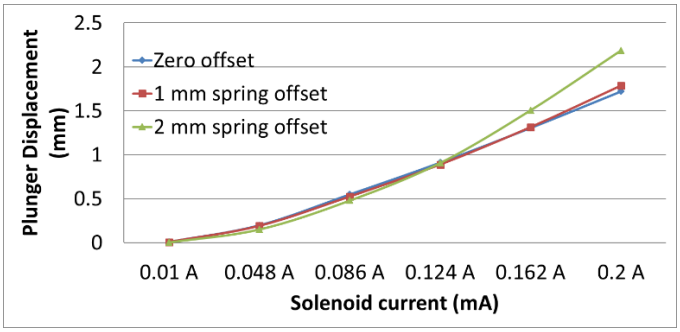


Figure 33: Effective plunger displacement vs solenoid current characteristics of the sharp non-optimal design with various offsets

Having the objective of achieving an optimized geometry of proportional solenoid to produce linear displacement for coil currents regardless of the initial offset, the experimental displacements from initial offsets of 0 mm, 1 mm and 2 mm are compared with the corresponding computed displacements as shown in Figure 34.

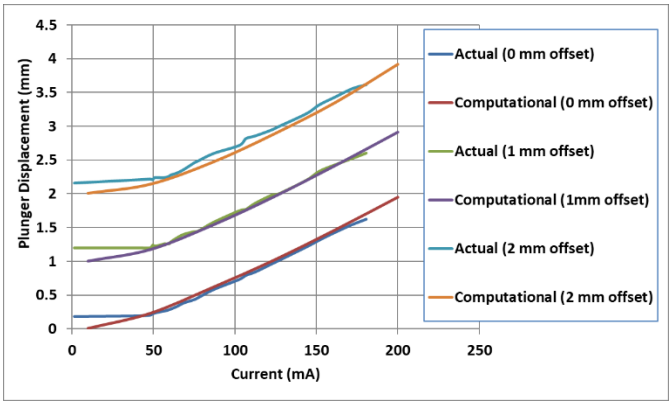


Figure 34: Experimental plunger displacement and computed plunger displacement

The graphs show close agreement between actual and computed values, which validates the proposed optimization method based on recursive technique. The actual displacement with 0 mm offset is slightly lower than the computational displacement due to the plunger being near the far end of the proportional cone. With increased offset, i.e., when the plunger position is well inside the proportional cone, the force on plunger tends to be higher resulting in higher displacement. However, still higher offsets would result in the displacement getting flattened when the plunger goes too much inside the proportional cone due to the flux in the air gap becoming more lateral than axial.

5. Conclusion

This paper has presented the technical approach to the development of a proportional solenoid valve. The basic operation of the proportional solenoid, selection of materials, power supply related design approaches have been discussed. Optimization of the proportional core, being one of the crucial steps in the design of a proportional solenoid has been given primary focus in this report. The recursive method of optimization is used for the finding the best geometry of the proportional core of the solenoid valve due to its effective approach in yielding the optimization results in less than three iterations. The step by step process of optimization of the geometrical parameters of the proportional core is illustrated with diagrams and graphs. A hardware version of the proportional solenoid valve based on the optimal design is manufactured and tested for its performance. The results show that the proportional solenoid optimized using the proposed technique of

recursive method exhibited linear displacement for the solenoid current for various offsets. The design approach illustrated in this technical report can be utilized for manufacturing proportional solenoid valves suitable for a variety of applications.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgment

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Analyzing the Impact of Challenges in Prefabricated Building Construction Supply Chains

Rishabh Rastogi, Sushil Kumar Solanki *, Virendra Kumar Paul

School of Planning and Architecture, New Delhi, 110002, India
*Corresponding author: Sushil Kumar Solanki, Contact: +917828253917, Email: sushilsolanki@spa.ac.in

ABSTRACT: Across various barriers pertaining to prefabricated building construction projects, a major barrier identified by the literature was integration of various components of prefabricated building project supply chain network, including the material and human resource supply chains. The literature suggests a need of exploring this barrier of supply chain integration into its various sub factors/challenges (termed as supply chain challenges) with the perspective of prefabricated building construction supply chains. This research tries to fill this gap by analyzing three cases of existing prefabricated building construction supply chains in Indian context with different configurations, geophysical profiles and project typologies. This study gives an understanding of the relationship among supply chain challenges, the variation in their relative impact on project time and cost (within the supply chain and across the different configurations of supply chains), and the underlying causes of these variations.

KEYWORDS: Supply Chain Challenges, Prefabricated Construction, Relative Impact, Relationship Matrix

1. Introduction

The integration of supply chain management in the construction industry is a relatively new concept in India, which has attracted the attention of professionals in recent few years. Various theories and models of supply chain and its management from the vast knowledge pool of industrial/manufacturing supply chains have been adopted and have been implemented in the construction industry. However, the effectiveness and benefits of implementing these models for a successful management of construction supply chains is questionable. This is because, unlike the sequential and mostly linear manufacturing supply chains, the construction supply chains are rather more complex [1], comprising of activities and multiple acting parties which involve various other types of interdependencies apart from the traditional sequential/linear dependency. Also, construction supply chains are unique with respect to the project in consideration which, in a generalized way can be broadly classified into two major categories of supply chains, a) The material and equipment supply chains and; b) The human resource supply chains [2] ; which formulate the three dimensions of a supply chain in a project namely; design dimension, demand dimension and supply dimension. Efficiency of supply chain as a whole is dependent upon individual performance as well as the integration among these dimensions.

These supply chain fundamentals apply to the realm of prefabricated building construction as well, however the uniqueness of this typology of construction is that it comprises of a traditional sequential manufacturing supply chain (for prefabricated building component manufacture and supply) as a very significant component in the material and equipment supply chain network of the project [3]. An established prefabricated building component supply chain consists of a stable and consistent manufacturing process and has low uncertainties associated with it for a specific construction project [4]. This stability promotes the adoption of supply chain management principles of "Lean thinking" and "Just in Time Production" to improve its efficiency. However, the integration of these supply chain principles and models with the overall network of supply chains in a construction project raises its own challenges in terms of management and optimization of project schedule and cost (as the high levels of uncertainties in construction

project favors agile principles instead of lean principles) [3].

Literature on prefabricated construction suggests that most of the barriers in prefabricated building construction are multi stakeholder in nature and are influenced by various entities throughout the manufacture, construction and design dimensions of a prefabricated construction project [2]-[6] and can be broadly classified into following six factors,

Table 1: Barriers of Prefabricated Building Construction

Factor 1: Industry Chain	Factor 4: Construction Implementation
Factor 2: Cost Parameters	Factor 5: Architectural Performance
Factor 3: Social Climate and Public Opinion	Factor 6: External Conditions

Source: [7]-[11]

According to literature, major hindrances in implementation of prefabricated construction were in factors of – "Industry Chain", "Cost Parameters" and "Construction Implementation" [6]-[8], [10], [12]. Industry experts in India also identified that nature of planning system and fragmented industry are among the major barriers for prefabricated construction in India [9]. The multi-stakeholder characteristic of barriers of prefabricated construction demands an analysis at industry chain and supply chain levels, to identify the root causes of multi-dimensional supply chain challenges of prefabricated construction projects in India [1].

This paper attempts at bridging the gap by analyzing the impact of various challenges pertaining to the prefabricated building supply chains; using relative impact tables and relationship matrix and diagrams. The data obtained for this study is through structured interviews and discussions with industry professionals of considered supply chain cases in Indian context.

2. Prefabricated Building Construction Supply Chains

A prefabricated building project essentially comprises of two different material supply chains, including raw material supply chain (Type-1) such as that of cement, aggregate, sand, infill wall blocks (AAC blocks / bricks / cement blocks / CLC blocks), etc. These materials are required on a continuous basis and are ordered in bulk for in-situ works for walling, casting of foundation, unique building elements and high tensile grouting for the prefabricated component assembly, etc. The ordering strategy of these materials is variable and follows the principle of make-to-stock, as their utilization rate changes throughout the construction schedule (as per the sequence of construction activities) of a prefabricated construction project.

The second kind of material supply chain for a prefabricated construction project is that of precast components, manufactured on-site or off-site (Type-2). These include the precast structural components such as, beams, columns, slabs, shear walls, infill wall panels, etc. These components are unique for every construction project, with respect to their size, shape and joinery between various components. The components are quantified in exact numbers as per the building plans and details; hence, the ordering strategy for such building material components is highly specific and follows the principle of make-to-order [13]. As these components are termed as highly essential and critical as per construction schedule and their supply is dependent on a third agency associated to the construction process (the supplier), thus, their ordering schedules are well monitored and controlled to mitigate any deviation from the planned construction schedule.

The third supply chain comprises of human resource, such as the designers / architects, engineers, project managers, etc. These are the primary decision making bodies for a construction project. Engineers and architects are responsible for defining and providing various details for prefabricated components to the manufacturer. Project managers are responsible for determining the construction schedule, which governs the ordering schedule of various materials including order of prefab components from the manufacturer. Hence, it becomes essential for the manufacturer to receive information from both sources (designers and site supervisors) to process the production of required component as per the details and its supply as per the provided schedule [14], [15]. Coordination between these three entities is essential for a successful supply of correct building component with minimal processing / waiting time and achieving low lead times.

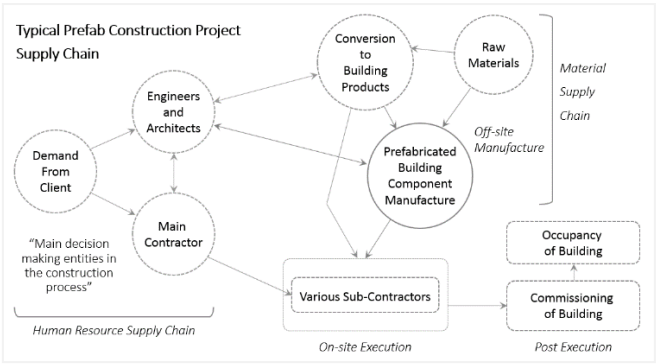


Figure 1: Supply chain network diagram for prefabricated construction project
Source: Adapted from typical construction project supply chain by [16]

3. Supply Chain Configuration

Data for the configuration of considered cases of supply chain in India was carried out using structured interviews and

discussions with the industry professionals. Details are presented as appendix.

4. Relative Impact of Supply Chain Challenges

Structured interviews were conducted with the suppliers to identify and score the likelihood of occurrence, relative impact on project time and cost for various supply chain challenges. This data was collected by interviewing 3-4 responders from their respective supply chains. As the responses from these responders were specific, pertaining to a single supply chain, the mean values of these responses was considered for each respective supply chain. This data was then analyzed using the likelihood vs. relative impact graph, to identify critical challenges.

5. Identification of Critical Challenges

The plotted graphs of likelihood of occurrence vs relative time / cost impact represent that the challenges that are most critical with respect to the supply chain in Case-1 are presented in table 2.

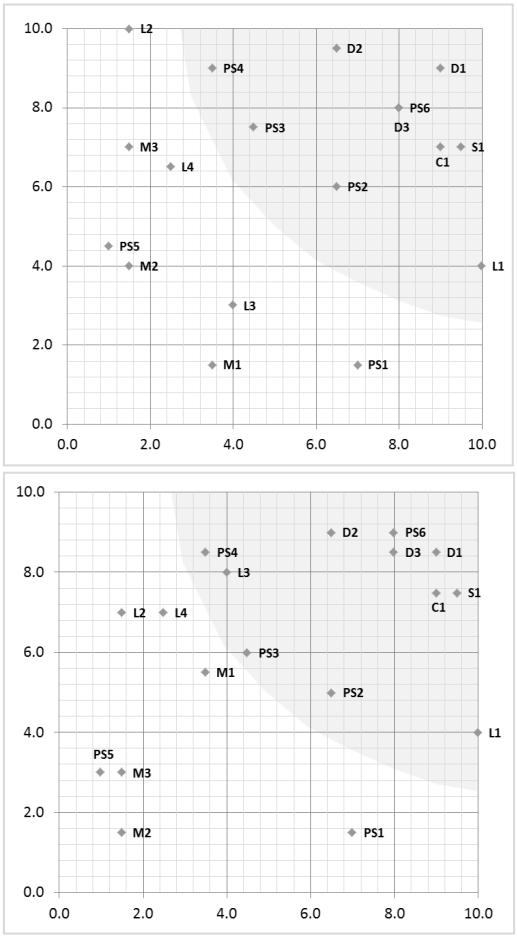


Figure 2: Likelihood vs Relative Time Impact (left), Likelihood vs Relative Cost Impact (right)

Table 2: Critical Challenges

Material supply chain related challenges	Human resource supply chain related challenges
L1 - Weather Change (Precipitation, etc.)	D1 - Inadequate planning of precast works
L3 - Transport Regulation Restrictions	D2 - Approvals from regulatory authorities (delays)
PS2 - Inadequate site / storage space	D3 - Changes in specification
PS3 - Accessibility to Site (obstructions)	S1 - Disparities in received information from designers and contractors
PS4 - Reduction in efficiency of resource utilization rate on site	C1 - Late client payment
PS6 - Inaccuracy of Cast in-situ Works	

These challenges are then ranked based on the score of likelihood of occurrence x relative impact (both for cost and time impact). The score is shown below,

Table 3: Rank of Critical Challenges

	Material Supply Chain						*Human Resource Supply Chain*				
Challenge	*L1*	*L3*	*PS2*	*PS3*	*PS4*	*PS6*	*D1*	*D2*	*D3*	*S1*	*C1*
Relative Cost Impact	40.0	32.0	32.5	27.0	29.8	72.0	76.5	58.5	68.0	71.3	67.5
Relative Time Impact	40.0	12.0	39.0	33.8	31.5	64.0	81.0	61.8	64.0	66.5	63.0
RANK	2	6	3	5	4	1	1	5	3	2	4

6. Critical Challenges: Plotted against the precast project supply chain

Figure 3 suggested that major challenges in the prefabricated building supply chains are towards the downstream of the project supply chain network. The impact is significant for post manufacture stages within the supply chain and increases downstream up until the project site parameters of the supply chain, where the synchronic interdependencies arise.

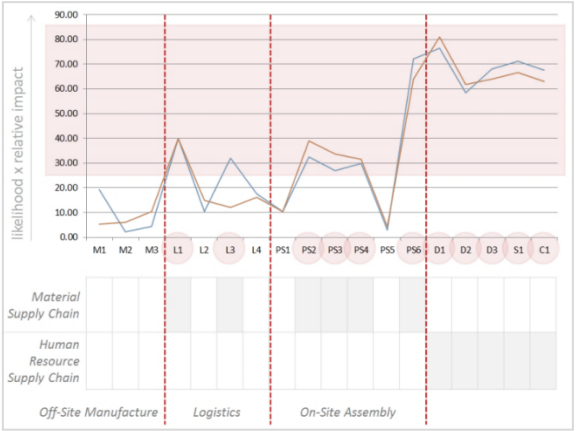


Figure 3: Challenges Plotted Against Precast Project Supply Chain

7. Inter-relationship of Supply Chain Challenges

Existence of directional relationship between various challenges and its strength was identified on the basis of literature; and discussion and interview sessions with professionals (responders) from the case specific supply chains. A relationship matrix (Figure 4) is developed using the obtained information, which is used to calculate the matrix permanent values to represent the relative stability of the supply chains as compared to each other. This matrix also helps in identifying the dominant and critical relations among the challenges, and eventually gives the major underlying causes (external and internal factors) of the repercussions within the supply chains of prefabricated building construction.

Factor	M1	M2	M3	L1	L2	L3	L4	PS1	PS2	PS3	PS4	PS5	PS6	D1	D2	D3	S1	C1
Price Change / Market Fluctuations	M1		3	2		2			1									2
Insufficient Resources for production	M2			3		2		1	1									3
Reduction in production efficiency of supplier	M3								3					3		3	4	
Weather Change (Precipitation, etc.)	L1							1	1		1	2		1				
Environmental Hazards	L2							5	5	1	3	3	1	1				2
Transport regulation restrictions	L3							2								1	1	
Delivery bottlenecks / breakdowns	L4								4		2							
Early or late deliveries	PS1									1	1	2			4	2	1	4	2
Inadequate site / storage space	PS2										1	1	2	3	3		2		
Accessibility to Site (obstructions)	PS3														2				
Reduction in efficiency of resource utilisation rate on site	PS4												2	3	4		2	3	
Insufficient Workspace	PS5														2		1		
Inaccuracy of Cast in-situ Works	PS6																2	4	2
Inadequate planning of precast works	D1															4	3	5	3
Approvals from regulatory authorities (delays)	D2																2		
Changes in specification	D3																	4	
Disparities in received information from designers and contractors	S1																		2
Late client payment	C1																		

Figure 4: Relationship Matrix CASE-1

The relationship matrix was used to develop a relationship flow diagram (Figure 5) representing the major relationships (with a value of 3 or more than 3). This flow diagram was analyzed to identify the supply chain challenges that affect multiple parameters of a precast project.

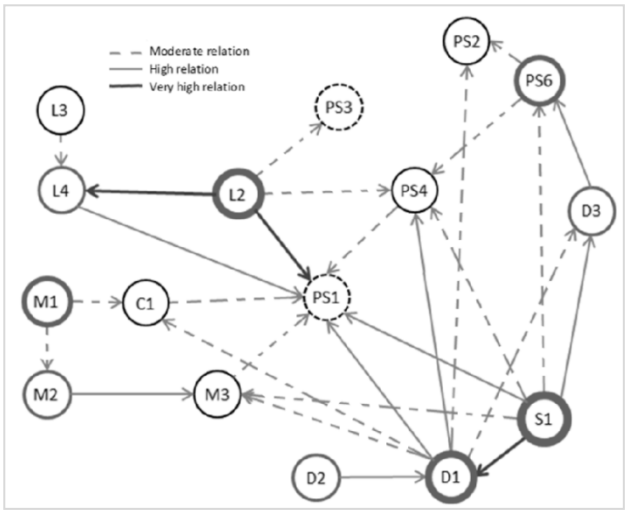


Figure 5: Relationship Flow Diagram CASE-1

Major causes of existence of various challenges in prefabricated building supply chains were as follows,

S1: Disparities with received information from designers and contractors, is a major underlying cause of existence of challenges – D1, D3, PS1, PS2, PS4, PS5, PS6 & M3.

D1: Inadequate planning of precast works, causes the existence of challenges – D3, PS1, PS2, PS4, PS5, M3 and C1.

M1: Price Change / Market Fluctuations, causes the existence of challenges – M2, M3 and PS1.

L2: Environmental Hazards, causes and affects the existence of challenges – L4, PS1, PS3 and PS4.

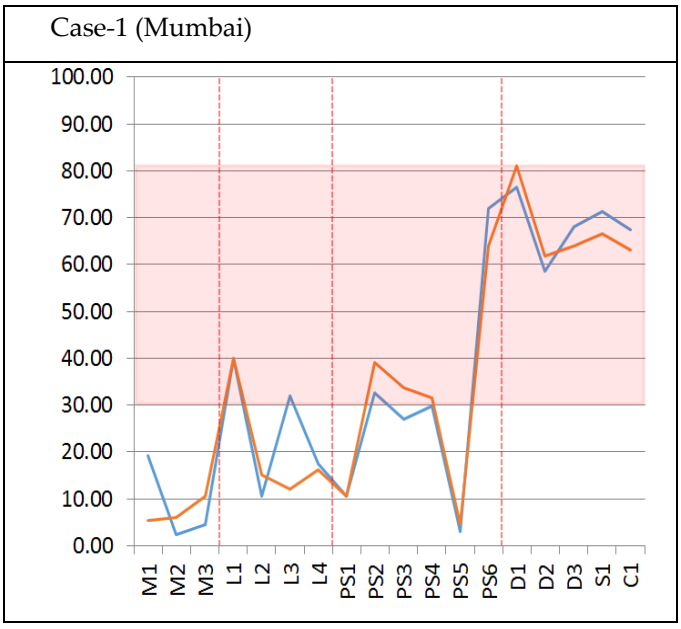
L3: Transport Regulation Restrictions, causes and affects the existence of challenges – L4 and PS1.

Above stated underlying causes – S1 and D1 are internal factors and can be controlled to reduce the overall impact on precast project supply chain and optimize the project time and cost. However, the underlying causes – M1, L2, and L3 are external factors, although beyond the control of project parameters and its stakeholders, but due consideration has to be given to these factors to improve supply chain stability.

8. Results and Discussions

8.1 Analysis of Relative Impact of Challenges across all Case Typologies

Relative impact on project cost and time in Case-2 is lower than in Case-1 because the supplier in Case-2 undertakes precast projects which involve the manufacture and supply of highly repetitive components like modular RCC wall panels, RCC planks for boundary walls, etc. The standardization of component sizes and shapes in Case-2 improves the efficiency of transportation of these panels, resulting in lowering the logistics cost and reducing schedule deviations. Moreover, projects undertaken by the supplier in Case-2 has lower dependency on cast in-situ works, which reduces the likelihood of occurrence of challenges such as, inaccuracy of cast in-situ works, etc. and also reduces the relative impact of these challenges.



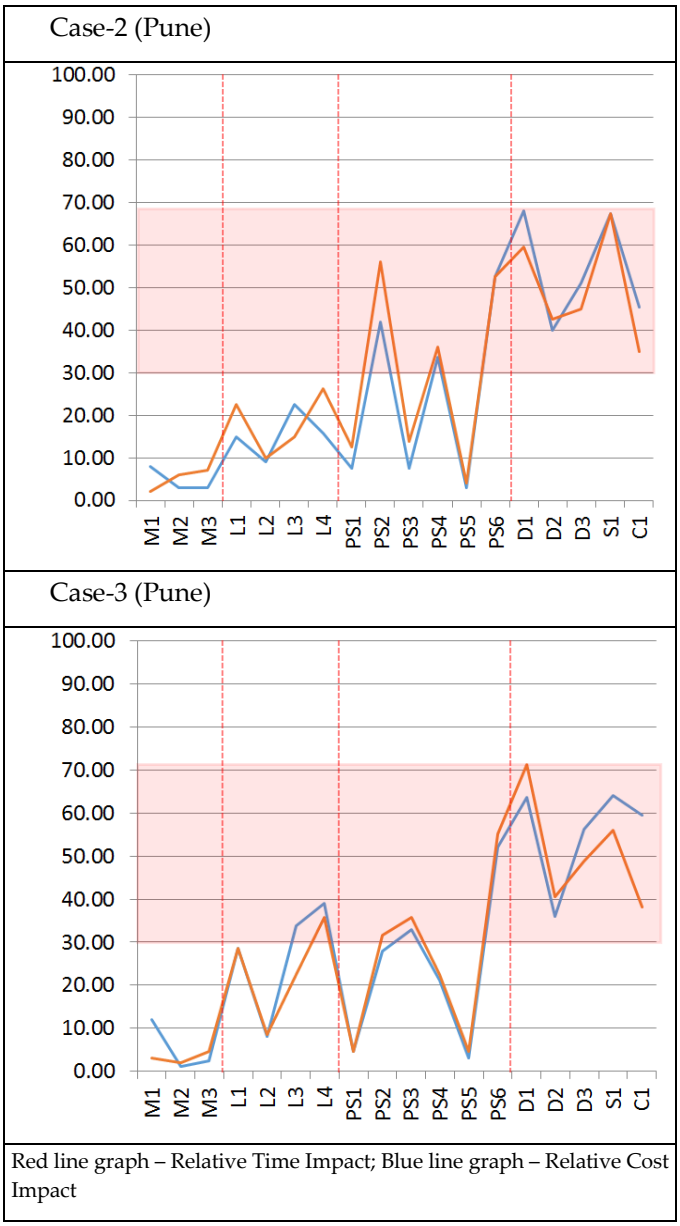


Figure 6: Relative Impact across all Case Typologies

Relative impact in the Case-1 and Case-3 is higher than in Case-2 because of the large range of customizable building components, as opposed to the supplier in Case-2. This reduces financial efficiency of the logistics operations of the project because of high variation in sizes & shapes of the manufactured components. The projects undertaken by suppliers in Case-1 and Case-3 involve substantial cast in-situ works along with precast works, making the projects more susceptible to project site related challenges. This higher susceptibility increases the likelihood of occurrence and impact of these challenges arising during the project timeline.

Relative impact in Case-3 is lower as compared to Case-1 because of the differences in supply chain configurations between the two. The large scale projects (as compared to Case-1) undertaken by the supplier in Case-3 benefits from economy of scale. Larger production capacity with high raw material and finished product storage space in Case-3 reduces the susceptibility of precast projects to the site related challenges. In-house logistics department in Case-3 reduces the susceptibility of precast projects to logistics related challenges. Moreover, with respect to the challenges of weather change (L1), the supplier in Case-1 is more prone because of its proximity to Mumbai city.

8.2 *Analysis of Relationship Matrix of Challenges across all Case Typologies*

The supply chain of Case-1 consists of a total of 28 critical relations (17 moderate, 8 high and 3 very high relations) indicating a higher susceptibility to impact to project cost and time. In the configurations and features of Figure 7, the critical relations reduced to 25 (14 moderate, 8 high and 3 very high relations). Implying that supply chain in Figure 7 (Case-2) is slightly less susceptible to impact to project time and cost, as compared to Figure 7 (Case-1).

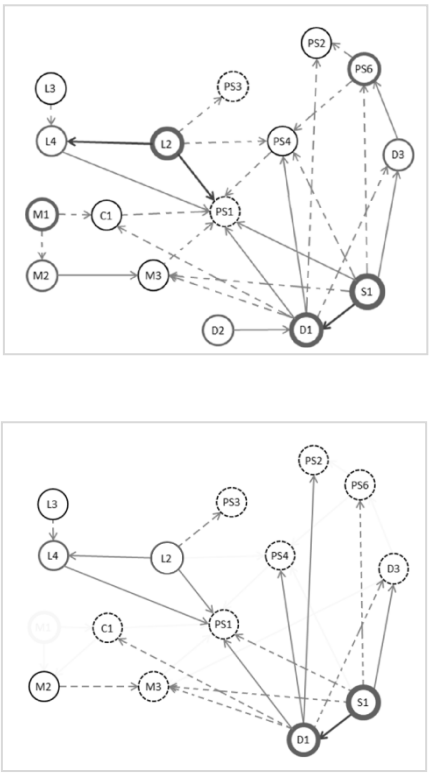


Figure 7: Relationship Flow Diagram CASE-1 (above), CASE-2 (below) Source: Authors

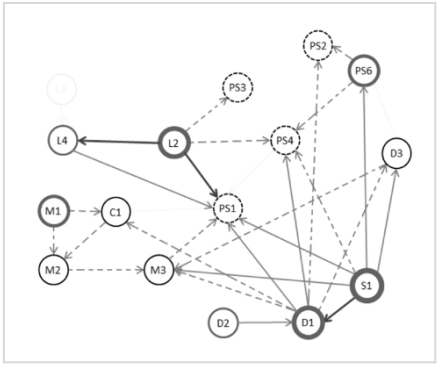


Figure 8: Relationship Flow Diagram CASE-3

In Figure 8 (Case-3), the critical relations are reduced to 17 (9 moderate, 7 high and 1 very high relations), which is

substantially lower than the relations in Figure 7 (Case-1 and Case-2). Configuration and geophysical mapping of supply chain in Figure 8 (Case-3) renders it least susceptible to impact to project time and cost.

This is also evident by comparing the matrix permanent values (Table 7) representing the relative stability (Higher values of matrix permanent indicate a lower relative stability) of the considered supply chains, which were calculated using the relationship matrix.

Table 4: Matrix Permanent Values (Ryser Algorithm) for all Cases

Case-1 (Mumbai)	Case-2 (Pune)	Case-3 (Pune)
0.0142 (matrix permanent = 100.46 while considering relative impact values)	0.0050 (matrix permanent = 27.96 while considering relative impact values)	0.0007 (matrix permanent = 5.133 while considering relative impact values)

9. Conclusion

Prefabricated building construction is a growing industry in India consisting of its challenges pertaining to dimensions of construction implementation, architectural performance, social climate & public opinion, costing, and supply chain management. Across these dimensions, major challenge was integration of various components of supply chain in a prefabricated building project including the material and human resource supply chain networks. This research explored the challenge in supply chain integration by studying case of prefabricated building construction supply chains with different configurations, geophysical profile and project typologies to understand the relation among supply chain challenges and variation in relative impact on project time and cost, within the supply chain and across the different supply chains.

The relative impact analysis of identified challenges suggested that major challenges in the prefabricated building supply chains are towards the downstream of the project supply chain network. Bullwhip effect of the critical challenges in supply chain affected the delivery schedule of precast component and logistics cost upstream in the supply chain and the resource utilization rate on the construction site greatly.

Various external and internal underlying causes of disturbances in supply chain processes were identified from the analysis of relationship matrix and flow diagram for each of the considered cases. This indicated that factors, (internal factors) S1 – Disparities with received information from designers and contractors, D1 – Inadequate planning of precast works, (external factors) M1 – Price Change / Market Fluctuations, L2 – Environmental Hazards, and L3 – Transport Regulation Restrictions; were major contributors to existence of various other challenges in the supply chain. Hence, considerations to mitigate the impact of these challenges will reduce their repercussions throughout the prefabricated building construction supply chain.

Conflict of Interest

The authors declare no conflict of interest.

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Rishabh Rastogi: Student, Department of Building Engineering and Management, School of Planning and Architecture, New Delhi, India

Sushil Kumar Solanki: Associate Professor, Department of Building Engineering and Management, School of Planning and Architecture, New Delhi, India

Virendra Kumar Paul: Professor & Head of Department, Department of Building Engineering and Management, School of Planning and Architecture, New Delhi, India

Appendix

Table 5: Supplier Details

SN	Parameter	Case-3 (Mumbai)	Case-2 (Pune)	Case-3 (Pune)
1.0	Procurement at the manufacturing unit	Multiple Suppliers	Multiple Suppliers	Multiple Suppliers
1.1	Location of raw material supplier	Within 30 km radius of facility location (logistics cost: 10-50km: Rs 100/km; >50 km: Rs 105/km)	Within 20 km radius of facility location (logistics cost: 10-30km: Rs 90/km; >30 km: Rs 100/km)	Within 50 km radius of facility location (logistics cost: 10-50km: Rs 100/km; >50km: Rs 105/km)
1.2	Order size and order frequency of raw materials	Depends upon the order size for project (does not manage a minimum stock level)	Depends upon the order size for project (does not manage a minimum stock level)	Manages minimum stock level of: Cement: 500 cum; Aggregate: 1500 cum; Sand: 400 cum
1.3	Raw material utilization rate at manufacturing unit	Cement: 400-550 cum/month Aggregate: 1200-1500 cum/month Sand: 250-350 cum/month	Cement: 200-300 cum/month Aggregate: 600-900 cum/month Sand: 150-200 cum/month	Cement: 2700-3200 cum/month Aggregate: 7500-9000 cum/month Sand: 1700-2000 cum/month
2.0	Warehousing at the manufacturing unit			
2.1	Capacity of the raw material warehouse	To support the production of a total of 500 cum of concrete per week	To support the production of a total of 200 cum of concrete per week	To support the production of a total of 3000 cum of concrete per week
3.0	Production capacity of manufacturing unit	2000 - 2500 cum of precast components	1000-1500 cum of precast components	13000-15000 cum of precast components
4.0	Production process of precast component			
4.1	Lead time for manufacturing	5-6 days for laying of reinforcement	6-7 days for laying of reinforcement	2-3 days as the facility consists of automated bar bending yard
4.2	Waiting time on the casting moulds	7-10 days including reinforcement laying + casting + curing	8-12 days including reinforcement laying + casting + curing	5-8 days including reinforcement laying + casting + curing
4.3	Waiting time on inspections	1-2 days	1-2 days	1 day
5.0	Capacity of the warehousing yard for finished goods	Supports at least 1/4th of the monthly production capacity	Supports the storage of 50-60 cum of finished precast components	Supports the storage of 100% of the monthly production capacity
6.0	Stock holding period and cost	3-5 days, depending upon warehousing capacity	1-2 days maximum to keep the space available	8-10 days, depending upon warehousing

		at project site	for next batch of components	capacity at project site
7.0	Physical parameters			
7.1	Mode of transport	Outsourced logistics support, including 10T open trucks, 20ft-40ft flat/open-bed trailers	Outsourced logistics support, including 10T open trucks, 20ft-40ft flat/open-bed trailers	In-house logistics fleet comprising of 10T-20T open trucks, 20ft-40ft flat/open-bed trailers
7.2	Size of components to be transported	1m-3m long, 2.4m wide components	2m-3m long, 2.4m wide components	3m-4m long, 2.4m wide components
7.3	General shipping distance and operational area	200-250 km	100-150 km	100-200 km
8.0	Facility location reason	Low cost of land, connectivity with major highways, and close proximity to raw material suppliers	Low cost of land, close proximity to raw material suppliers, and away from city traffic to facilitate movement	Low cost of land, adjacent to Wagholi road for better connectivity with sites

Source: Structured interviews of industry professionals from the considered cases

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Electrochemical Desalination Test of Bricks as a Building Material for Historical Buildings in Japan

Risako Fukami *, Toshiya Matsui

Faculty of Art and Design, University of Tsukuba. 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8577, Japan
*Corresponding author: Risako Fukami, Department of cultural heritage studies, Graduate School of University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki, Japan, +81 80-5277-4790, warasiha@gmail.com

ABSTRACT: Brick buildings and structures are often exposed to outdoor condition, and deterioration of the bricks due to salt weathering caused by the surrounding environment has been reported in various parts of Japan. In Japan, not only the preservation of cultural properties but also their utilization is currently being promoted, and the beauty of brick surfaces is at a stage where it is becoming more important. For these reasons, a simple, low-cost, easily installed desalination model to desalinate only those areas where salt weathering was observed as first aid of deteriorated bricks was created. Powdered cellulose and copper plates were used as electrodes and these materials are readily available and easy to handle for professionals of conservation science as well as non-professionals. The aim of the research presented in this paper was twofold: to investigate the desalination effect of a simple electrochemical desalination model and to obtain knowledge for practical tests by conducting experiments under different energization conditions and observing the surface of the bricks after energization. Na_2SO_4 solution was used in the experiments and the brick samples containing Na_2SO_4 were used for desalination test by energizing for 8 days and sample exposure test after energization. When powdered cellulose and copper plates were used as electrodes, it was found that when sufficient water was supplied, approximately 64% of sulfate ions in the brick sample were removed when the energization conditions were 5 V and 0.5 A and 73% of sulfate ions were removed when the energization conditions were 5 V and 1 A. Visual observation confirmed that this removal rate suffices in preventing salt precipitation after energization is applied. This desalination method is expected to be suitable for Japanese historical bricks, which have varied characteristics, because it is possible to adjust the amount of water supplied during the energization by using an easily removable powdered cellulose for the electrode, and desalination can be performed without damaging the brick surface. However, it was found that the black areas consisting mainly of Cu_2O were formed after the 8-day energization. Since the efficiency of desalination from this area to the anode may be low, this remains a challenge for the future.

KEYWORDS: Brick, Conservation science, Desalination, Modernization heritage, Salt weathering

1. Introduction

In recent years, Japanese brick structures have been attracting attention as industrial and modernization heritage. Many brick buildings and structures were constructed throughout Japan as symbols of modernization. However, a great amount collapsed during the Great Kanto Earthquake of 1923 [1]. Since then, bricks have rarely been used as construction materials in Japan, which is prone to frequent earthquakes. For this reason, the brick buildings and structures that were constructed before 1923 and remain in Japan are extremely valuable and have historical and artistic value.

However, these brick buildings and structures are often exposed to outdoor condition. In Japan, not only the preservation of cultural properties but also their utilization is currently being promoted, and the beauty of brick surfaces is at a stage where it is becoming more important. However, brick deterioration due to salt

weathering caused by the surrounding environment (Figure 1 and Figure 2) has been reported in various parts

Figure 1: Buildings showing signs of deterioration due to salt weathering

Figure 2: Bricks with peeling due to salt weathering

of Japan. Responding to this issue, the application of a hydrophilic resin was tested to prevent the penetration of water, which is one of the causes of salt weathering [2], [3]. Other attempts have been made to treat bricks with penetrating coatings, which have been reported to be effective in inhibiting salt weathering in Japan [4]. More recently, other methods have been used to adjust the temperature and relative humidity environment through numerical analysis and simulation to predict the occurrence of salt weathering from the perspective of environmental engineering [5], [6], constructions to break the origin of moisture that causes salt weathering [7] and restoring the deteriorated parts of bricks with restoration materials [7], [8]. However, these methods require extensive construction, large amounts of money and manpower although municipalities and organizations that own brick cultural properties have limited budgets for the conservation and restoration of cultural properties, and there are challenges such as a lack of professionals in conservation of brick cultural properties and the shortage of local staff in Japan. Moreover, treatment or desalination methods for salt weathering using hydrophilic resin or penetrating coatings have yet to be thoroughly established. Additionally, few efforts have been made to remove salt within the Japanese environment, and there is a need to develop more effective desalination methods to control the deterioration of bricks.

In this study, electrochemical desalination (ED) which has been mainly used to desalinate concrete structures was applied to remove the salt contained in bricks. ED is a method for removing or reducing the number of anions, such as chloride (Cl^-) and sulfate (SO_4^{2-}) ions, from a material by transferring them through electrophoresis. This method has been applied to concrete structures in Japan since 1992, and its effectiveness has been reported since [9]. While these promising effects can be expected to occur in bricks, there are few examples of Japanese historical building bricks being desalinated. Outside of Japan, an electrokinetic desalination test on bricks has been active. Various types of salt were the target of desalination in the tests and it was reported that 99% of chlorides and nitrates could be removed from the bricks using ED [10], [11]. However, sulfate was more difficult to remove completely than other salts and the removal rate of sulfate was reported to be only 89% [12]. Indeed, ED is still seemingly in the testing stage and has not yet been implemented. Moreover, it is necessary to select a more manageable material as an electrode to perform ED locally. In the case of Japanese brick cultural properties, not all brick walls are deteriorated due to salt weathering, and there is often variation in the areas where salt weathering is observed. Therefore, we consider that the time and cost of conservation treatment are able to be reduced by desalinating only those areas where salt weathering is observed, rather than desalinating the entire wall surface. However, desalination of only the necessary areas has not been considered. Therefore, as an first aid, it is necessary to develop a method to desalinate only those parts of the bricks that need desalination, without modifying the bricks that are not deteriorated. This study proposes that a viable solution to the aforementioned issues surrounding brick cultural properties is to create a simple, low-cost, easily installed desalination model for individual bricks. In other words, to create a simple desalination method the that specifically targets the parts that require desalination rather than the entire brick wall.

For the research presented in this paper, sulfate, which is difficult to remove, was targeted for the desalination tests. A simple, low-cost, easily installed desalination model for individual bricks was created using materials that are readily available and easy to handle for professionals of conservation science as well as non-professionals. The aim of the research was to investigate the desalination effect of the simple ED model and to obtain knowledge for practical tests by conducting experiments under different energization conditions and observing the surface of the bricks after energization.

2. Salt weathering in bricks

Salt weathering in bricks is a phenomenon that occurs when water that has penetrated the bricks and joints

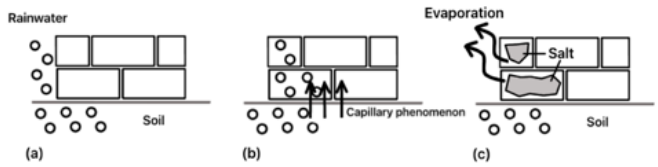


Figure 3: Schematic diagram of salt weathering process in bricks material

through groundwater or rain evaporates, causing the salts dissolved in the water to crystallize in the voids and on the surface, resulting in brick deterioration (Figure 3). When the stress exerted by the salts exceeds the tensile strength of the brick, brick failure occurs. [13]. Various types of salts, such as Na_2SO_4 (thenardite), $MgSO_4{\cdot}7H_2O$ (epsomite), and $CaSO_4$ (gypsum), have been detected or precipitated from deteriorated bricks. Additionally, it is known that different salts precipitate in different seasons and locations [14]. These salts progressively deteriorate the bricks through repeated precipitation and deliquescence. Na_2SO_4 (thenardite) is one of the most common salts that can deteriorate bricks, and is reported to be one of the most damage-inducing salts [15]. Furthermore, when the relative humidity changes from 70% to 100% at a temperature of 20°C, it undergoes a phase change to $Na_2SO_4{\cdot}10H_2O$ (mirabilite). Additionally, the hydration and dehydration process of these salts is more rapid than other salts and this phase change is repeated several times during the day and is accompanied by a large hydration pressure, which accelerates the fracture of the bricks. [16].

3. Methods

3.1. Brick samples

The bricks used as samples were made imitating the characteristics of the bricks used in the Tomioka Silk Mill, which were produced in Japan in the 1870s. Bricks made before 1887 were fired at a low temperature, resulting in a water absorption rate of about 17% and a compressive strength of about 9.5 N/mm², both of which are lower than modern brick standards. In addition, since the first Japanese brick standards were established in 1924, bricks manufactured before that date were considered to have varied characteristics [17]. The brick samples were each made to the following standards in order to make the brick samples large enough to be easily cut for evaluation after energization and to minimize waste after the experiments. Therefore, the brick samples were cut into 5 cm × 5 cm × 11 cm pieces for Test 1, and 5 cm × 5 cm × 4 cm for Test 2. Each brick sample was immersed in 35.5 g/L (0.25 M) Na_2SO_4 solution for 5 days, and dried until the moisture content was under 0.05%. The concentration of Na_2SO_4 solution was set at 0.25M, which was the concentration that did not affect the evaluation of the brick surface condition throughout the preliminary experiments. Table 1 shows the properties of the samples.

Table 1: Physical properties of brick samples

		Absolute dry weight [g]	Water absorption [%]	Volume [cm³]	Dry density [g/cm³]	Na_2SO_4 content [g]
Test 1	Control	592.45	17.91	275	2.15	5.14
	A1	556.29	18.44	275	2.02	3.19
	A2	621.96	18.8	275	2.26	4.86
	B1	581.75	18.87	275	2.12	4.03
	B2	589.41	18.65	275	2.14	5.55
	C1	586.42	18.81	275	2.13	5.70
Test 2	Control	147.79	18.11	100	1.48	1.64
	I	143.22	18.29	100	1.43	1.62
	II	161.33	18.22	100	1.61	2.03

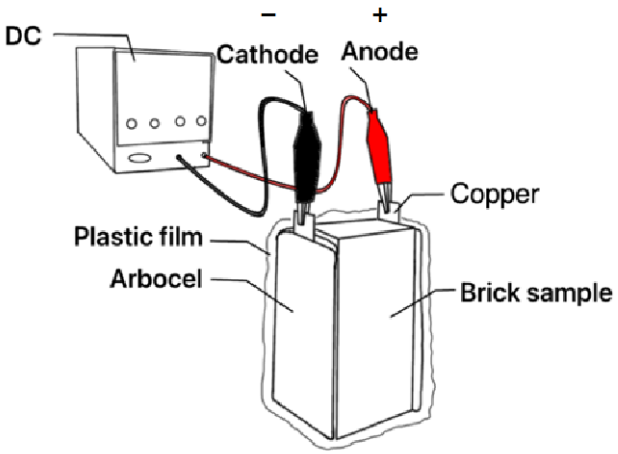


Figure 4: ED model (created by the author)

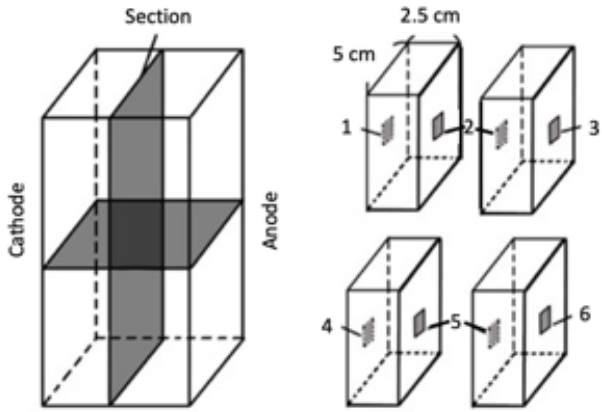


Figure 5: Schematic of the division of the sample (left) and the brick powder sampling point (right)

Na_2SO_4 solution was used in the tests. Na_2SO_4 (thenardite) is one of the most common and reportedly one of the most damage-inducing salts for bricks [15]. Furthermore, as mentioned above, it is more difficult to remove from bricks than other salts. For these reasons,

Na_2SO_4 solution was selected to be used in the experiments.

3.2. Process of the tests

3.2.1. Electrodes

Powdered cellulose (Arbocel BC1000 from Holland Gwabo) and copper plates (Kenis) were used to create the electrodes. Arbocel is originally used as an inert filler for cleaning rocks and frescoes and for conditioning poultices and has hydrophilic and insoluble properties [18, 19]. The copper plate (15 mm in width, 45 mm in length) had a purity of 99.96%. To 25g of dried powdered cellulose, ultrapure water with an electrical resistivity of 18.2 MΩ/cm was added, amounting to 20% of the dry weight of the brick samples. The mixture was combined until the Arbocel was moistened. Since the absorption rate of the brick samples was 20% of the dry weight, this amount of water was determined to represent the saturated water content and added to the powdered cellulose. Moistened Arbocel was placed on two sides and bottom of the brick sample, and copper plates were inserted into the lateral Arbocel layers, so that the copper plates did not touch the brick material. The test was conducted on the smaller surfaces of the brick (5 cm × 5 cm), namely the top and bottom, and the electrodes were placed at the top of the two sides. The surface was covered with a plastic film to prevent the Arbocel from drying out (Figure 4).

3.2.2. ED test under different energization conditions (Test 1)

In Test 1, the quantitative evaluation of the SO_4^{2-} concentration in the bricks was conducted by ED. Table 2 shows the voltage and current conditions applied to each sample. The energization period was 8 days. On the fourth day of energization, ultrapure water was added to the Arbocel of both electrodes in the amount of 20% of the dry weight. After the energization was completed, the samples were cut into half using a hammer and a blade, and further divided so that the top and bottom were equal. After cutting, approximately 3 g of brick powder was collected from the locations shown in Figure 5. After the test, ion chromatography and visual observation were used for evaluation. Visual observations focused on the brick surface conditions and on the form of salts that precipitated there after energization. The presence of any deterioration indications such as peeling or powdering on the surface of the bricks was also inspected.

3.2.3. Ion chromatography

Ion chromatography was used as the evaluation method for Test 1. The extract solution used for the analysis was prepared by grinding the collected brick powder, then soaking it in ultrapure water, shaking it for 48 hours, and letting it stand for 24 hours. The volume of ultrapure water used was 1.5 ml, corresponding to 15 mg of brick powder. The extract was filtered through a 0.45 μm diameter filter (Minisart RC4 from Sartorius) and then analyzed for anions. Metrohm 883 Basic IC plus was used as the analyzer. A separation column METRO A Supp 5 25/4.0 (6.1006.530) was used, and the flow rate was 0.70 mL/min.

Table 2: Energization conditions of the samples used in the tests

		Voltage [V]	Current [A]	Additional water supply
Test 1	Control	0	0	×
	A1	5	0.1	○
	A2	5	0.1	○
	B1	5	0.5	○
	B2	5	0.5	○
	C1	5	1	○
Test 2	Control	0	0	×
	I	5	0.5	○
	II	5	0.5	×

○ Water was added on the fourth day of energization.

× Water was not added while energization.

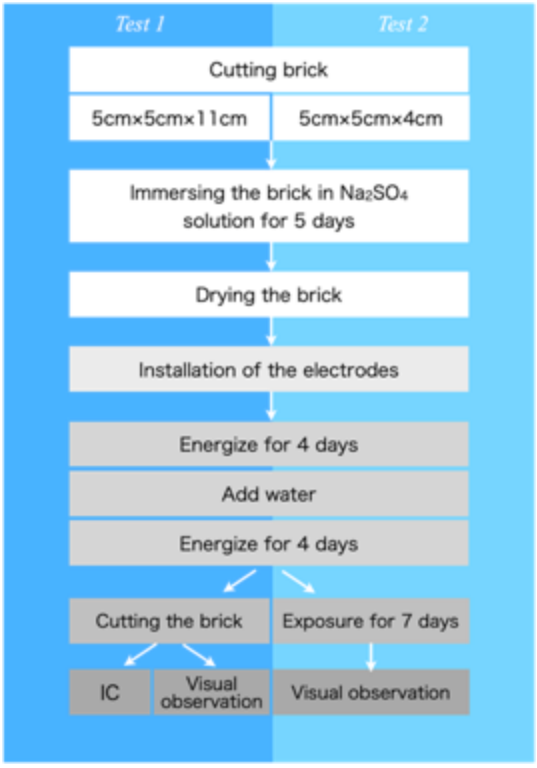


Figure 6: Flowchart of Test 1 and Test 2

3.2.4. Sample exposure test after ED test (Test 2)

Building on the results of Test 1, visual observations were conducted in Test 2 to evaluate the changes in the brick surface condition after energization. The samples

were exposed to an environment with a temperature of 25°C and a relative humidity of 60% for 7 days after being energized following the same procedures thank those of Test 1. The same current-carrying conditions (5 V, 0.5 A) both with and without the addition of ultrapure water during energization were also prepared (Table 2). The flowcharts for Test 1 and Test 2 are shown in Figure 6.

3.2.5. *Visual observation*

Visual observation was conducted as an evaluation method for Test 1 and 2. For each test, the brick samples were dried after being energized and the presence or absence of salt precipitation was checked. In addition, for Test 1, the brick surface was observed using a KEYENCE Digital microscope VHX 900 in order to inspect the conditions of the brick surface in more detail.

4. Results

4.1. SO_4^{2-} *concentration after ED test*

The results of the ion chromatography analysis are described separately for the top and bottom of the brick samples. Regarding the top, the SO_4^{2-} concentration in the entire upper part of the brick samples decreased compared to that of the control sample when the current was applied at 0.1 A or higher. The decrease in SO_4^{2-} concentration in the middle and cathode side was especially pronounced when the energizing conditions were 0.5 A and 1 A. It was also found that under 0.5 A energizing conditions, SO_4^{2-} content in the brick powder collected from the top of the brick sample decreased by 35.5% compared to the control, and under 1 A, it decreased by 54.8%. However, as shown in Figure 7, SO_4^{2-} concentrations on the anode side were high, suggesting that SO_4^{2-} in the brick moved from the cathode to the anode, and some ions were removed from the brick by moving to the Arbocel on the anode side, while some remained on the anode side of the brick sample.

Regarding the lower part of the brick samples, there was no decrease in the SO_4^{2-} concentration in the entire lower part compared to the control brick sample, even when changing the current values. However, it was found that the SO_4^{2-} concentration on the cathode side decreased while it increased on the anode side when applying a current of 0.1 A or higher. Furthermore, when a current of 0.5 A or 1 A was applied, the SO_4^{2-} concentration decreased not only on the cathode side but also in the middle part (Figure 7). These results suggest that SO_4^{2-} in the lower part of the brick samples moved from the cathode to the anode when energization was applied under conditions of 5 V, 0.5 A or 1 A. However, SO_4^{2-} concentrations in the lower part of the brick samples did not decrease even when the energization was applied under 0.5 A or 1 A, which were effective in desalination for the upper part of the brick samples, suggesting that SO_4^{2-} ions were not removed in the lower part of the brick samples and the desalination efficiency was lower than that of the upper part.

4.2. *Presence or absence of salt precipitation*

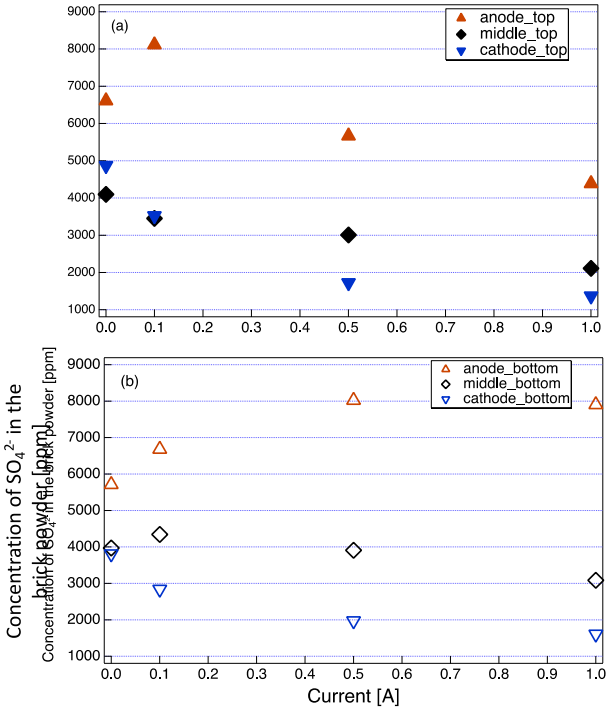


Figure 7: (a) Concentration of SO_4^{2-} in the upper part of the brick sample (b) Concentration of SO_4^{2-} in the lower part of the brick sample

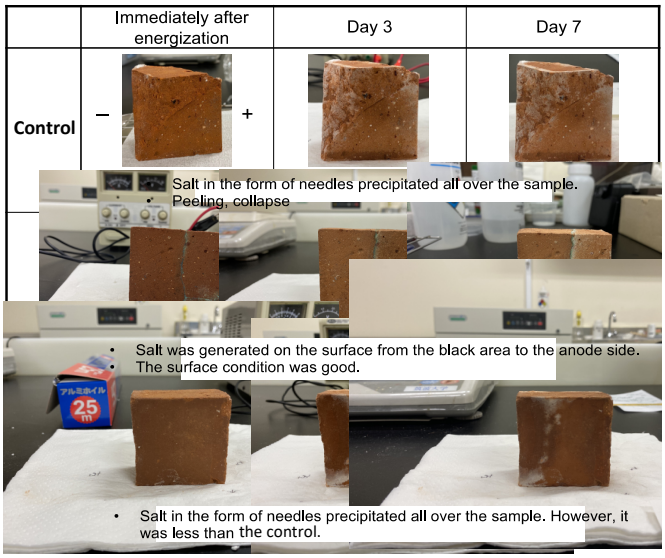
Table 3: Conditions of the brick surfaces after Test 1

	Control	A1	B1	B2	C1
Whole picture	Cathode / Anode				
Microphotograph					
Surface condition	• Salt was deposited on the entire test piece. • Peeling	• Salt was deposited on the entire test piece. • Peeling	• No salt precipitation.	• Salt was slightly deposited on the entire test piece.	• Salt was slightly deposited on the entire test piece except the anode side.

Results of the Test 1 visual observations are shown in Table 3. The squares in the photos of the whole brick pictures (first row) indicate the areas where the sample surfaces were observed using an electron microscope. First, salt precipitation was observed on the entire brick sample when no current was applied. Additionally, the sample surface presented thin peeling due to salt precipitation. Furthermore, microscopic observation revealed that the salt formed needles and that brick grains were attached around the salt. Although the amount of salt precipitated in A1 decreased compared to that of the control sample, salt precipitated on the entire surface, and the microscopic images show that the brick surface

deteriorated through salt precipitation. On the other hand, only a small amount of salt precipitation or no precipitation at all were observed in B1, B2, and C1 where the current-carrying conditions were 0.5 A or higher.

Table 4: Conditions of the brick surfaces after Test 2



Microscopic observation revealed that the small amount of salt precipitated formed a film. The brick surfaces of these samples were in good condition, and no deterioration was observed in the form of peeling or powdering. The conclusion can be drawn from the visual observation results that the bricks are highly effective in desalination when energized under 5 V, 0.5 A conditions or higher. However, while the desalination effect was observed, it was found that black areas formed in these bricks after the energization.

The results of Test 2 are shown in Table 4. For Sample Ⅰ, where water was added during the test, a black area formed (Figure 8), and salt was generated on the surface from the black area to the anode side. However, salt did not precipitate from the cathode side to the black area, and surface conditions were good. For Sample II, where no water was added during the test, no black area formed. Furthermore, salt precipitation was observed throughout the brick sample, although it was reduced.

5. Discussion

The reactions that have occurred at each electrode due to energization are shown below (1), (2).

$$Cu \rightarrow Cu^{2+} + 2e^- \quad (1)$$

$$1/2O_2 + H_2O + 2e^- \rightarrow 2OH^- \quad (2)$$

From the results of Tests 1 and 2, it was found that the desalination of the bricks was made possible by energizing under the conditions of 5 V and 0.5 A or 1 A and the addition of water during the test, to the extent that only a small amount of salt or no salt was deposited after energization. X-ray diffraction analysis of the salt precipitated after energization revealed $Na_2CO_3 \cdot H_2O$ (thermonatrite) in addition to Na_2SO_4. This is thought to indicate that SO_4^{2-}, which could not be removed from the

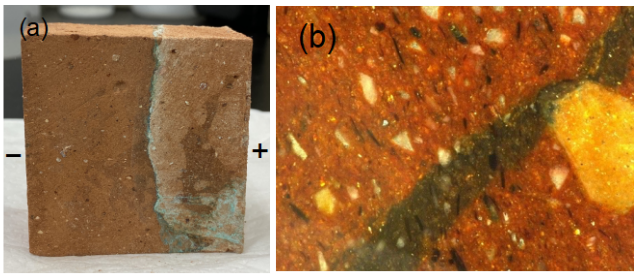


Figure 8: (a) The brick sample with the observed black area. (b) Enlarged photo of the black area.

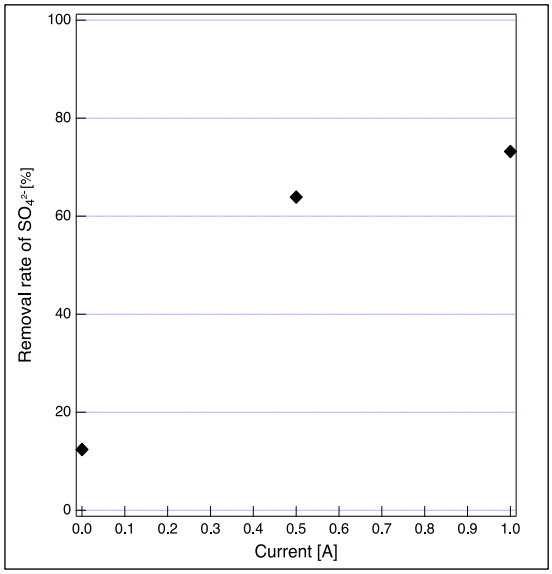


Figure 9: Change in removal rate of SO_4^{2-}

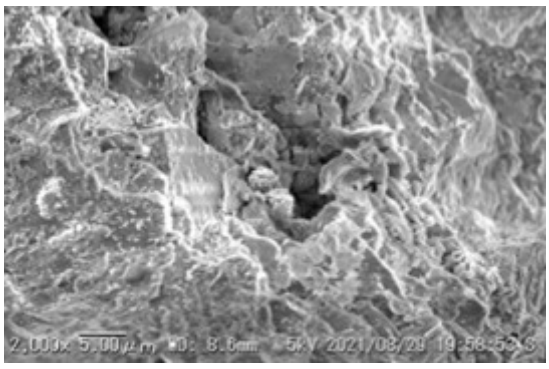


Figure 10: SEM image of the black area

brick by ED, precipitated as Na_2SO_4, and that $Na_2CO_3 \cdot H_2O$ was formed by Na^+ remaining in the brick due to the removal of some of the SO_4^{2-}. This can be attributed to the fact that the SO_4^{2-} in the brick sample moved to the anode side during the energization and was fixed as $CuSO_4 \cdot 5H_2O$ on the copper plate of the anode, resulting in a decrease in SO_4^{2-} concentrations. Since $CuSO_4 \cdot 5H_2O$ was generated on the electrode as a product

of ED, the removal rate of SO_4^{2-} concentration in the brick sample was calculated using the weight change of the electrodes before and after energizing and the molecular weight of $CuSO_4 \cdot 5H_2O$. Results indicate that when sufficient water was supplied to the brick sample, approximately 64% of SO_4^{2-} in the brick sample was removed when the energization conditions were 5 V and 0.5 A. Moreover, 73% of SO_4^{2-} ions were removed when the energization conditions were 5 V, 1 A (Figure 9). When a current of 0.5 A was applied, the removal rate of SO_4^{2-} increased by approximately 5 times compared to the removal rate when there was no current. However, when the current increased to 1 A, which is twice as large as 0.5 A, the removal rate dropped to about 1.1 times, and no significant differences were observed. Consequently, it is possible that the removal rate increases significantly when the current is up to 0.5 A, but that the relationship between the removal rate and the current value is low when the current is higher than 0.5 A. Since the number of samples tested was small in this iteration, it is necessary to increase the number of tests in the future and discuss subsequently. Although these removal rates are lower than the results of previous studies, visual observations showed that salt precipitation and deterioration of the brick surface could be reduced even after a current was applied, suggesting that ED current conditions are effective in inhibiting deterioration caused by salt weathering. At the same time, this ED model is expected to be suitable for Japanese historical bricks, which have varied characteristics, because it is possible to adjust the amount of water supplied during the energization by using an easily removable powdered cellulose for the electrode, and desalination can be performed without damaging the brick surface. In addition, the continuous fixation of $CuSO_4 \cdot 5H_2O$ on the copper plate of the anode caused even the Arbocel installed on the electrode to turn blue, and the migration of SO_4^{2-} to the electrode during energization could be visually confirmed. This is one of the advantages of using copper plates as electrodes. However, under energizing conditions where the desalination effect was observed, the efficiency of desalination at the lower part of the brick sample was low, suggesting that the length of the electrode was insufficient for the brick sample. Moreover, even though the energizing conditions for B1 and B2 were the same, visual observation after energizing showed a slight precipitation of salt in B2. This indicates that the reproducibility of the test may be insufficient.

Visual observation of Tests 1 and 2 showed a black area forming in the brick samples after energization. The black area was observed using scanning electron microscopy (SEM). Objects that appear particles were observed, as shown in Figure 10. Moreover, Cu_2O (Cuprite) was detected with X-ray diffraction analysis of this area. According to Kawanishi, Cu_2O is formed in neutral aqueous solutions near room temperatures [20]. The pH of the area where the black part was formed was found to be 6.2, which is close to neutral. Additionally, it has been pointed out that metal elution occurs at the metal surface during the electrochemical process [21]. Therefore, it is possible that Cu^+ ions leached from the copper plate used as the electrode during the ED test and flowed into the brick sample.

For the reasons described above, it is possible that reaction (3) occurred. In other words, the black area, which was mainly composed of Cu_2O, may have formed in the neutral region in the process of copper ions eluting from the copper plate used as the electrode by energizing, flowing into the brick sample, and then moving to the cathode side.

$$Cu^+ + Cu^+ + O^{2-} \rightarrow Cu_2O \quad (3)$$

In addition, since the desalination efficiency was low from the black area to the anode side, it is necessary to review the conditions to prevent the formation of black areas or to improve the desalination efficiency, even if black areas are formed.

6. Conclusion

The main conclusions derived from this study are as follows.

- When powdered cellulose and copper plates, which are materials that are easy to obtain and handle, were used as electrodes, it was found that when sufficient water was supplied to the brick sample, approximately 64% of SO_4^{2-} ions in the brick sample were removed if the energization conditions were 5 V and 0.5 A and 73% of SO_4^{2-} was removed by energizing under the condition of 5 V, 1 A conditions. Visual observation confirmed that this removal rate is sufficient to prevent salt precipitation after energization. At the same time, this desalination method is expected to be suitable for Japanese historical bricks, which have varied characteristics, because it is possible to adjust the amount of water supplied during the energization by using an easily removable powdered cellulose for the electrode, and desalination can be performed without damaging the brick surface. However, the desalination efficiency of the lower part of the sample was lower than that of the upper part, so the length of the electrode needs to be reconsidered.
- By using copper plates as electrodes, the formation of copper sulfate on the anode and the change in color during energization could be observed. This would be to the advantage of being able to visually confirming the desalination effect during energization that they

are desalinated when this model is installed by non-professionals on site.

- On the other hand, it was found that the black parts consisting mainly of Cu_2O were formed after the 8-day energization. Since the efficiency of desalination from this film to the anode may be low, it is necessary to change the material of the electrode to prevent the formation of black areas, or to study the conditions to increase the efficiency of desalination even if black areas are formed.

In addition, at present, the reproducibility of the current-carrying conditions that are effective in desalination is insufficient, so it is necessary to increase the number of tests under the same conditions to improve the reproducibility. The remaining challenges and future prospects are to develop this method into a practical model that can be applied to actual wall installations and to discuss sustainable electricity supply methods.

The future implementation of this ED model is expected to reduce the progression of brick deterioration and it will help small municipalities and organizations that are trying to preserve and manage brick cultural properties under the situation of lack of personnel and limited budgets because intensive desalination of only those areas where salt weathering is observed will reduce the time and cost of conservation treatment.

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RISAKO FUKAMI has done her bachelor's degree (Archaeology) from University of Tsukuba in 2017. She has done her master's degree (World heritage studies) from University of Tsukuba in 2019.

Her main research theme is the conservation of Japanese brick cultural properties. She is working on the characterization of historical bricks using natural scientific methods and the development of methods for inhibition of salt weathering.

TOSHIYA MATSUI has done his bachelor's degree from Nara University of education in 1991. He has done his master's degree from Nara University of education in 1993. He has completed his PhD degree from Okayama University in 2020.

His research focuses on the conservation and restoration of cultural properties from the perspectives of materials science and environmental science. The development of technologies to protect cultural heritage exposed to various threats in outdoor heritage sites, buildings, movable cultural properties, museums, and archives, as well as actual repair, restoration, and conservation work, and proposals for monitoring systems are also the main topics of his research.

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Layer Based Firewall Application for Detection and Mitigation of Flooding Attack on SDN Network

Yubaraj Gautam [1], Kazuhiko Sato [1], Bishnu Prasad Gautam [2,*]

[1] Division of Information and Electronic Engineering, Muroran Institute of Technology, Muroran, 050-0071, Japan
[2] Department of Economic Informatics, Kanazawa Gakuen University, Kanazawa, 920-1392, Japan
*Corresponding author: Bishnu Prasad Gautam, Kanazawa Gakuen University, Kanazawa, 920-1392, Japan, gautam@kanazawa-gu.ac.jp

ABSTRACT: Software-Defined Networking (SDN) is an emerging Network technology that can augment the data plane with control plane by using programming technique. However, there are a numbers of security challenges which are required to address to achieve secured communication. Flooding attack is one of the most common threats on the internet for the last decades which is becoming the challenging issues in SDN networks too. To address these issues, we proposed a novel firewall application developed based on the multiple stages of packets filtering technique to provide flooding attack prevention system and layer-based packets detection system. In this research, we are using two main stages to detect the flooding attack and mitigate the flooding packets. The first stage is to identify the attacks and, the second stage is to identify the attacker's information and act them based on layer-based packet header entity. The system contains two security entities to identify the flooding attacks, one is by measuring the packet size, and the other is by counting the packets flow. We used the details of packets flow to control over the flow and to identify the attacks being occurred or not. Along with, to identify the attacker's information, we used layers (layer 2 to layer 4) based packet header entities by using multi-table architecture. The proposed solution was tested for different attack scenarios and successfully reduced the flow of volume-based bulk-size flooding attack and infinite packets flooding attack in SDN network.

KEYWORDS: Software Defined Network, Flooding Attack, Layer Based Security Architecture

1. Introduction

Traditional network refers to the network architecture based on old conventional way of networking which uses fixed and dedicated hardware devices to control the flow of network traffic. With the growth of the traffic or data in network, the network expansion takes place, and it may lead to inefficiencies in monitor or control over the network traffic. In order to meet the growing traffic demands, network expansion may require and much of the efforts go towards configuring switches and routers even for changes in a smaller segment of a local area network that may contain hundreds of nodes. Therefore, SDN network are desired that would control routing of flows in more efficient way. SDN separates the control plane from the data plane and single control plane can control all the network flows. There are different controllers available to use for the different purposes. Among them, widely used SDN controllers are Ryu, POX, ODL, and Floodlight etc. Specifically, the python-based Ryu controller is mostly used SDN controller for the research proposes [1]. Therefore, in this research we used the Ryu controller as an SDN controller.

In SDN network, the lack of efficient solution of packets flow control is the measure issue. To overcome those issues, we focused on the measurement of flow control based on counting the number of packets and their size. SDN has basically three layers which are infrastructure layer, control layer and application layer. Infrastructure layer contains the physical devices such as router, switch, hub etc. and control layer contains the controller which control all the network flows therefore, it is also called as brain of the SDN Network. And

application layer contains the applications to operate the whole SDN network through controller. There are different controllers available to use for the different purposes. Among them, widely used SDN controllers are Ryu, POX, ODL, and Floodlight etc. Specifically, the python-based Ryu controller is mostly used SDN controller for the security-based research proposes. Therefore, in this research we used the Ryu controller as an SDN controller for SDN security research.

2. Literature Review

SDN system is an emerging network system for the general user and the network administrator also. It has centralized controlling system, faster and programmable features, which were lacking in traditional network system. However, it has high chances to be attacked by the attacker in various ways also. Research paper in [2] presents the evidence for three sides of the security pyramid that SDN possesses in its architecture. One side of the security pyramid consists of the advancement and other two sides consist of inherited vulnerability and its consequences on information security [2]. To address these attacks, we focused on the weak information security on SDN network architecture. For example, the attacker could easily spoof new flows in the controller and would forward specific types of traffic that should be rejected across the network. To minimize such kind of attack, we have developed a prototype application that can handle different types of flooding attacks in SDN network. Layered based security approaches are taken in many previous researches. Gautam and Shrestha [3] have presented a model for cloud computing security which are proposed in a layer based architecture. The authors propose different solutions and security policies to promote a common level of understanding between the users, business communities, and necessary security requirements for the Jyaguchi (it is a cloud system in which daily activity of the users and services are mined by considering time factor to analyze behavior of users) application. In SDN network, the vulnerability of network traffic in data centers under various kinds of attacks researches [4], [5] and [6] provide us some detail of SYN flood and DNS attack monitoring and analysis of network traffic by using TCP dump and Wireshark using Ryu controller [7], [8]. The vulnerability of network traffic in the data center under various kinds of attacks like DoS/DDoS attack is the biggest issue in traditional network system. To minimize this, there were some experiments and analysis to reduce such kinds of attacks by highlighting the major security threats based upon SYN floods followed by currently faced real working scenario by giving an example for DNS attack. It is also a fact that many organizations have not adequately secured there DNS servers. If the network system is centralized, then the analysis of network traffic will be easier to do. Providing a security policy for such a network system is our research objective. Previously, we have done some experiments on SDN system by developing the SDN hub application into different manners and checked the quality of service (QoS) based on its bandwidth, latency, and packet loss [9], [10]. The limitation of this research was that we had not considered the security issues in the SDN control plane. In the research of [11], the authors proposed an SDN design with star topology. Here, authors have argued that by using SDN multi-controller, it is effective to secure the network environment which is the better architecture for preserving or holding time than other works in the literature. In the SDN network system, DoS and DDoS attacks are the major issues like traditional network. The article in [12] provides the solution of the defending system for attack where the number of packets could either be high or low. The article of the effect of input-output buffering to minimize flow control blocking [13], [14] analyzes the different input-output buffering strategies which affects the flow control blocking in a SDN system. The network architecture of the SDN based 5G network system [15] with a centralized security controller that communicates with the SDN controller has been conducted previously. Related to the IoT security, authors in [16] have analyzed IoT security requirements, challenges, and their countermeasures via software defined security. Furthermore, they have highlighted some future research directions of SDN based IoT security technologies. They have mentioned that an adaptive, novel and worthy IoT security system is required to tackle the current security landscape which should be proactive in nature providing baseline security to end users, network, applications, data and devices. To overcome such issues, proactive switches are one of the solutions as we have implemented in this research. There are few other relevant researches in the SDN system security [17], [18]. The authors are mentioning different applications for working at different layers to block unwanted packets. Research papers of [19]-[21] have provided us some DoS or DDoS attacked based firewall application with load balancing.

3. Proposed Solution

We realized that there are some research gaps in SDN security if we analyze it on the perspective of layer-wise security or quantity-based flooding attack. In this research, we focused on layer-based security and flooding

attack detection in the SDN (i.e. control plane) briefly to provide more protection by using multiple stages of filtering with multi table method. In order to address this issue, we have done some works in our previous researches [1], [22]. This is the continuity of our previous work in SDN to improve the security. Thus, we have found gap in the literature specifically in preventing flooding attacks based on bulk-size packets flooding and infinite packets flooding and, the flow control to provide SDN layer-base security. In this attack, an attacker can flood the unwanted packets to the network server to spoil the SDN network server. In such an attack, there is no satisfactory solution in SDN and conventional network systems.

Thus, in this research, we proposed an SDN network firewall application with having the features of layered based security architecture to detect the details of flows and flooding detection technique that can overcome the security issue of SDN network. We argue that by providing packet evaluation scheme based on security rules, security vulnerabilities of SDN network can be reduced sharply. Particularly, we would like to develop an application implemented by multiple filtering system to monitor the flow. We designed a firewall application applicable for the SDN control plane and conducted a number of experiments by flooding the packets. We defined specific rules and policies into the program by which the incoming packets are compared as per the firewall rules. If the flow matches with the defined rules, the packets will be allowed to flow to the targeted destination. Otherwise, firewall program declares those flows as a harmful flow and the system rejects them by minimizing the flooded packets and take actions to the attackers accordingly.

4. Research Methodology

In Figure 1, the system is categorized according to the SDN layers. The infrastructure layer represents the senders or receiver hosts and Open vSwitches It is the physical layer responsible for collecting the network statuses such as traffic statistic, network topology, network usage, etc. and send them to the control plane. Control plane is the mid-layer that connects the applications layer and infrastructure layer. This layer processes the instructions and requirements sent by the application layer and proceeds them to the network components. It also communicates back necessary information extracted from the networking devices to the application for it function optimally. There are already many controllers which were developed by different peoples for different purposes, but, for this research, we used Ryu controller as an SDN controller because, Ryu is mostly used controller for the research proposes.

4.1. Flow Table and Controller

To stablish the connection between infrastructure layer and control layer, we used OpenFlow protocol as a southbound API. We designed and developed a firewall application with multiple stages of filtering technique and applied this in SDN controller to filter the packets. By using this application, when Open vSwitch receives the packets from the source hosts, it will add the flow to the flow table on layer-based header entities and send the *PacketIn* message to the controller. The controller and switch perform three-way handshake by synchronizing the packets to stablish the connection between them. After

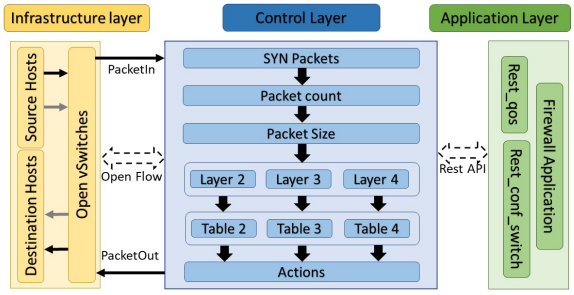

Figure 1: Overview of Firewall Application

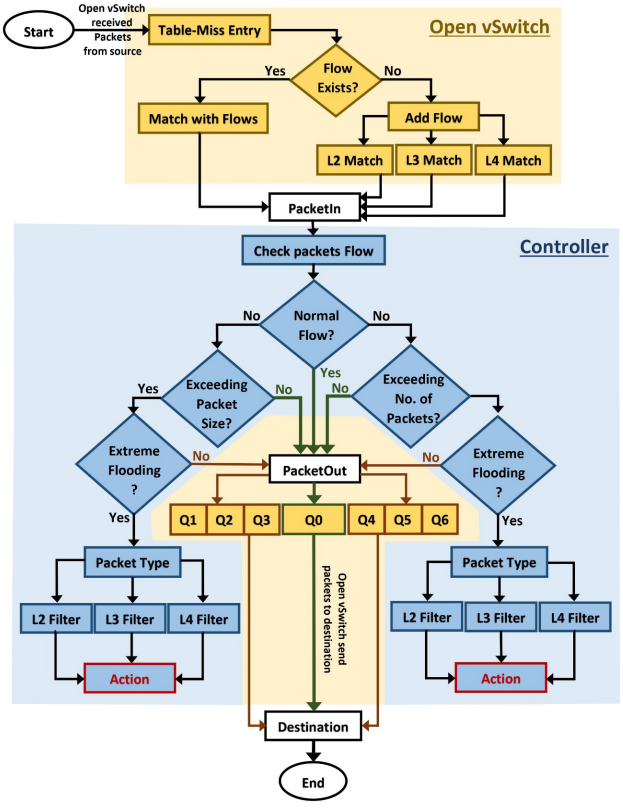

Figure 2: Packets Flow in Firewall Application

the completion of SYN process, the controller starts monitoring the packets based on packets size and total number of packets flow and send the *PacketOut* message to the destination if flows are normal. When system detects the flooding attack, it will minimize or drop those packets and take an action to the attackers based on their layer-based packets header entities. To perform these whole actions, we used three applications by running on the application layer. The rest API is used to stablish the connection between application layer and controller. *'Rest_qos'* and *'Rest_conf_switch'* is used to provide switch features to monitor the packets flow in Open vSwitch. And we used our developed *'Firewall Application'* to identify the flooding attacks and an act to the attackers accordingly.

4.2. Packets Flow Scenario

We designed a network scenario of packets flow as shown in Figure 2. When the source generates the traffic and send them to the destination, the traffic passes through different Open vSwitches (depends on mininet network architecture) and controller with being monitored by the system on different stages. Mainly, we categorized the flow of packets into two parts, one is the flow of traffic in Open vSwitch (OVS) and the other is traffic in controller. The OVS stores the details of flows on layer-based packets header entities when it receives the traffic from source, and when filtration completes, it forwards the selected traffic to the destination. And controller monitors the traffic flow to control over them based on their flow size.

4.3. Algorithm of Flow Control

We presented here the algorithm of packets flow in table 1 to detect the flooding attack and act to them based on their flooded types. Where, all the flows have divided into the four parts. The first stage of application adds the flows on flow table based on their packet's header entities to categorize the flow more specifically. Second stage of packets filtering measure the size of packets and act to them based on their size of packets by forwarding through different queues. Third stage of filtering counts the number of packets in every second and act them based on the defined rules on controller by sending the traffic through different queues. We can see in Figure 2 that the queues that counts the number of packets are Q4, Q5 and Q6. And fourth stage of filtering used to take an action to those packets flow which exceed the limits of numbers and size of packets as defined rules. In this stage, the flow

Algorithm: Flow of traffic on proposed firewall application to detect flooding attack

Results: Flooding attack detection and prevention by monitoring the flow of traffic
Initialization;
Check table-miss entry
Check flow table
First Stage: Add flow based on layer-based header
If *Flow exist* **Then**
  Match with existing flow;
Else
  Add new flows
If *Layer 2 packets* **Then**
  Add flow with layer 2 packets header entities;
Elif *Layer 3 packets*
  Add flow with layer 3 packets header;
Elif *Layer 4 packets*
  Add flow with layer 4 packets header;
PacketIn
Check packets flow
Second Stage: Measure size of flow
If *Size of packets flow is normal* **Then**
  PacketOut
Else
  If *Exceeding first stage of packets size filtering* **Then**
    Send packets to queue 1;
  If *Exceeding second stage of packets size filtering* **Then**
    Send packets to queue 2;
  If *Exceeding third stage of packet size filtering* **Then**
    Send packets to queue 3;
Third Stage: Count No.of packets flow
  If *Exceeding all the limits* **Then**
    Send packets to Filter table;
If *Flow of packets are normal* **Then**
  PacketOut
Else
  If *Exceeding first stage of packets count filtering* **Then**
    Send packets to queue 4;
  If *Exceeding second stage of packet count filtering* **Then**
    Send packets to queue 5;
  If *Exceeding third stage of packet count filtering* **Then**
    Send packets to queue 6;
Fourth Stage: Act based on packets header
  If *Exceeding all the limits* **Then**
    Send packets to Filter table;
Filter table data send to action table
If *Layer 2* **Then**
  Act based on layer 2 action rules;
Elif *Layer 3*
  Act based on layer 3 action rules;
Elif *Layer 4*
  Act based on layer 4 action rules;
End

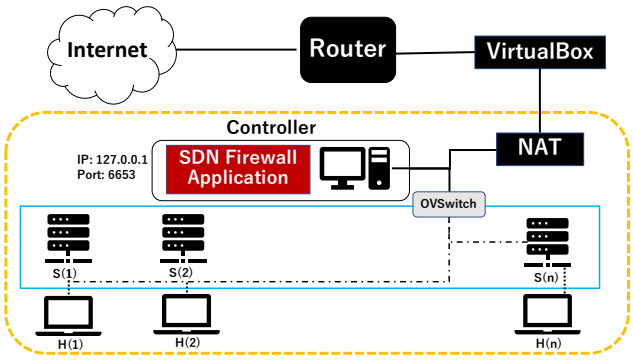

Figure 3: Lab Scenario

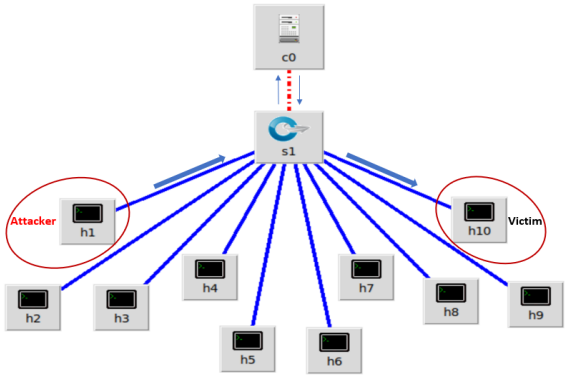

Figure 4: Single Topology with Multiple Hosts

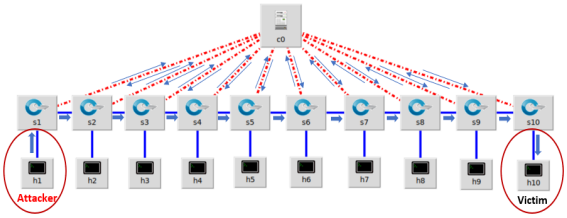

Figure 5: Linear Mininet Topology

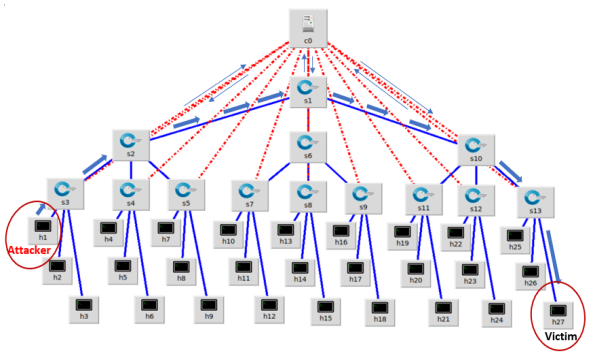

Figure 6: Tree Topology with Three Depth and Three Fanout

will be stopped by using layer-based packets header entities.

5. Experimental Scenario

5.1. Lab Setup

To conduct experiments, we created the laboratory as like Figure 3. We installed the virtual machine (Ubuntu 20.04) in the VirtualBox, and created the experimental scenario by installing mininet emulator on this machine.

5.2. Experimental Setup

5.2.1. Single Mininet Network

Figure 4 shows that the single mininet network topology which has single switch and multiple hosts connected to the OpenvSwitch. To create this network topology, we used one switch with ten mininet hosts (h1 to h10). All hosts are connected directly to the switch (s1) and the switch is connected with the Ryu controller remotely. In this network topology, h1 is used as an attacker and h10 is used as a victim machine. The flowing packets from attacker to the victim will flow through the switch s1.

5.2.2. Linear Mininet Network

To create linear mininet network topology, we used ten switches and ten hosts connected in a linear way as we can see in Figure 5. All switches are directly connected to the remote controller (c0) to get the instruction from controller. To conduct an experiment on linear mininet network topology, h1 is used as an attacker and h10 is used as a victim. When h1 sends packets to the victim, the packets pass through all the switches that exists in between source and destination. In our case, we used first host as sender and last host as the receiver, therefore the flooded packets will bypass all the existing switches in our designed system.

5.2.3. Tree Mininet network

To create tree mininet network topology, we used three depth and three fanout as we can see in Figure 6. We created Open vSwitch from s1 to s13 and hosts from h1 to h27. In tree topology of SDN network, three depth means that the switches have three layers with the same number

Table 1: Experimental Plans

Attacks	Packets Type	Tools	Total Time	Flows Type	Time Interval (seconds)
Bulk-Size Flooding	UDP	Iperf	90 to 95	1. Normal Flow 2. Flooded Flow	5
Packets Flood	ICMP	Hping3	90 to 95	1. Normal flow 2. Flooded flow	10

of fanouts. And, fanout means the number of children on each switch. In our tree network topology, s1 have three child switches (s2, s6 and s10) and further child switches have three more child switches, and all three child switches are connected with their parent switch. To conduct an experiment on this network topology, we used host s1 as an attacker host and s27 used as a victim host. As like the previous network scenarios, the flooded packets flow through the switches in between source and destination by identifying the best path to reach to the destination. In tree network topology, it forwards the packet flows to their parent switch by using the best path and reach to the targeted hosts.

5.3. Method of Data Collection

As shown in Figure 7 that *OFPFlowStatsRequest* are the flows between controller and switches. We accessed the size of packets flows by monitoring *OFPFlowStatsRequest* and saved as an CSV file in every 10 seconds. Similarly, to measure the flow of packets, we used the data of *OFPPortStatsReply*. We measured the flow of *PortStatsReply* that are directly connected to the attackers hosts and the victim hosts and compare with them to get the dropped packets. Moreover, we calculated the flow of increased packets and the packets that are permitted to enter the network as allowed packets.

To evaluate the system performance, mainly, we analyzed the flow of flooded packets and the flow of normal packets. We compared between those two different types of packets flows and evaluate the system based on how the controller takes an action to those individual packets flow. We used time series analysis to evaluate the system. Time series analysis is a statistical technique used to identify trends of flow over time. We used the sequence of data points which measure the same variable at different points in time.

5.4. Experimental Setup

As shown in table , we prepared two different kinds of attacks to collect the flow of data. One is by flooding the bulk-size packets to the victim and the other is by flooding the infinite packets. For Bulk-size flooding attack, we used UDP packets because we can set the size of UDP packets from low to the high range (8 to 65535 bytes). Specifically, to evaluate the packets flow, we sent two different types of flow. One is normal flow with smaller packets size, and another is flooded flow with higher packets size on same network architecture. Similarly, to evaluate the system performance with infinite packets flooding, we send normal traffic with less packets flow and flooded traffic with infinite packets in a

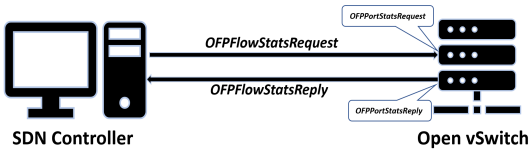

Figure 7: Figure of Packets Flow to Collect Data

Table 2: Simulation Scenario & Parameters Settings

Configuration	**Parameters**	
Mininet	Network Topologies 1. Single topology Topo=single, Hosts=10, IP=127.0.0.1, Port=6633 2. Linear topology Topo=linear, Hosts=10, IP=127.0.0.1, Port=6633 3. Tree topology Topo=tree, depth=3, fanout=3, IP=127.0.0.1, Port=6633	
Implemented Firewall Application	Queues (Q): Q0 = Normal Flow Q1 = Max Rate 9000000, Q2 = Max Rate 7000000, Q3 = Max Rate 5000000 Q4 = Max Rate 500000, Q5 = Max Rate 400000, Q6 = Max Rate 300000 If Byte count < 60000000 or Packets count < 200000 (Q0 active)	
	Bulk-size Flooding	Packets Flooding
	If Byte count > 6000000 (Q1 active) If Byte count > 7000000 (Q2 active) If Byte count > 8000000 (Q3 active) If Byte count > 9000000 (Drop all)	If Packet count > 200000 (Q4 active) If Packet count > 300000 (Q5 active) If Packet count > 400000 (Q6 active) If Packet count > 500000 (Drop all)
Experiments	Tool: Iperf Measured Time: 90 to 95 sec	Tool: hping3 Measured Time: 90 to 95 sec

second and evaluate the execution of SDN controller to those different packets flow. We collected the data of bulk-size flooding on every 5 seconds and 10 seconds to monitor the data of infinite packets flooding.

5.5. Simulation Scenario and Parameter Settings

To evaluate our application, we used the simulation parameters as shown in Table 2. We configured the Mininet emulator by using 3 types of topologies (i.e., Single, Linear and Tree). These topologies satisfy our experimental requirements of simple to complex networks thus we did not apply other network topologies such as star and mesh. Similarly, the parameters of firewall application are given such that the normal packets flow through Q0 when the size of packets flow is less than 6000000 bytes. When the size of packets crosses 6000000 bytes continuously, the system considers it as the flooded flow and forwards these flows to the different queues (Q1, Q2 and Q3) depending on their flooded packets size. Similarly, to detect the packets flooding, the rules have defined in the controller that if the total number of packets crosses the 200000, the system will recognize it as a flooded flow and forward the flows to the different queues (Q4, Q5 and Q6) based on their total number of packets as show in table 2. Moreover, we used *iperf* and *hping3* to generate the flow of packets and monitor them up to 90/95 seconds to evaluate the system performance.

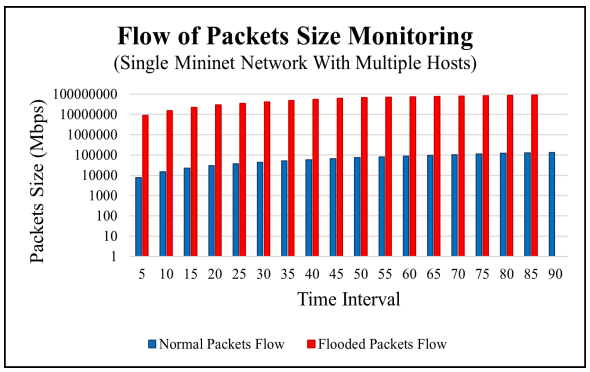

Figure 8: Packets Size Monitoring in Single Topology

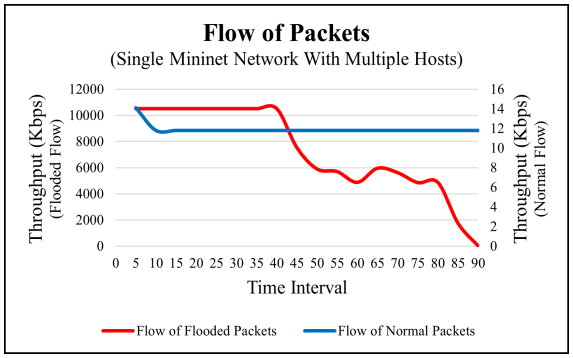

Figure 9: Flow of Packets in Single topology

Table 3: Packets Size Detection in Single Topology

		Normal Flow		Flooded Flow	
Number of Flows	**Time Interval**	**Packets_Size**	**Throughput (kbits/s)**	**Packets_Size**	**Throughput (kbits/s)**
1	5	7560	14.1	8799840	10500
2	10	15120	11.8	15563016	10500
3	15	22680	11.8	22326192	10500
4	20	30240	11.8	29098440	10500
5	25	36288	11.8	35194824	10500
6	30	43848	11.8	41953464	10500
7	35	51408	11.8	48719664	10500
8	40	58968	11.8	55488888	10500
9	45	66528	11.8	62242992	7520
10	50	74088	11.8	66348072	5890
11	55	81648	11.8	70214256	5690
12	60	89208	11.8	73859688	4870
13	65	96768	11.8	77001624	5950
14	70	104328	11.8	80988768	5610
15	75	111888	11.8	84333312	4850
16	80	119448	11.8	87461640	4860
17	85	127008	11.8	90588456	1740
18	90	134568	11.8	0	0

6. Experiments and results

The designed network scenarios are shown in figures 3-6 which have the several number of virtual hosts and switches to monitor the different packet flows. We set up three different network scenarios (i.e., figure 4, 5 and 6) to analyze the SDN network packets flow. To investigate the performance of firewall application, we used four different types of packet flows in each network scenario. Among them, one is bulk-size packets flooding with the flow rate of 10Mbps and compare with the normal packets flow with the flow rate of 1Kbps. The other is by flooding the infinite packets in a second with ten thousand packets in a second and compare with the less packets flow. We sent ten packets in a second as a normal flow from source to destination.

6.1. Experiment 1: bulk-size flooding on Single mininet network

To conduct this experiment, we collected the total of 18 flows in every 5 seconds time interval. In normal flow, the throughput of the packet's flows was constant but in flooded flow, the throughput of the packets flow was constantly decreasing as the flow of packets size goes increases as we can see in Table 3.

Figure 8 shows the flow of packets with their flow size and Figure 9 shows the flow of packets based on their throughput. In Figure 9, we can see that only the flow of flooded packets gets decreasing, whereas flow of normal packets remained constant.

6.2. Experiment 2: Infinite packets flooding on single mininet network

To conduct this experiment, we used the same network architecture as of experiment 1 with single

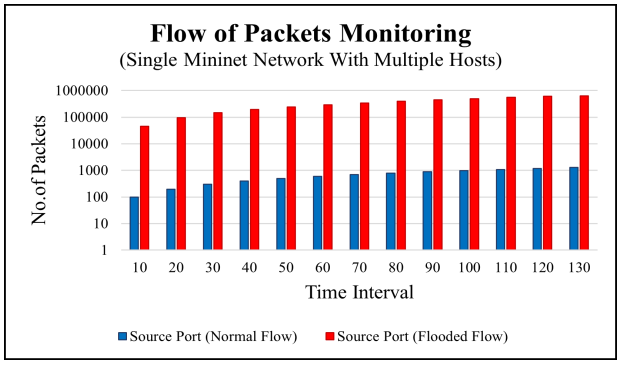

Figure 10: Packets Size Monitoring in Single Topology

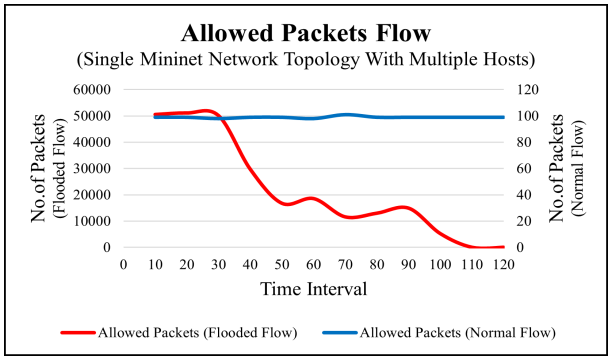

Figure 11: Flow of Packets in Single Topology

Table 4: Packets Flooding in Single Mininet Topology

		Normal Flow					Flooded Flow				
Flows	Time Interval	Sender	Receiver	Dropped	Per Flow	Allowed Packets	Sender	Receiver	Dropped	Per Flow	Allowed Packets
1	10	99	99	0	99	99	46209	46208	1	50581	50582
2	20	198	198	0	99	99	96790	96790	0	51158	51158
3	30	297	297	0	98	98	147948	147948	0	50129	50129
4	40	395	395	0	99	99	198077	198077	0	45616	29756
5	50	494	494	0	99	99	243693	227833	15860	50539	16756
6	60	593	593	0	98	98	294232	244589	49643	48618	18554
7	70	691	691	0	101	101	342850	263143	79707	53513	11582
8	80	792	792	0	99	99	396363	274725	121638	52977	12984
9	90	891	891	0	99	99	449340	287709	161631	52019	14910
10	100	990	990	0	99	99	501359	302619	198740	55931	5220
11	110	1089	1089	0	99	99	557290	307839	249451	59402	1
12	120	1188	1188	0	99	99	616692	307840	308852	21636	0
13	130	1287	1287	0			638328	307840	330488		

switch and ten hosts. We flooded ten thousand packets in a second to get the flooded flow and ten packets in a second to get the normal traffic flow and then analyzed the response of firewall application over the different types of flows. We compared with those different flows and got the following results as shown in Table 4.

We collected the data of normal flow and flooded flow by using *OFPflOFPFlowStats* provided by Ryu controller API. We collected the data of 13 flow in every 10 seconds time interval. In normal flows, there are 0 dropped packets because the controller recognize that all the packets sent by source hosts are under the defined policy therefore, controller considers all the packets as a normal flow and forwards those packets to the destination. But on the other hand, in flooded flow, the controller detects that the incoming packets are exceeding the controller's limits and recognizes as a flooding attack. As a result, the controller controls over those flooded packets by dropping them. To visualize the flow of packets, we prepared two graphs. Figure 10 is the graph of packets flow before going through our firewall application located in controller whereas Figure 11 is the graph of allowed packet flow after tested through our firewall rules targeted to the destination. The flow of normal packets is flowing constantly without any packets loss but if we observe the flow of flooded packets, we can see that the flow of allowed packets constantly decreasing and end up with 0 allowed packets. This shows the effectiveness of our firewall application.

6.3. Experiment 3: Bulk-size flooding on linear network

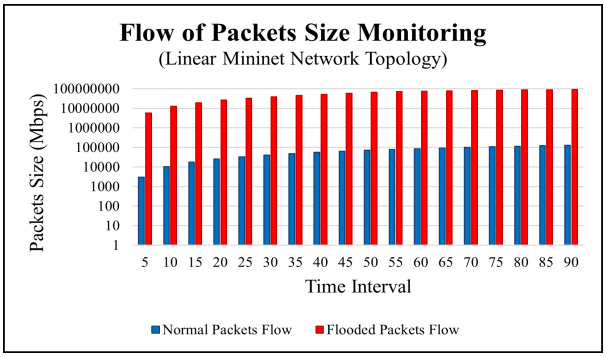

Figure 12: Packet's Size Monitoring in Linear Topology

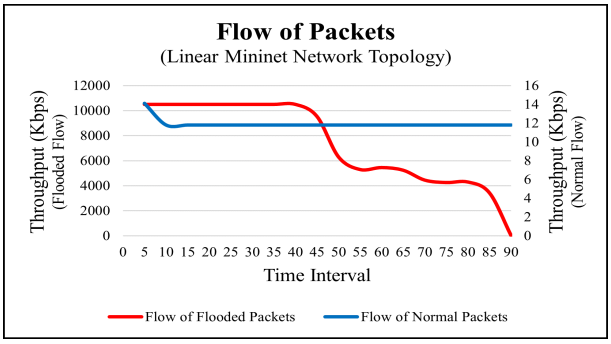

Figure 13: Flow of Packets in Linear Topology

Table 5: Packets Size Detection in Linear Topology

		Normal Flow		Flooded Flow	
Number of Flows	**Time Interval**	**Packets Size**	**Throughput (kbits/s)**	**packets Size**	**Throughput (kbits/s)**
1	5	3024	14.1	5821200	10500
2	10	10584	11.8	12593448	10500
3	15	18144	11.8	19361160	10500
4	20	25704	11.8	26124336	10500
5	25	33264	11.8	32210136	10500
6	30	40824	11.8	38976336	10500
7	35	48384	11.8	45733464	10500
8	40	55944	11.8	52489080	10500
9	45	63504	11.8	59253768	9530
10	50	71064	11.8	66016944	6290
11	55	78624	11.8	70409304	5290
12	60	86184	11.8	73994256	5450
13	65	93744	11.8	77440104	5230
14	70	101304	11.8	80876880	4440
15	75	108864	11.8	83876688	4250
16	80	116424	11.8	86660280	4290
17	85	123984	11.8	89445384	3410
18	90	131544	11.8	92157912	0

To conduct this experiment, we took h1 as a source and h10 as a destination host. H1 is directly connected to the switch s1 and h10 is directly connected to switch s10 as shown in Figure 5. To collect the data, we monitored the flow of packets passed by the controller and collect the size of flows in every five seconds time interval. We monitored the total of 18 flows and collected the data of normal and flooded flow as shown in Table 5. We monitored the flows up to 90 seconds and analyzed them based on throughput. We monitored the flow size of normal packets and flooded packets as shown in Table 5. To differentiate between normal and flooded packets, we graphed the flow of packets size before implementing the filtering system and packets flow after the packet's filtration. Figure 12shows the flow of packets size monitored by the controller and Figure 13 shows the packets flow with their flow's throughput.

6.4. Experiment 4: Infinite packets flooding on linear topology

To conduct this experiment, we used the network architecture of linear topology. To generate the traffic, we used h1 as an attacker and h10 as a victim host. We evaluated the system by collecting all the flowing data based on the controller's response to the traffic flows. To collect the data, we monitored both ingress and egress ports of source and destination. Based on those two different flows, we collected the data of dropped packets, and allowed packets etc.

After the experiments, we got the following data as we can see in table 6. In normal flow, there are no dropped packets, because all the packets sent by the source reached to the destination with no issues. But, as we can see in flooded flow, it has the dropped packets right from the beginning. The allowed packets are getting lower and lower as the flooded packets getting bigger. Eventually, controller dropped the flooded packets completely. In Table 6 this is indicated with 0 packets. Figure 14 shows

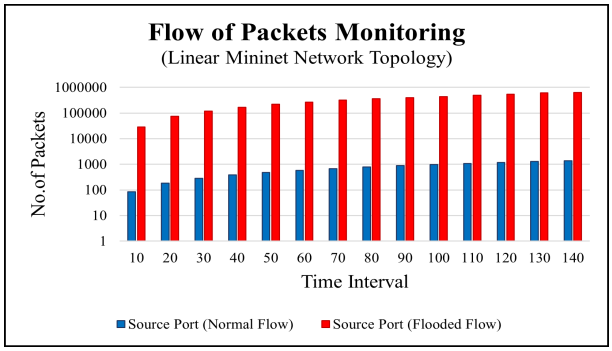

Figure 14: Packets Flow in Linear Topology

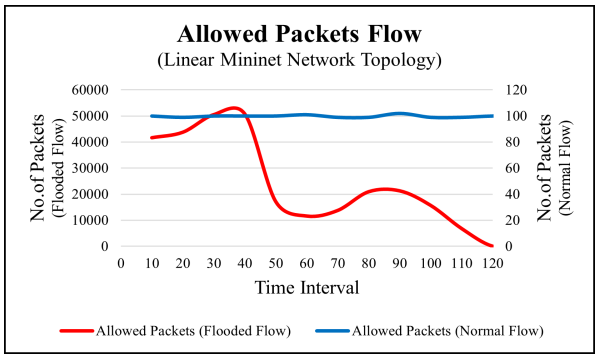

Figure 15: Allowed Packets Flow in Linear Topology

Table 6: Packets Flow in Linear Topology

		Normal Flow					Flooded Flow				
Flows	Time Interval	Sender	Receiver	Dropped	Per Flow	Allowed	Sender	Receiver	Dropped	Per Flow	Allowed
1	10	84	84	0	100	100	28371	28244	127	45215	41642
2	20	184	184	0	99	99	73586	69886	3700	43767	43764
3	30	283	283	0	100	100	117353	113650	3703	50515	50519
4	40	383	383	0	100	100	167868	164169	3699	50763	50760
5	50	483	483	0	100	100	218631	214929	3702	45523	17107
6	60	583	583	0	101	101	264154	232036	32118	52938	11589
7	70	684	684	0	99	99	317092	243625	73467	49801	13737
8	80	783	783	0	99	99	366893	257362	109531	32628	20930
9	90	882	882	0	102	102	399521	278292	121229	41537	21261
10	100	984	984	0	99	99	441058	299553	141505	47997	15673
11	110	1083	1083	0	99	99	489055	315226	173829	54705	6782
12	120	1182	1182	0	100	100	543760	322008	221752	60909	1
13	130	1282	1282	0	100	100	604669	322009	282660	20706	0
14	140	1382	1382	0			625375	322009	303366		

the flow of packets before the filtration and Figure 15 shows the allowed packets flow passes by the controller. As we can see in Figure 15 that allowed packet of normal flow remain constant in every time interval. But flooded flows have the dropped packets therefore, the allowed packets decreased and end up with 0 at the end.

6.5. Experiment 5: Bulk-size packets flooding on tree topology

To conduct the experiment on this network topology, h1 is used as source host and h27 is used as a destination host as shown in figure 6. In this topology, we got the total of 19 flows in 95 seconds. As like earlier experiments, normal packets have the constant flows with stable throughput whereas the flooded flow was decreasing constantly in their throughput as time went by. The Figure 16 and Figure 17 shows the flow of packets and the number of allowed packets respectively, and table 7 shows the details of collected data.

6.6. Experiment 6: Infinite packets flooding on tree topology

This is our last experiment to evaluate the performance of firewall application. To conduct this experiment, we sent 10 thousand packets per second as a flooded packet and 10 packets per second as a normal flow as like earlier experiments. The details of packets are shown in table 8. In normal flow, all packets sent by the source are delivered perfectly to the destination with 0

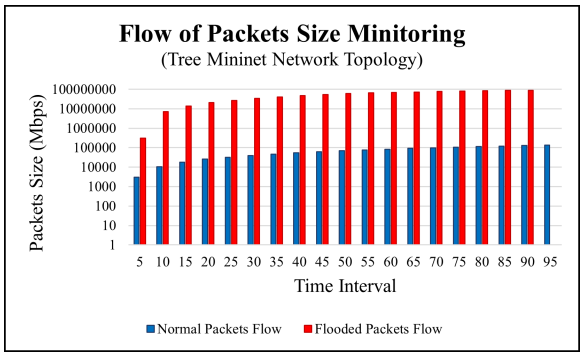

Figure 16: Packet's Size Monitoring in Tree Topology

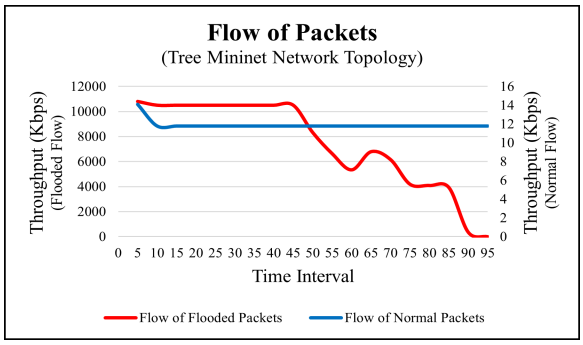

Figure 17: Packets Flow in Tree Topology

Table 7: Packets Size Detection in Tree Topology

		Normal Flow		Flooded Flow	
Number of Flows	**Time Interval**	**Packets_Size**	**Throughput (kbits/s)**	**Packets_Size**	**Throughput (kbits/s)**
1	5	3024	14.1	317520	10800
2	10	10584	11.8	7080696	10500
3	15	18144	11.8	13852944	10500
4	20	25704	11.8	20623680	10500
5	25	31752	11.8	27392904	10500
6	30	39312	11.8	34156080	10500
7	35	46872	11.8	40916232	10500
8	40	54432	11.8	47027736	10500
9	45	61992	11.8	53822664	10500
10	50	69552	11.8	60584328	8320
11	55	77112	11.8	66101616	6630
12	60	84672	11.8	70401744	5340
13	65	92232	11.8	73844568	6790
14	70	99792	11.8	78179472	6160
15	75	107352	11.8	82175688	4190
16	80	114912	11.8	84968352	4090
17	85	122472	11.8	87609816	3930
18	90	130032	11.8	90107640	348
19	95	137592	11.8	0	0

packet loss. On the other hand, the flooded flow has dropped packets because, the controller is controlling over the flooded packets by dropping them based on the defined policy in controller. As a result, in flooded flow, the total number of packets per flow and allowed packets by the controller has differences. In Figure 18, we monitor the flow of packets before reaching to the controller and collect the data in every 10 seconds. Vertical-axis represents the number of packets and horizontal-axis represents the time interval in both Figures. In Figure 19, we can see that the flow of allowed packets getting reduced in flooded flow and flow of normal packets remained constant over all the period of time.

7. Conclusions and Future Works

In this study, we proposed a new security firewall application that can be deployed in an SDN. Our application was designed based on layer-based security filtering techniques to monitor the attackers and strengthen the network-wide security in an SDN. We presented security solutions based on measuring the flow of packets and their size and managed them based on different rule-based filtering tables, and briefly described the rules associated with the security solution. The defined rules control the limits of packets flow and flow size based on the system need. We have conducted two major experiments on four different network scenarios by flooding UDP and ICMP packets as a network flow. To analyze the performance of firewall application, we analyzed the flow pattern of normal packets flow and flooded packets flow. To evaluate the system, we monitored packets flow and packets drop ratio while reaching to the targeted destination. As a result, the controller detected the flow of packets based on layer-based packets headers entities and filtered those packets flow by counting the flow of packets and their flow size.

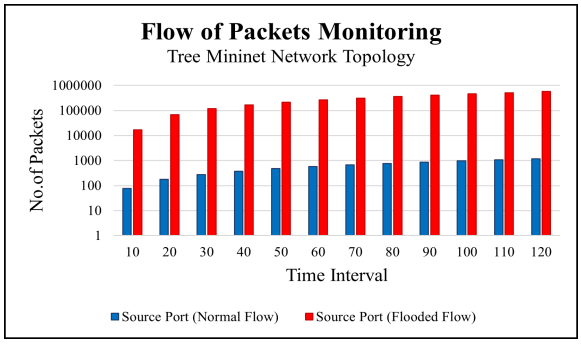

Figure 18: Packets Flow in Tree Topology

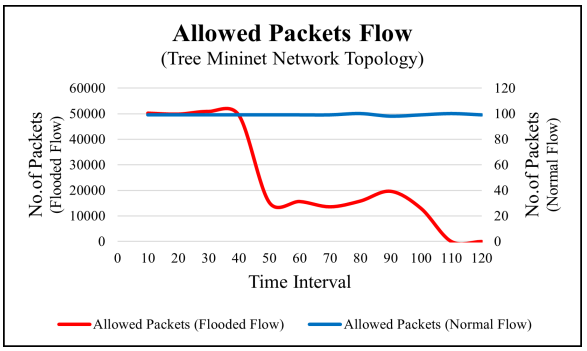

Figure 19: Allowed Packets Flow in Tree Topology

Table 8: Packets Flow in Tree Topology

		Normal Flow					Flooded Flow				
Flows	Time Interval	Sender	Receiver	Dropped	Per Flow	Allowed	Sender	Receiver	Dropped	Per Flow	Allowed
1	10	78	78	0	99	99	17023	17023	0	50215	50211
2	20	177	177	0	99	99	67238	67234	4	49827	49831
3	30	276	276	0	99	99	117065	117065	0	50882	50878
4	40	375	375	0	99	99	167947	167943	4	49392	49396
5	50	474	474	0	99	99	217339	217339	0	49608	15305
6	60	573	573	0	99	99	266947	232644	34303	48269	15655
7	70	672	672	0	99	99	315216	248299	66917	52365	13580
8	80	771	771	0	100	100	367581	261879	105702	46520	15819
9	90	871	871	0	98	98	414101	277698	136403	48565	19644
10	100	969	969	0	99	99	462666	297342	165324	51482	12981
11	110	1068	1068	0	100	100	514148	310323	203825	60450	9
12	120	1168	1168	0	99	99	574598	310332	264266	60457	0
13	130	1267	1267	0			635055	310332	324723		

Finally, we concluded that the proposed firewall application is successful to minimize the bulk-size packets flooding and infinite packets flooding.

The limitation of current implementation is that it used single controller as a master controller which has all of authorities to control over the network. It might have issues of controller failure or other security issues which would destroy whole SDN network. Therefore, in our future work, we will apply the redundant controller to address this issue with high performance computing resources. The technique of load balancing would be crucial in such kind of experiments; however, this task is remained for our future works.

Conflict of Interest

The authors declare no conflict of interest.

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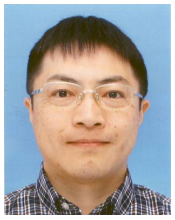
Yubaraj Gautam has done his bachelor's degree from Wakkanai Hokusei Gakuen University in 2020. He is currently doing his master's degree from Muroran Institute of Technology. His research interest includes Network management and security.



Kazuhiko Sato has done his bachelor's degree from University of Aizu in 1997. He has done his master's degree from Graduate School of University of AIZU in 1999. He has completed his Ph.D. in Computer Science degree from Graduate School of University of AIZU in 2002. He is currently working as Professor (Associate) in Muroran Institute of Technology since 2015. He is actively engaged in various research societies of Japan such as IEICE, IPSJ and JSAI. He has published more

than 35 research articles in International Journals and reputed International Conferences.

Bishnu Prasad Gautam received his bachelor degree from Wakkanai Hokusei Gakuen University, Japan. He has done his master's and Ph.D. in Computer Engineering from Shinshu University. He has published over 45 papers in international journals and reputed international conferences. He has been invited as a key speaker in several International Workshop, Conferences and Universities. He is currently working as Professor (Full) at Kanazawa Gakuin University, and he is a member of IEEE, IPSJ and IAENG. His current research interest includes Sustainable Computing, Network Architecture, Network Security, and IoT.

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Loaded by RL-Branch EMC Filter on the Output of the Inverter Transfer Function Taking into Account Resistances and Electric Transformer's Transfer Function Derivation

Pustovetov Mikhail *

Department of Engineering Technology Technological Institute (Branch) of Don State Technical University in the City of Azov, 346780, Russia
*Corresponding author: Pustovetov Mikhail, Contact: No+79885651027, Email: mgsn2006@yandex.ru

ABSTRACT: The derivation of the transfer function of the output filter of the electromagnetic compatibility of the inverter, loaded by RL-branch, proposed, which differs by taking into account the presence of resistances in the longitudinal and transverse branches of the L-shaped filter. The form of recording the voltage transfer function of an electrical transformer loaded by RL branch presented. A method for deriving the transfer function from the equations of the mathematical model of a single-phase two-winding transformer proposed. The transfer function derivation has made on T-shaped equivalent circuit of transformer basis, and takes into account the presence of resistance in the transformer windings, the winding connection group. To author's opinion, results can be useful in the design of control systems and their mathematical models for electrical complexes, which include a sine-wave filter or a dv/dt filter and transformer.

KEYWORDS: Sine-wave filter, dv/dt filter, Transfer function, Active-inductive load, Transformer, Simulation

1. Introduction

A sine-wave filter (SF) is one of the common options for the output filter of the electromagnetic compatibility (EMC) of an inverter with pulse-width modulation of voltage [1-4]. The SF performs the maximum approximation of the form of the output voltage of the inverter to a sinusoid, minimizing the value of the THDu, %. The task of the dv/dt filters is to reduce the rate of change of the pulsed voltage (smoothing, collapse of the pulse fronts) often to a level of less than 500 V/μs. In this case, the shape of the voltage on the load remains pulsed.

Electrical transformers [5-8] are very common and important elements in electrical systems and complexes, power management, automation. Even more common devices than EMC filters. An effective research tool in these areas is mathematical modeling, which requires the representation of data about an object in special formats. For example, to select the type of controller in an automatic control system, it is necessary to know the transfer function of the regulated object. The latter may include a transformer. Therefore, it is advisable to know the transfer function of the transformer.

The author could not find a record of transfer functions in the form of interest to him in publications, so he decided to derive them on his own.

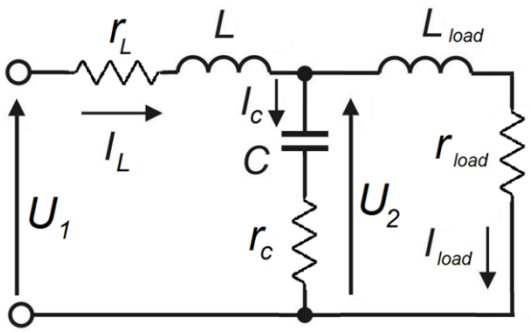

Figure 1: Schematic diagram of the L-shaped filter

2. Schematic Diagram of the L-Shaped Filter

Each phase of an SF or dv/dt filter is an L-shaped filter with inductance L in the longitudinal branch and capacitance C in the transverse (see Figure 1). Strictly

speaking, one should take into account the presence of the resistance of the inductive reactor in the longitudinal branch, including the resistance r_L in series with L. In the transverse branch, in series with C, in some cases, a damping resistor r_C is included. When used in an AC variable frequency drive, the SF or dv/dt filter is loaded on an active-inductive load, which can be represented by a series connection r_{load} and L_{load}.

3. L-Shaped Filter's Transfer Function Derivation

To build control systems for electrical complexes containing an SF or dv/dt filter, you need to know the transfer function (TF) of the latter. Let us write down in the Laplace s-domain form the equations of the electrical circuit shown in the Fig. 1, using Kirchhoff's laws.

$$i_L(s) = i_C(s) + i_{load}(s); \quad (1)$$

$$u_2(s) = i_C(s)\left(\frac{1}{C \cdot s} + r_C\right); \quad (2)$$

$$u_2(s) = i_{load}(s)\left(L_{load} \cdot s + r_{load}\right); \quad (3)$$

$$i_L(s) = \frac{u_1(s) - u_2(s)}{L \cdot s + r_L}. \quad (4)$$

Express $i_C(s)$ from equation (2):

$$i_C(s) = \frac{u_2(s)}{\frac{1}{C \cdot s} + r_C}. \quad (5)$$

Taking into account equation (5), we express from equation (1) $i_L(s)$, and from equation (3) we express $i_{load}(s)$:

$$i_L(s) = \frac{u_2(s)}{\frac{1}{C \cdot s} + r_C} + i_{load}(s); \quad (6)$$

$$i_{load}(s) = \frac{u_2(s)}{L_{load} \cdot s + r_{load}}. \quad (7)$$

Substituting equation (7) into (6), we obtain

$$i_L(s) = \frac{u_2(s)}{\frac{1}{C \cdot s} + r_C} + \frac{u_2(s)}{L_{load} \cdot s + r_{load}} = \\ = u_2(s)\left(\frac{1}{\frac{1}{C \cdot s} + r_C} + \frac{1}{L_{load} \cdot s + r_{load}}\right). \quad (8)$$

Let us equate the right parts of expressions (8) and (4), group the factors at the input and output voltages.

$$u_2(s)\left(\frac{1}{\frac{1}{C \cdot s} + r_C} + \frac{1}{L_{load} \cdot s + r_{load}} + \frac{1}{L \cdot s + r_L}\right) = \\ = u_1(s)\frac{1}{L \cdot s + r_L}. \quad (9)$$

Then we can write the filter's TF by voltage as

$$H(s) = \frac{u_2(s)}{u_1(s)} = \\ = \frac{1}{\left(L \cdot s + r_L\right)\left[\frac{1}{\frac{1}{C \cdot s} + r_C} + \frac{1}{L_{load} \cdot s + r_{load}}\right] + 1}. \quad (10)$$

If we check, assuming $r_C = r_L = L_{load} = 0$ as in [9], then expression (10) will turn into the well-known equality (such a check can be performed at any stage of the transformation of the filter's TF):

$$H(s) = \frac{1}{s^2 \cdot L \cdot C + \frac{L}{r_{load}} \cdot s + 1}. \quad (11)$$

Continuing the transformation of expression (10), we obtain a record of the TF, in which the parameters of the branches of the electrical circuit grouped in such a way that they can be denoted as time constants and resonant frequency:

$$H(s)=\frac{r_C C\frac{L_{load}}{r_{load}}\cdot s^2+\left(\frac{L_{load}}{r_{load}}+r_C C\right)\cdot s+1}{LC\frac{L_{load}}{r_{load}}\cdot s^3+}$$

$$+C\left[L\left(1+\frac{r_C}{r_{load}}\right)+\frac{L_{load}}{r_{load}}\left(r_L+r_C\right)\right]\cdot s^2+$$

$$+\left\{\frac{L}{r_{load}}+\frac{L_{load}}{r_{load}}+C\left[r_L\left(1+\frac{r_C}{r_{load}}\right)+r_C\right]\right\}\cdot s+$$

$$+\frac{r_L}{r_{load}}+1=$$

$$=\frac{T_C\cdot T_{load}\cdot s^2+\left(T_C+T_{load}\right)\cdot s+1}{\frac{T_{load}}{\omega_0^2}\cdot s^3+\left[\frac{1}{\omega_0^2}\left(1+\frac{r_C}{r_{load}}\right)+T_{load}\left(T_C+r_L C\right)\right]\cdot s^2+} \quad (12)$$

$$+\left\{\frac{L}{r_{load}}+T_{load}+r_L C+T_C\left(\frac{r_L}{r_{load}}+1\right)\right\}\cdot s+\left(\frac{r_L}{r_{load}}+1\right)$$

If we accept $r_C=r_L=0$, and $L_{load}\neq 0$, then expression (12) can be transformed in this particular case to the form

$$H(s)=\frac{\frac{L_{load}}{r_{load}}\cdot s+1}{L\cdot C\cdot\frac{L_{load}}{r_{load}}\cdot s^3+C\cdot L\cdot s^2+}$$

$$+\frac{L+L_{load}}{r_{load}}\cdot s+1= \quad . \quad (13)$$

$$=\frac{T_{load}\cdot s+1}{\frac{T_{load}}{\omega_0^2}\cdot s^3+\frac{s^2}{\omega_0^2}+\left(\frac{L}{r_{load}}+T_{load}\right)\cdot s+1}$$

In some cases, the value of r_L at $r_C\neq 0$ and $L_{load}\neq 0$ can be neglected, then expression (12) will take the form

$$H(s)=\frac{}{\frac{T_{load}}{\omega_0^2}\cdot s^3+}$$

$$\frac{T_C\cdot T_{load}\cdot s^2+\left(T_C+T_{load}\right)\cdot s+1}{+\left(\frac{1}{\omega_0^2}+\frac{L}{r_{load}}T_C+T_C\cdot T_{load}\right)\cdot s^2+} \quad . \quad (14)$$

$$+\left(\frac{L}{r_{load}}+T_C+T_{load}\right)\cdot s+1$$

4. Transformer's Transfer Function Derivation

For the synthesis of transformer's TF, we take as a basis the equations of the mathematical model of a single-phase two-winding transformer [8], assuming that the conclusions obtained will be valid for each phase of multi-phase transformers.

$$\begin{cases} v_1-r_1 i_1-L_{\sigma 1}\frac{di_1}{dt}=v_{01} \\ e_2-r_2 i_2=v_2 \end{cases}, \quad (15)$$

where:

$$e_1=-\left(v_{01}+L_{\sigma 1}\frac{di_1}{dt}\right); \quad (16)$$

$$e_2=\mp\left(\frac{w_2}{w_1}v_{01}+L_{\sigma 2}\frac{di_2}{dt}\right). \quad (17)$$

EMF of the magnetizing branch of the primary winding v_{01}:

$$v_{01}=L_m\left(\frac{di_1}{dt}+\frac{w_2}{w_1}\cdot\frac{di_2}{dt}\right)+$$

$$+r_m\left(i_1+\frac{w_2}{w_1}\cdot i_2\right)=L_m\frac{di_\mu}{dt}+r_m i_\mu \quad . \quad (18)$$

On the right side of equation (17), for the I/I-0 connection group, select the "+" sign (consonant connection of inductances), and for I/I-6, the "–" sign (opposite connection). In expressions (16) - (18) the following designations are accepted: v and e - voltage and EMF, V; i – current, A; L_σ and L_m – leakage inductance of the winding and total inductance of the primary winding from the main magnetic flux, H; r and r_m - resistances of the winding and of the iron losses, Ohm; w is the number of winding turns. Indices 1 indicate belonging to the primary winding of the transformer, and indices 2 - to the secondary one; the μ index at current means belonging to the magnetization

branch of the T-shaped equivalent circuit (expression (18) is written for the case of r_m and L_m series connection). For the smallness of the active component of the magnetizing current of the transformer, we will take the assumption $r_m = 0$ for further transformations.

Let us rewrite system (15) taking into account (17) and (18) equations for the clock-notation group I/I-0:

$$\begin{cases} v_1 - r_1 i_1 - L_{\sigma 1}\dfrac{di_1}{dt} = \\ L_m\left(\dfrac{di_1}{dt} + \dfrac{w_2}{w_1}\cdot\dfrac{di_2}{dt}\right); \\ \left(\dfrac{w_2}{w_1}L_m\left(\dfrac{di_1}{dt} + \dfrac{w_2}{w_1}\cdot\dfrac{di_2}{dt}\right) + L_{\sigma 2}\dfrac{di_2}{dt}\right) - \\ -r_2 i_2 = v_2 \end{cases}, \quad (19)$$

To shorten the notation, we introduce the following designations:

$$L_1 = L_m + L_{\sigma 1}; \quad (20)$$

$$L_2 = \frac{w_2^2}{w_1^2}\cdot L_m + L_{\sigma 2}. \quad (21)$$

Using (20) and (21) equations, we rewrite equation (19):

$$\begin{cases} v_1 = r_1 i_1 + L_1\dfrac{di_1}{dt} + \dfrac{w_2}{w_1}\cdot L_m\dfrac{di_2}{dt} \\ 0 = r_2 i_2 - L_2\dfrac{di_2}{dt} - \dfrac{w_2}{w_1}L_m\dfrac{di_1}{dt} + v_2 \end{cases}. \quad (22)$$

We write equation (8) in the Laplace s-domain form

$$\begin{cases} v_1(s) = r_1 i_1(s) + L_1\cdot s\cdot i_1(s) + \\ + \dfrac{w_2}{w_1}\cdot L_m\cdot s\cdot i_2(s); \\ 0 = r_2 i_2(s) - L_2\cdot s\cdot i_2(s) - \\ - \dfrac{w_2}{w_1}L_m\cdot s\cdot i_1(s) + v_2(s) \end{cases}. \quad (23)$$

Let the load connected to the terminals of the secondary winding of the transformer, that is, to $v_2(p)$ voltage, be represented by a series connection of r_{load} and L_{load}. Then the current in the secondary winding can be expressed as

$$i_2(s) = \frac{v_2(s)}{r_{load} + L_{load}\cdot s}. \quad (24)$$

Let us rewrite the second equation of system (23) taking into account (24)

$$\begin{aligned} 0 = &\left(\frac{r_2}{r_{load} + L_{load}\cdot s} - \frac{L_2\cdot s}{r_{load} + L_{load}\cdot s} + 1\right)\times \\ &\times v_2(s) - \frac{w_2}{w_1}L_m\cdot s\cdot i_1(s) \end{aligned}. \quad (25)$$

Let us express $i_1(s)$ from the first equation of system (23) taking into account equation (24).

$$i_1(s) = \frac{v_1(s)}{r_1 + L_1\cdot s} - \frac{\dfrac{w_2}{w_1}\cdot L_m\cdot s\cdot v_2(s)}{(r_1 + L_1\cdot s)(r_{load} + L_{load}\cdot s)}. \quad (26)$$

Let us rewrite equation (25) taking into account equation (26) and perform some transformations:

$$\begin{aligned} &v_1(s)\frac{w_2}{w_1}\cdot L_m\cdot s(r_{load} + L_{load}\cdot s) = \\ &= v_2(s)\cdot\{r_1(r_{load} + r_2) + \\ &+\left[r_1(L_{load} - L_2) + L_1(r_{load} + r_2)\right]\cdot s + \\ &+\left[L_1\cdot L_{load} - L_1\cdot L_2 + \frac{w_2^2}{w_1^2}\cdot L_m{}^2\right]\cdot s^2\} \end{aligned}. \quad (27)$$

We express from equation (27) the voltage TF of the transformer.

$$W(s)=\frac{v_2(s)}{v_1(s)}=$$
$$=\frac{\frac{w_2}{w_1}\cdot\frac{L_m\cdot r_{load}}{r_1\cdot(r_{load}+r_2)}\cdot s\cdot\left(1+\frac{L_{load}}{r_{load}}\cdot s\right)}{1+\left(\frac{L_{load}-L_2}{r_{load}+r_2}+\frac{L_1}{r_1}\right)\cdot s+}$$
$$\frac{}{+\left(\frac{L_1\cdot(L_{load}-L_2)+\frac{w_2^2}{w_1^2}\cdot L_m{}^2}{r_1\cdot(r_{load}+r_2)}\right)\cdot s^2}=$$
$$=\frac{\frac{w_2}{w_1}\cdot\frac{L_m\cdot r_{load}}{r_1\cdot(r_{load}+r_2)}\cdot s+}{1+\left(\frac{L_{load}-L_2}{r_{load}+r_2}+\frac{L_1}{r_1}\right)\cdot s+}\quad(28)$$
$$\frac{+\frac{w_2}{w_1}\cdot\frac{L_m\cdot L_{load}}{r_1\cdot(r_{load}+r_2)}\cdot s^2}{+\left(\frac{L_1\cdot(L_{load}-L_2)+\frac{w_2^2}{w_1^2}\cdot L_m{}^2}{r_1\cdot(r_{load}+r_2)}\right)\cdot s^2}$$

We can write equation (28) in the form

$$W(s)=\frac{A\cdot s+A\cdot T_{load}\cdot s^2}{1+B\cdot s+C\cdot s^2}=$$
$$=\frac{A\cdot s\cdot(1+T_{load}\cdot s)}{1+B\cdot s+C\cdot s^2},\quad(29)$$

where is the load time constant

$$T_{load}=\frac{L_{load}}{r_{load}}.\quad(30)$$

For the I/I-0 connection group the difference in simulation results must be only as inverted phase of output voltage signal.

Let's introduce a special multiplier G for right side of equation (28), which is responsible for belonging to one of the winding connection groups in accordance with clock-notation rules. Let $G=1$, if I/I-0, and $G=-1$, if I/I-6.

Now we can rewrite equation (29) in the form

$$W(s)=G\cdot\frac{A\cdot s+A\cdot T_{load}\cdot s^2}{1+B\cdot s+C\cdot s^2}.\quad(30)$$

5. Simulation Results Discussing

Mathematical transformations derived for practical use is recommended to be justified with a simulation study. Because of this the author has constructed by means of OrCAD [10] computer models of L-shaped filter and single-phase transformer. Figure 2 demonstrates electric circuit-like (upper picture) and of block-diagram type (lower picture) variants of L-shaped filter models. The block-diagram type model based on equation (10). The electric circuit-like model based on Figure 1 scheme.

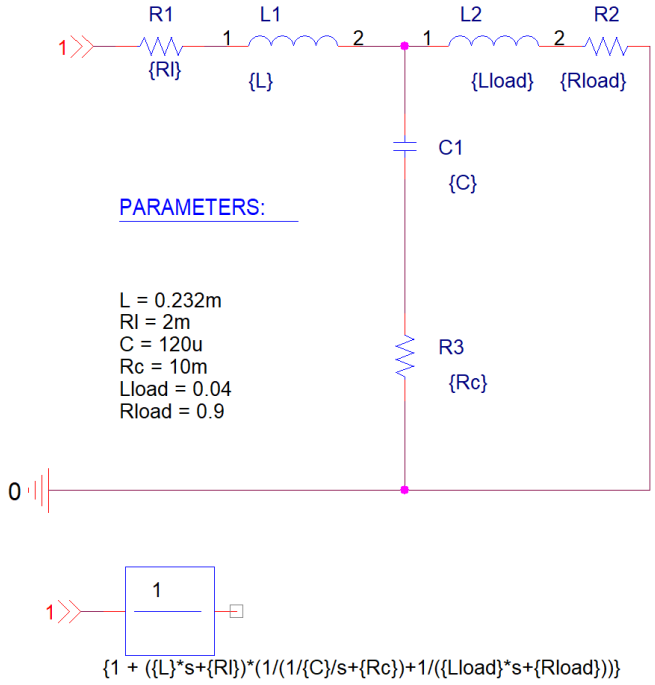

Figure 2: Computer models of the L-shaped filter designed by means of OrCAD (electric circuit-like (upper picture) and of block-diagram type (lower picture))

Figure 3 demonstrates simulated Bode diagram for both types of computer models of L-shaped filter with the same parameters: graphs are totally coincide.

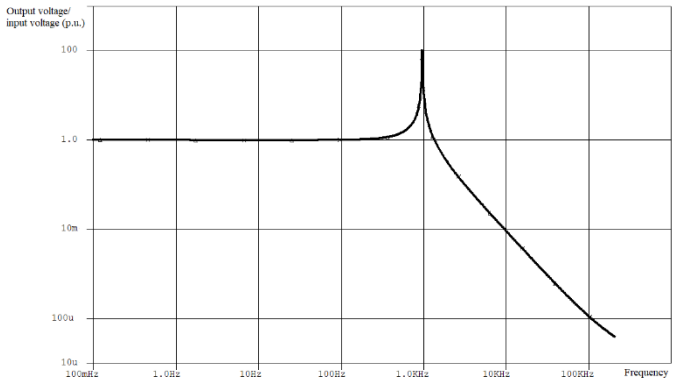

Figure 3: Simulated Bode diagram for both types of computer models of L-shaped filter with the same parameters: graphs are coincide

Figure 4 shows simulated response of the L-shaped filter computer models to the input voltage signal of the "step" type of 1.0 V amplitude. We can observe minor discrepancies in the graphs at the end of the transient process only. For ease of comparison, graph 1 in Figure 4 shown inverted.

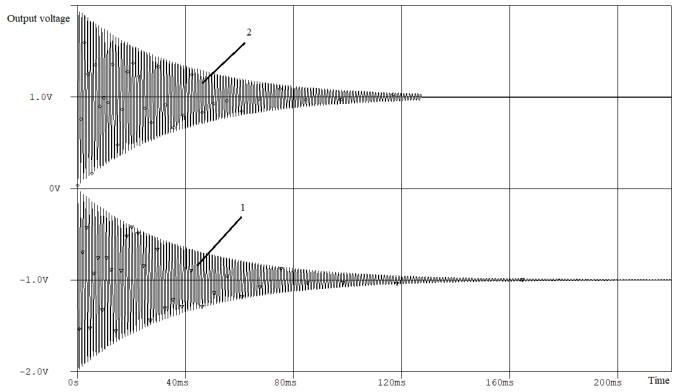

Figure 4: Simulated response of L-shaped filter computer models to the input voltage signal of the "step" type of 1.0 V amplitude. 1 – inversed output voltage graph for model of electric circuit type . 2 - output voltage graph for model of block-diagram type

Figure 5 demonstrates the block-diagram type computer model of the single-phase transformer.

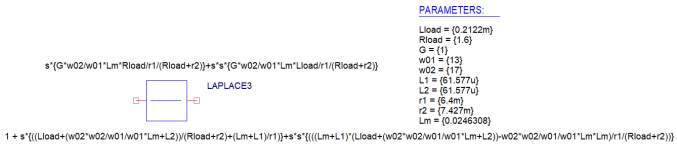

Figure 5: Block-diagram type computer model of the single-phase transformer designed by means of OrCAD (LAPLACE block-based equations (28), (30))

Figure 6 demonstrates the Electric circuit-like computer model of the single-phase transformer. This model designed in form of hierarchical block [8, 10].

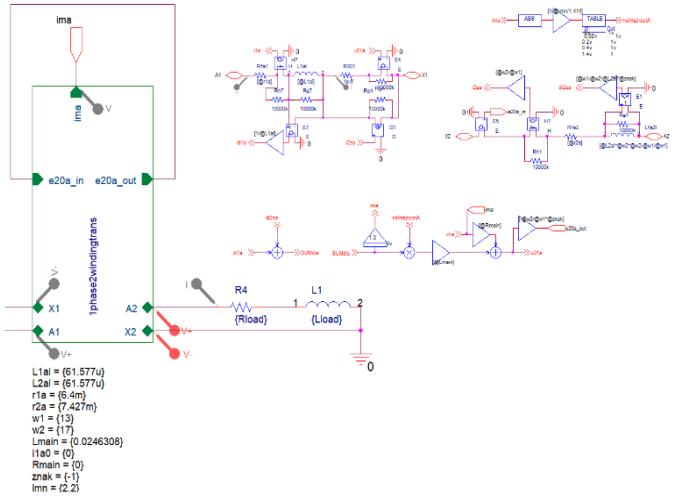

Figure 6: Electric circuit-like computer model of the single-phase transformer designed by means of OrCAD (hierarchical block (left) and it's internal content (right))

In Figure 7 we can see simulated Bode diagram for both types of computer models of the single-phase transformer (I/I-6 or I/I-0) with the same parameters: graphs are coincide at low and medium frequencies area, but there is a significant discrepancy at high frequency area.

Comparing the resulting Bode diagrams, we can assume that models of different types will work equally in the low and medium frequencies, but in the high frequency range, the waveforms will differ markedly. This is exactly what you can see in Figures 8 - 10.

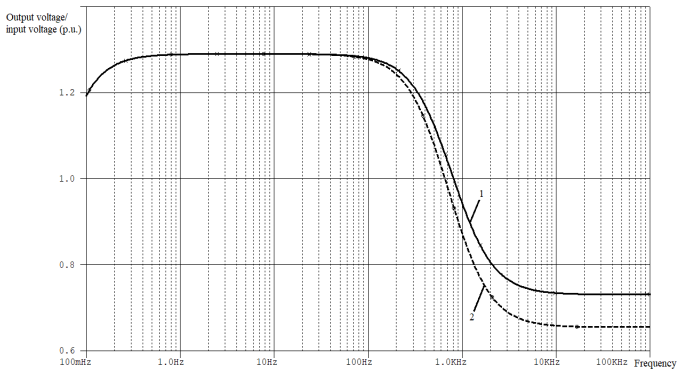

Figure 7: Simulated Bode diagram for both types of computer models of the single-phase transformer (I/I-6 or I/I-0) with the same parameters: graphs are coincide at low and medium frequencies area, but there is a significant discrepancy at high frequency area. 1 - graph for model of block-diagram type; 2 - graph for model of electric circuit type

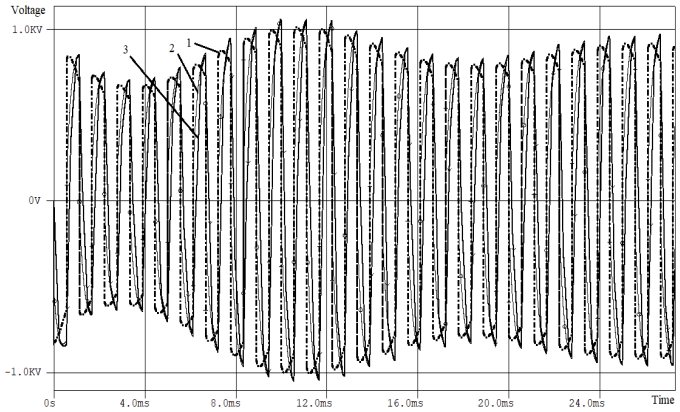

Figure 8: Simulation results. Transformer (I/I-0) voltages transient. 1 – input voltage graph. 2 – output voltage graph for model of electric circuit type. 3 - output voltage graph for block-diagram type computer model

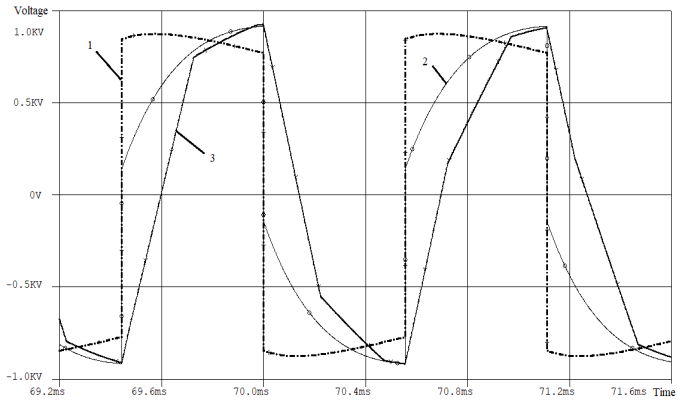

Figure 9: Simulation results. Transformer (I/I-0) voltages at static mode. 1 – input voltage graph. 2 – output voltage graph for model of electric circuit type. 3 - output voltage graph for block-diagram type computer model

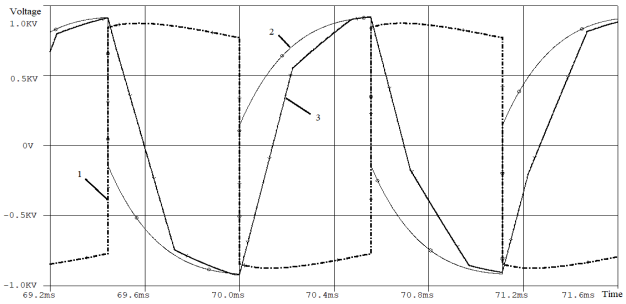

Figure 10: Simulation results. Transformer (I/I-6) voltages at static mode. 1 – input voltage graph. 2 – output voltage graph for model of electric circuit type. 3 - output voltage graph for block-diagram type computer model

With a polyharmonic input voltage, the low-frequency shape of the output voltage envelope is treated the same by both models. Almost the same amplitude of the output voltage. But the shape of the output voltage for different models is different due to the presence of high-frequency components in the spectrum. Given the shape of input voltage 1, the shape of the output voltage graph 2 is more realistic.

6. Conclusion

The derivation of the transfer function of the low pass L-shaped filter (for example output filter of the electromagnetic compatibility of the inverter), loaded by RL-branch, is proposed, which differs by taking into account the presence of resistances in the longitudinal and transverse branches of the L-shaped filter.

As a result of the mathematical transformations done, the transfer function of the transformer was obtained in a form suitable and convenient for practical use in the design of automatic control systems in which the control object (or its component) is an electric transformer. The transfer function is derived on the basis of the T-shaped equivalent circuit of the transformer, and takes into account the presence of resistance in the transformer windings, the winding connection group.

The adequacy of mathematical transformations for the derivation of transfer functions is confirmed by the results of computer simulation using OrCAD. As a result of the simulation, it was found that the response of the model based on the transfer function (block-diagram type) in the high-frequency region visibly differs from the response of the circuit model. This can lead to distortion of high-frequency signals and polyharmonic voltage shapes.

The achieved results can be useful in the design of control systems and their mathematical models for electrical complexes, which include a sine-wave filter or a dv/dt filter and electrical transformer.

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PUSTOVETOV MIKHAIL has done his engineering degree (electrical machines) in 1992 from Rostov-on-Don Institution of Railway Engineering. Theme of the diploma paper: "Linear induction motor with the development of technology for its production".

He has completed his Ph.D. degree (candidate of engineering sciences degree (electromechanics)) in 2000 from Platov South-Russian State Polytechnic University (NPI), Novocherkassk, Russia. Theme of the dissertation: "Traction induction motors calculation methods advancement with the aim of motor's energy performance improving and the torque ripples reduction".

Work experience:

Electrical Design Engineer for the RIF Shipyard (currently);

Acting Head of Department of Engineering Technology (Technological Institute (Branch) of Don State Technical University in the City of Azov) (2020); Associate Professor of Smart Electric Grids Department (Don State Technical University) (2016 - 2019); Director of Science-investigating and testing center "Cryotransenergo" at Rostov State Transport University (2012 - 2016); Chief of Department of Automation and electric drive of machine-tool systems (Don State Technical University) (2007 - 2012); Engineer-researcher in All-Russian Research and Design Institution of Electrical Locomotives Building (VELNII, Novocherkassk) (2000 - 2011). Has written and coauthored more than 160 papers (mainly in russian). Holds eight patents (RUS).

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Humankind and Ubiquitous Autonomous AI: A Symbiotic or Dystopian Interaction? A Socio-Philosophical Inquiry

Michael A. Vidalis [1], **Antonios S. Andreatos** [*,2]
[1]Independent Researcher, Athens 16674, Greece
[2]Hellenic Air Force Academy, Div. of Computer Engineering and Information Science, Dekeleia, Attica 13671, Greece
[*]Corresponding author: Antonios S. Andreatos, Email: antonios.andreatos@hafa.haf.gr
Corresponding author ORCID: 0000-0002-2271-8764

ABSTRACT: The technological revolution in Artificial Intelligence (AI) and Autonomous Robotics is expected to transform societies in ways we cannot even imagine. The way we live, interact, work, and fight wars, will not be like anything witnessed before in human history. This qualitative research paper endeavors to examine the effect of said technological advancements on multiple socio-philosophical planes, including societal structure and ethics. AI mismanagement which we are already beginning to witness, coupled with humankinds' historical ethical infractions, serve as an awakening call for global action to safeguard humanity; AI ethics ought to be examined through the Social Principle and the Social Contract. A proactive, vigilant stance seems imperative, in order to safeguard misuse, as in the case of robot-soldiers or armed drones, which is a case of amensalism disguised. As technological progress is already interfering with humankind and conscience, and in light of expressed concerns from legal and civil liberties groups, it is imperative to immediately criminalize any research in AI weapons, transhumans and the crossbreeding of humans with machines, considering these as crimes against humanity.

KEYWORDS Artificial Moral Agents (AMA), Amensalism, Artificial Intelligence (AI), Transhumanism, Superintelligence, Technoethics

1. Introduction

> "The rise of powerful AI will be either the best or the worst thing ever to happen to humanity. We do not yet know which". Stephen Hawking, 2017.

Most of us in the Western world, including the authors of this paper, grew up reading the comic strips of Buck Rogers and watching Dr. Who, Star Trek and the like, idealizing technological progress as well as admiring the capabilities of the human brain. In our formative years, technology seemed certain to assure an ideal future, a more just world, while enhancing and improving our lives.

However, since then, many questionable developments have been envisioned or realized, such as, Artificial Intelligence, brain transplants, autonomous robotics, and transhumanism. Artificial Intelligence and autonomous robots have been used in an ever increasing variety of applications, positive (ethical) or negative (of questionable ethics), such as, autonomous automobiles, electronic payment protection, digital marketing, human resources, big data processing, medicine (such as medical imaging and radiology), human companions, bomb detonation, surveillance, warfare, etc.

This qualitative research paper argues that AI including autonomous robots, and brain transplants, may indeed benefit humanity as attested by its various pragmatic applications; however, its mismanagement which we are already beginning to witness, coupled with humankinds' historical ethical infractions, serve as an awakening call for global action to safeguard humanity. Hawking's now infamous quote above, presents an opportunity to assure that AI will remain peaceful, purposeful, and most importantly, ethical, serving humankind instead of possibly controlling or dominating it, as will be explicated below. It is up to us to assure the direction of AI's future outcome, eliminating the uncertainty of a dystopian future Hawking entertained as a possible scenario.

Humans have made great strides throughout history, resulting in profound and purposeful inventions, such as electricity, the telephone, the automobile, the X-Ray, or the internet, all of which undeniably contributed to our welfare and enhanced our quality of life. Unfortunately, scientists have also concentrated their research on ways to harm humankind; or, purposeful inventions, were turned into devastating weapons of mass destruction. Besides the obvious atomic or nuclear bomb examples, the list seems endless. Deadly Sarin gas, used by the Nazis, has also been employed recently in the Iran-Iraq war. Chlorine gas was used by the Germans in WW1. "Agent Orange" (triiodobenzoic acid), originally developed as a chemical to accelerate the growth of soybeans in areas of a short growing season, was employed extensively in high concentrations by the

United States during the Vietnam, over a period of ten years, resulting in countless casualties and birth defects. Last, but not least, landmines abandoned or forgotten since WW2 or other conflicts, kill annually thousands of innocent civilians, mostly children (in 2019 less than 7,000 people died as a result of landmines) [1]. It immediately becomes apparent that in order to win a war, or change the outcome of a conflict, countries like Germany or the United States, have resorted to unethical means, embracing a Machiavellian approach; which of course does not excuse a crime against humanity.

The idiosyncratic perspective of the authors as partly reflected in the title, as well as a field at its infancy, have made it challenging to locate relative applicable research – with the exception of [2]–[4]. In [2], it presents four different scenarios (a. the optimists; b. the pessimists; c. the pragmatists; d. the doubters) relative to future AI progress, however, although he acknowledges the potentially devastating consequences for humanity, and he appears hopeful that scientists will safeguard applicable research. He expresses his uncertainty relative to possible risks in the following statement:

> "What is uncertain is if such an impact will lead to a utopian or dystopian future, or somewhere in between. Elsewhere he notes in concern: Whether this dream is a utopian or dystopian future is left up to the reader to decide, not underestimating however, that intelligent machines will eventually become at least as smart as us and a serious competitor to the human race if left unchecked and if their great potential to augment our own intellectual abilities is not exploited to the maximum" [2].

In [3], adopts and astutely explicates the argument that self-preservation should be humankind's first ethical priority. He supports that without humankind moral argument could not occur (on his assumption that only humans possess complex morality), therefore, "the most fundamental human moral obligation is to avoid extinction" [3]. While Jimenez [4] states that humanoid robots with human like self-awareness AI, will use consumer brands as a means of self-expression. He expects these robots to play a prominent role in society, especially in the healthcare, education and relationship sectors, i.e., he foresees an increased human-robot interaction [4].

Next, a few terms ought to be defined. Artificial Intelligence (AI) "... or sometimes called machine intelligence, is intelligence demonstrated by machines, in contrast to the natural intelligence displayed by humans and other animals. Some of the activities that it is designed to do is speech recognition, learning, planning and problem solving. Since Robotics is the field concerned with the connection of perception to action, Artificial Intelligence must have a central role in Robotics if the connection is to be intelligent".

The independent High-Level Expert Group on Artificial Intelligence, of the European Commission (E.C.), adopted the following definition of AI: "Artificial intelligence systems are software (and possibly also hardware) systems designed by humans that, given a complex goal, act in the physical or digital dimension by perceiving their environment through data acquisition, interpreting the collected structured or unstructured data, reasoning on the knowledge, or processing the information, derived from this data and deciding the best actions to take to achieve the given goal. AI systems can either use symbolic rules or learn a numeric model, and they can also adapt their behavior by analyzing how the environment is affected by their previous actions. As a scientific discipline, AI includes several approaches and techniques, such as machine learning (of which deep learning and reinforcement learning are specific examples), machine reasoning (which includes planning, scheduling, knowledge representation and reasoning, search, and optimization), and robotics (which includes control, perception, sensors and actuators, as well as the integration of all other techniques into cyber-physical systems)" [5].

Symbiosis, from the Greek 'Syn+bios' (meaning 'together'+'life'= living together), is "1: The living together in more or less intimate association or close union of two dissimilar organisms (as in parasitism or commensalism). Especially: mutualism; 2. A cooperative relationship (as between two persons or groups)" [6]. The term was adopted by the life sciences in the nineteenth century, specifically by biology and medicine. Symbiosis can be either mutually beneficent, i.e., a cooperative relationship, in which case it is characterized as mutualism, or, one organism living off another at the other's expense, which is characterized as parasitism. Relative to this is the concept of commensalism, where members of one species gain benefits while those of the other species neither benefit nor are harmed. Amensalism "is an interaction in which presence of one species does not allow individuals of other species to grow or live... this is called antibiosis" [7]. It should be noted that the term symbiosis, in a general use, i.e., without clarifying it as per the aforementioned, signifies a long-term interaction.

Simply stated, Dystopia is anti-utopia. Specifically, Dystopia is "an imagined world or society in which people lead wretched, dehumanized, fearful lives". As such, it is undesirable and considered as hostile to humankind [8].

Society is "a large group of interacting people in a defined territory, sharing a common culture" [9]. The consideration of a potential future coexistence or interface between humans and autonomous AI machines or autonomous robots, inevitably gives rise to a plethora of sociological and philosophical issues, some of which are formulated and explicated below.

Last, transhumanism "is a class of philosophies of life that seek the continuation and acceleration of the evolution of intelligent life beyond its currently human form and human limitations by means of science and technology, guided by life-promoting principles and values" [10]. Known as "Humanity Plus", it claims it seeks to elevate the human condition [11]. Also, as extropy, is an essential element of transhumanism [12].

This paper is organized into five parts. It first overviews the subject and provides the working definitions of seminal terminology. Second, it investigates the era we are currently in, specifically, the Fourth Industrial Revolution. Third, the effect on labor is examined, although in a laconic fashion, attempting to gauge whether this new technological progress

will result in additional employment or unemployment. Fourth, societal and ethical issues are investigated and explicated. Last, in the fifth section, we question whether brain transplants or a human-robot symbiosis are possible, or most importantly, legal or desirable, from an ethical stance. The contribution of this work is an idiosyncratic yet holistic perspective on a field in its infancy, based on an extensive literature review. Furthermore, we have pointed out pertinent issues in the recent Russo-Ukrainian conflict.

The consideration of a potential future coexistence or interface between humans and autonomous AI machines or autonomous robots, inevitably gives rise to a plethora of sociological and philosophical issues, some of which are formulated and explicated below.

2. The Fourth Industrial Revolution

We are in an age of profound and systemic change. To comprehend this statement, one needs to consider the modernization of industrial progress, from the 18th century until today; and its four distinct phases. Our present phase may be defined as the Fourth Industrial Revolution [13]. Specifically, these phases are:

1. The Machine Age.
2. Mass Production.
3. The Digital Revolution.
4. The Fourth Industrial Revolution.

The underlying technologies of the Fourth Industrial Revolution are: intense interconnectivity (implemented by 5G), the Internet of Things (IoT), AI, gene sequencing and nanotechnology (Figure 1). Most of the changes in phases three and four were fast-tracked, ultimately spreading globally. This provided a new level of change that had never been witnessed before. Not only were people aware of events happening halfway across the world, but economies had become so intertwined that they were affected by them. Schwab proceeds to recommend four types of intelligence in order to deal with the new reality: Contextual, emotional, inspired and physical. This fourth wave of technological change may be encapsulated in a reader's review of the keystone book on the subject:

> "This book documents how people will be consolidated as valueless beings in a world ran by robots, AI and those in the upper echelon of politics and wealth. This outlines the coming power of globalization over all nations everywhere. Read it and look at it from a big picture perspective. It is scary" [14].

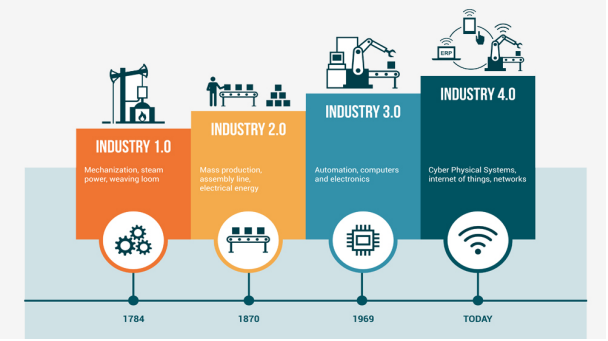

Figure 1: The Evolution of Industry from 1.0 to 4.0. Source: https://www.seekmomentum.com/blog/manufacturing/the-evolution-of-industry-from-1-to-4

3. AI and robotics on labor: Societal and ethical issues

The application of AI on labor raises some ethical implications. Granted, a company may wish to maximize its revenues by utilizing robots or AI. However, what happens when such a decision is adopted on a wide scale results in massive unemployment? When do the rights (if maximization of corporate profit is a right) of the few and powerful outweigh the rights of the many?

Various studies of the effect of progress on the work scene, especially, potential employment opportunities or resulting unemployment, have been conducted. There seems to be an ongoing debate on humans versus robots and whether AI will replace workers thus increasing the unemployment rate, or, aid workers to ultimately become more productive. Technological unemployment, the jobs lost as a result of technological progress or advances, is not a new phenomenon. Weiyu Wang and Keng Siau state that "some jobs, that have disappeared as technology has advanced, include steam-train operators, switchboard operators, elevator operators, and typists. The disappearance of obsolete jobs that have been replaced by technologies is referred to as "technological job obliteration". Each time an industrial revolution has occurred, people have been concerned about technological unemployment and technological job obliteration" [15].

However, humans seem to have innate qualities, such as morality and ethics, which cannot be replicated by robotics or AI, while in some professions, interpersonal skills and communication is utterly important. Jack Dorsey, CEO of Twitter, warns that AI may threaten entry level computer programming jobs, as these will no longer be relevant. Even beginning-level software engineers will face less demand, as AI will soon write its own programs [16]. As with all new technologies, especially in the field of AI, fear of the unknown is present.

Andy Haldane (2015), the Chief Economist of the Bank of England, predicts that up to 15 million jobs in Britain could be lost, due to robots. Hardest hit are expected to be the administrative, clerical and production tasks. As Haldane stated, in the 20th Century machines have substituted not just for manual tasks but for cognitive as well; machines are becoming even smarter and can reproduce the set of human skills at a lower cost [17].

One needs to remember the first automobile assembly

lines being labor intensive and how these ultimately became automated; while the initial jobs were lost, new specializations surfaced, requiring labor. Likewise, the introduction of the personal computer in the 1970s and 1980s, created millions of new jobs (semiconductor makers, software and app developers, information analysts, etc.), as technology has been historically a net job creator [18]. According to a modeling scenario, up to 14% of the global workforce will need to change occupational categories by the year 2030. Different modeling scenarios have also attempted to predict the number of jobs lost due to automation. According to the fastest scenario modeled, up to 30% or 800 million workers, could be displaced in the period 2016-2030 [18].

As this is a field with on-going developments occurring at a high speed, we can state that it is presently inconclusive whether the associated technological progress will affect overall employment negatively. The evidence of studies to date is inconclusive. However, we need to endeavor to strike a balance between the needs of the employers against the needs of the labor force, such that an ethical symbiosis can be realized.

4. Societal and ethical issues

A human is an individual, while an aggregation of humans forms families and ultimately, societies; a human is considered the core or cell of society (as defined above). Whereas, an AI robot or autonomous machine is initially a unit, while an aggregation of these, simply results in more units; not society, as we perceive it. Immediately, we perceive the duality "man" versus "machine". Even if these can communicate, interact or interface, between themselves and humans, they are still devoid of the idiosyncratic human characteristics or innate human qualities (such as empathy or an impulse to play and fool around) central to all societal conceptions; at least for the time being. In [19], the author has entertained and presented the frightening concept of singularity, the union of the best of human and machine, where our knowledge and skills (located within our brains) would merge with the superior capacity, speed, knowledge and sharing abilities of our machines. Given the author's prominence, who also happens to be a noted inventor, one can only speculate that scientists around the globe are secretly researching this dystopian scenario. AI has many seemingly practical applications, such as, in medicine, insurance, facial recognition, predictive policing, self-driving automobiles, mortgage or job applications, judicial algorithms, etc. An example of the latter is the 'COMPAS' software used in the U.S. [20]. COMPAS (an acronym for "Correctional Offender Management Profiling for Alternative Sanctions") is an algorithm to assess potential recidivism risk; employed by some judicial systems in the U.S. It is a disputed risk assessment method, with an accuracy of 65%.

However, a closer examination, invariably reveals a plethora of ethical issues. For example, facial recognition may be acceptable in Facebook, should one accept to use the specific social medium and elect to apply that option, however, when done by a network of cameras on the streets and other public spaces, it can violate our privacy; for it would reveal our associations, our mood, and the like. In the case of autonomous vehicles, an ethical issue arises, when considering the following possible scenario. A child suddenly crosses the road in front of the moving vehicle, while the available choices are only two: Kill the child, or, hit a wall in order to save the child which will result in the passenger's death. What will the AI system be programmed to do? More specifically, what sort of ethical constraints should be built in [21]?

Predictive policing is employed in order to predict where crimes are likely to occur. In predictive policing as done in the U.S. or Europe, areas habited by black people may be targeted, resulting in bias and unjust discrimination. As reported by the New York Times, Clearview, a facial recognition provider, has been sued by the American Civil Liberties Union (ACLU) for its controversial practices. Privacy, as we know it, will end, according to Nathan Freed Wessler, senior staff attorney at the ACLU. It is supported that Clearview's facial recognition system is used by more than 2,200 law enforcement agencies around the world, and businesses like Best Buy and Macy's. The ACLU's press release stated: "The New York Times revealed the company was secretly capturing untold numbers of biometric identifiers for purposes of surveillance and tracking, without notice to the individuals affected. The company's actions embodied the nightmare scenario privacy advocates long warned of, and accomplished what many companies - such as Google - refused to try due to ethical concerns" [22].

The ACLU appears committed to defend privacy rights against the growing threat of this unregulated surveillance technology. Larry Page, a former Google CEO, stated in 2010 in the book "In the Plex: How Google Thinks, Works and Shapes Our Lives" that "eventually you'll have the implant, where if you think about a fact, it will just tell you the answer" [23].

Robots camouflaged as seals have been employed in nursing homes to keep companionship to residents having no family or friends to visit them. While practical in its conception, it also serves as a sad commentary on contemporary society. Robotic "pet seals" have also been used in nursing homes in England, in therapeutic applications for dementia patients. A robot disguised as a baby harp seal, known as "Paro", is meant to remind the residents of their past pets and improve their quality of life [24].

During the contested Coronavirus (Covid-19) pandemic and the associated quarantine, drones were used in China, England and other countries, for the surveillance of public space, temperature measurement of citizens walking in public areas, occasionally for delivery of medicine, etc. Once spotted, the person was notified via loudspeaker, to promptly leave the area. It proved to be an effective police practice, regardless of the possible ethical considerations involved. Critics have considered the policing application of drones by law enforcement agencies, as an infringement on privacy [25].

Drones, now owned by many national armies, employ AI, like autonomous weapons, in order to kill without human intervention [21]. Obviously, this does not allow for aborting the decision should an unexpected or unprogrammed parameter surface seconds before firing. So the logical question surfaces, what happens when it is too late?

In the recent phase of the Russo-Ukrainian conflict that commenced on February 24, 2022, drones were used by both sides, in order to engage in reconnaissance so the air force that followed would deliver successful strikes. Ukraine relied on the Turkish made Bayraktar TB2 drones that proved quite effective despite their technical shortcomings; surprisingly the Russians relied less on drones. Ukraine's drones also shot guided missiles at Russian missile launchers [26]. Gone are the days of man-to-man confrontations. The new reality minimizes the risk of the aggressor, in effect rendering conflicts free of political cost in case of diseased soldiers? Wouldn't this practice render wars more common?

The U.S. Army has developed prototype robot-soldiers poised to fight the wars of the future. These automated robots were initially developed to detonate bombs, or perhaps to clear mine fields; indeed, a noble goal. However, it was apparently decided to fully exploit these robots in military applications (Figure 2). This robot was developed by Virginia Tech engineering students to support functions in the military; it can extinguish fires that break out on Naval ships.

Figure 2: The SAFFir robot. Source: https://149695847.v2.pressablecdn.com/wp-content/uploads/2018/02/saffir.jpg

Both the U.S. and Russia are exploring the possibility of swarms of robotic soldiers on the battlefield; supposedly to protect the lives of actual soldiers, as these AI machines target faster and more accurately than humans. However, "it doesn't help much, either, than the militaries responsible for pursuing this kind of battlefield autonomy already have atrocious records when it comes to avoiding civilian deaths" [27].

Richard Moyes, a co-founder of the Campaign to Stop Killer Robots (CSKR), is very concerned that autonomous military robots may develop their own intelligence and turn against their human creators; or, turn against real soldiers fighting at their side. CSKR has repeatedly called for the banning of autonomous robot soldiers, however, these are still being deployed in war-zones. As stated "... amorality is no longer an accurate characteristic of robotic systems. When discussing the ethics of artificial intelligence, experts warn that autonomous systems are inherently 'tainted' by its programmers. Decision-making processes, for example, are biased toward the person who designed the software" [28].

Unfortunately, it appears that for the U.S. and China, military soldiers will play a major role in the future [29]. In the past, men fought face to face, like real men; then came weapons, later stealth bombers and ships, and drones, while now, machines will hunt down and kill humans. Figure 3 shows MAARS (Modular Advanced Armed Robotic System). Having a modular design, it allows the controller to outfit it with a variety of armaments, ranging from lasers to tear gas. Once the political cost of dead soldiers is removed, wars can be started at will [30]. Joseph Weizenbaum had argued in 1976 that AI should not be applied to a few specific applications, one of them being soldiers.

A novel way has been proposed to effectively confront the challenging ethical dilemmas involved in AI - human interaction; by successfully utilizing the unique strengths of humans and the unique strengths of AI systems, in paradigm-shift solutions [31].

Another researcher embraces the view that it is imperative to immediately criminalize any research in AI weapons, and the crossbreeding of humans with machines, considering these as crimes against humanity; in order to avoid the likelihood where the other half of myself will be my robot [32].

Figure 3: MAARS - Modular Advanced Armed Robotic System. Source: https://analyticsindiamag.com/us-chinas-military-future- robots-india-competing/

Human Rights Watch addresses this issue quite eloquently:

> "Allowing innate human qualities to inform the use of force is a moral imperative. Weapons systems do not possess compassion and empathy, key checks on the killing of civilians. Furthermore, as inanimate objects, machines cannot truly appreciate the value of human life and thus delegating life-and-death decisions to machines undermines the dignity of their victims. Human control also promotes compliance with international law. For example, human judg-

> ment is essential to correctly balance civilian harm and military advantage and comply with international humanitarian law's proportionality test. Machines cannot be pre-programmed to respond appropriately to all of the complex scenarios they may face" [33].

The independent High-Level Expert Group on AI of the European Commission, published "Ethics Guidelines for Trustworthy Artificial Intelligence" [34]. The recommendations presented seven key requirements AI should meet in order to be deemed "trustworthy":

1. Human agency and oversight.
2. Technical robustness and safety.
3. Privacy and data governance.
4. Transparency.
5. Diversity, non-discrimination and fairness.
6. Societal and environmental well-being.
7. Accountability [34].

4.1. Implantable brain devices

On August 28, 2020, Elon Musk presented Neuralink's new seamlessly implantable brain device, having more than a thousand neuron channels, which supposedly can remedy neurological problems, such as brain and spine issues (strokes, spinal cord injuries, etc.) technoethics and artificial mora. This device which is connected to a computer and may be removed according to Musk, even allows us to control the autopilot of our Tesla automobile; simply thinking we need our automobile, the appropriate signal is transmitted to it, and it arrives. The whole surgical procedure is performed by a fully automated robot, in about an hour. The battery needs to be inductively charged daily. This device which has received FDA approval, was previously tested on pigs. The initial cost is expected to be "a few thousand", with the cost rapidly dropping in a short time. In the near future it is expected to save and replay memories. Neutralink's brain chip will literally make us superhuman, taking the word "fiction" out of "science fiction" [35]. How far do we experiment with human nature? Is this an ethical application of science (at least the summoning of our automobile part)?

4.2. Technoethics and Artificial Morality

This new age has given rise to an emerging, interdisciplinary field, centering around the idea of creating artificial moral agents (AMAs), through the implementing of moral competence in AI systems. An AMA is "an artificial autonomous agent that has moral value, rights and/or responsibilities. This is easy to say but I must acknowledge that no traditional ethical theory takes this notion seriously" [36]. This noble goal, however futile judging by the plethora of ethical infractions throughout human history, is to build the same ethical principles governing societies into machines. As ethics are subjective, culture and historic period dependent, it should be evident that this endeavor offers little hope. As an example, contemporary women's dresses or swimsuits, would be considered absolutely scandalous in the Victorian era. Moreover, some modes of behavior considered normative in Western European culture would annoy or be considered as unacceptable, in some Middle Eastern countries.

5. Human-robot symbiosis?

Anthropomorphic simulation of AI systems to such an extent that it becomes difficult to discern humans from robots, or even to entrench a social belief in the equality of man and machine, appears as an option scientists are willing to entertain, however unethical or contrary to theological doctrine that may be. The question, however, is not how to prepare for the upcoming autonomous artificial systems intelligence, but how to employ it in our ontological correlation with everyone and everything (Fellow humans, the world, God); for a machine by design, cannot enjoy bliss. Realbotix, a high-tech company in California, is already designing and producing sex robots with AI, life-like replicas of females, who can converse with their owners and engage in sexual intercourse. Harmony is the name of their first product, a thin blond with emphasized cheek bones, and protruding breast and buttocks. A client simply specifies the desirable facial characteristics, color of hair, body shape or traits, and personality, and purchases a specific robot for about $20,000. It is projected that in the coming decades, this may be viewed as mainstream, socially acceptable behavior. Aside from ontological or ethical concerns, critics insist that virtual partners over real partners will result in psychological distancing between people, affect human relationships, and a lower world population. The company is already working on a male version [37]. Robot dogs developed by Ghost Robotics will soon start patrolling the perimeter of the Tyndal Air Force base, in Panama City, Florida. Employed to enhance security and surveillance patrolling, these autonomous drones with high-tech sensors, two-way communication, seven hour power, and the ability to defend themselves, may be employed to all Air Force bases should testing provide satisfactory results [38].

If human bliss requires our deep and permanent association with others, the recognition of the "Social Principle" as a prerequisite for the operation of AI systems, appears as a necessary condition. A seminal point in any ethics conception of AI, should be the "Social Principle" [32].

Such a conception (i.e., based on the Social Principle), necessitates the operation of those systems to always, satisfy – whether short-term or long-term – the ontological need for a real coexistence of all people within the entire body of humanity. It is thus required to reject such systems that endanger the relative value of man, otherwise, man may willingly or not, be transformed into an inferior, sub-human entity; a man-beast or a man-machine (see the 'Upgrade' film [39]).

The technical and non-technical methods employed to satisfy the Social Principle's role in the design and operation of AI systems, should be undertaken by the scientific community itself. In order to avoid the risk of deifying the individualism we inherited from Europe in the last

century, resulting into a dystopic situation where the other half of myself will be my robot [32]! A sociological study of dystopia inevitably searches these three key issues: (a) Justice; (b) Liberation; and (c) Humanity [40]. Furthermore, a survey of dystopic literature highlights these five common points:

1. Government control.
2. Environmental destruction.
3. Technological control.
4. Survival.
5. Loss of individualism.

Obviously, the third point, that of "technological control" is pertinent to this paper and is indeed potentially alarming; as are the rest of the points. The Matrix, the Terminator, Upgrade [39] and other dystopic productions, portray a future society controlled by technology, whether in the form of AI computers or robots. Entities employ technology to control the masses, as a result, humans lose their sense of freedom and individuality. Jaron Zepel Lanier, a digital pioneer turned technological denouncer and web critic, has supported that technologies reflect and encourage the worst aspects of human nature; as a result, people are not acting responsibly [41].

In fact, new technologies tend to harm our interpersonal communication, relationships, and communities [42].

Human thought and emotion, the whole range of human emotions in general, including introspection and empathy, pose a challenge if we are considering a transfer to a non-human.

Oxford philosopher and founding director of the Future of Humanity Institute Nick Bostrom, whose work focuses on AI and has popularized the term "superintelligence", is very skeptical of the implications of a possible misuse of AI. Superintelligence is defined as any intellect that greatly exceeds the cognitive performance of humans in virtually all domains of interest [43]. Although we are not powerless, Bostrom views the rise of superintelligence as potentially disastrous for humankind. Vigilance is needed against the risks involved; in fact, in 2017 he cosigned a list of 23 principles that AI should adhere to.

In [44], the authors envisions the radical possibilities of our merging with the intelligent technology we are creating. Earlier he supported that the human being will be succeeded by a superintelligent entity that is partly biological, partly computerized [19]. A plausible future where machine intelligence outpaces the biological brain, transcending our biological limitations. In [45], the authors articulates the issue of whether our species can survive, exploring the perils of the heedless pursuit of advanced AI. Arthur C. Clarke, a technophile sci-fi legend, was highly skeptical of the future. He held that it is just a matter of time before machines dominate humankind, as AI would win.

Steven Poole raises the alarm, with an urgent call for action,

> "Wake up, humanity! A hi-tech dystopian future is not inevitable" [46].

There is

> "the worry that machines will take over. Could machines outsmart us and control us? Is AI still a mere tool, or is it slowly but surely becoming our master? What is to become of us? Will we become the slaves of machines?" [21]

The discussions regarding AI need to become mainstream, especially relative to ethics and the need for regulation [47]. AI could possibly be our final invention [45], in respect to AI's catastrophic downside, not to be entertained by Google, Apple, IBM, and DARPA. Table 1 summarizes the ethical issues examined, relative to AI and autonomous robotics. A close reading portrays a pessimistic reality already being witnessed.

Specifically, five (5) out of the ten (10) issues presented in Table 1, or 50% of these, already are a cause of concern. Robotic soldiers, armed drones, surveillance drones, implantable brain devices (store/recall memories, summon the automobile, etc.) and sex robots, *de facto* constitute ethical infractions (E.I.), as discussed and further elaborated in the Conclusions section.

Table 1: Technoethics

TECHNOETHICS	AERM	PEI	EI
Singularity		*	
Superintelligence		*	
Artificial Moral Agents	*		
Facial recognition providers		*	
Robot soldiers and robot dogs			*
Armed drones			*
Surveillance drones			*
Implantable brain devices (store/ recall memories, summon the automobile, etc.)			*
Sex robots			*
Robots for human companionship/ interaction		*	

where:
A.E.R.M. = Attempted ethical remedial measure
P.E.I. = Potential ethical infraction
E.I. = Ethical infraction

6. Conclusions

It seems certain that the new technological revolution in AI and autonomous robots will transform society in ways we cannot even imagine. The way we live, interact, work and fight wars, will not be like anything witnessed before in human history, based on the glimpse of things to come. As elaborated, we are already beginning to witness the adverse effects of some relative developments. At this point it is imperative that we reiterate the aforementioned definition of society, which is pivotal to our discourse. Society is "a large group of interacting people in a defined territory, sharing a common culture". It is immediately apparent that three ideas surface: Interaction, people and culture. Can a machine or an aggregation of machines, however intelligent,

constitute "people" who "interact" and produce "culture"? Furthermore, one ought to remember the theory of Social Contract, through which societies are regulated; otherwise, social disorder and chaos results. The justification of a society or a state, depends on showing that everyone essentially consents to it; the issue of justification is seminal. From Epicurus, to Hobbes, Locke, and Rousseau, the role of the Social Contract explicates how societies are structured and regulated; societies are expected to be legitimate, just, obligating, etc. [48]. This implies that man and machine are philosophically and sociologically incompatible, as said relationship would violate this widely adopted informal convention. Additionally, we are reminded of the Social Principle as a necessary ethical condition for the operation of AI systems, which unfortunately evades the researchers [32].

While the consequences on labor are unclear, the consequences on society seem pessimistic. Brain chips can now summon our automobile, while in the near future they may be manipulated to control a malicious robot? Storing and replaying memories sounds unnatural; whatever happened to authentic memories?

Furthermore, in reference to the aforementioned brain transplant that Google envisioned, we may question whether it is a noble or ethical goal for technology to take command of the human brain? Isn't transhumanism going to result in global overpopulation (by extending the human life span), while interfering with religious beliefs? Thus, is genetic engineering and biotechnology as manifested in transhumanism, legal or really desirable?

An epoch that resorts to AI sex robots for companionship and sexual gratification, like Realbotix's Harmony, raises Ontological, sociological, psychological and ethical questions. Virtual partners over real partners seems unnatural, however, the ground is being set to recognize this behavior as socially acceptable, or mainstream. The robotic therapeutic "pet seal" mentioned above, improving the quality of life of nursing home residents, is an example of technology summoned to serve humankind. Although one may wonder why a real pet was not used instead, but an invented one; a trained cat, for instance, would be a preferred alternative. Or, more importantly, whatever happened to real, altruistic and caring human beings, serving as volunteers?

As explicated above, Barrat, Arthur C. Clarke, Lekkas and others, have been highly skeptical of a safe and ethical human-AI interaction. It is imperative to reiterate the call to immediately criminalize any research in AI weapons, and the crossbreeding of humans with machines, considering these as crimes against humanity [32].

Legality as it relates to ethics (the legalization of ethics?) and technology, are issues to also be considered. In the aftermath of 9-11, the American people were willing to forsake some of their freedoms in order to enhance their safety, or at least their perception of safety; thus they apparently accepted the surveillance measures imposed by the Government, without any protests. Clearly, this is an issue of civil liberties vs. security [49].

The ACLU's legal action against facial recognition provider Clearview, is indicative of an unregulated industry, infringing upon our privacy. The present surveillance technology is already a nightmare for human rights; our facial characteristics, secretively and without our consent, have become a source of profit for others. Human Rights Watch is alarmed at the reality of autonomous lethal weapons, disregarding human life. As it supports, being inanimate objects, these machines cannot appreciate the value of human life, therefore, delegating life-and-death decisions to autonomous machines undermines the dignity of their victims; furthermore, such an approach, does not comply with international law. CSKR's repeated pleas for the legal prohibition of robot soldiers has landed on deaf ears. A proactive and vigilant stance seems imperative in order to safeguard probable misuse as in the case of the U.S.' robot-soldiers; an act which if left unchecked, will be copied by other major armies in the world. Obviously this is an example of the weaponization of AI, with a total disregard for its implications on humanity. It can effortlessly be surmised that the owner of these robot-soldiers may be immune from crimes against humanity, by possibly claiming "programming malfunction"; thus, a possibly deliberate small-scale genocide may be left unpunished. A democratic and true to its founding goals United Nations should have curtailed this at the very beginning. However, this is an additional testament of the U.N.'s questionable modus operandi, which traditionally supports the global superpowers' actions. The weaponization of AI systems is amensalism disguised, therefore, the global community needs to object vehemently to such potentially disastrous and inhuman practices, before Pandora's Box is opened. For it is highly probable that these robot-soldiers may even be used against peaceful urban protesters. If human soldiers have historically engaged in atrocities and genocides, can these machines be expected to act in a more humane or ethical manner? For human history, has showed time and time again, that in military confrontations, personal or group gains often prevail at the expense of ethics.

The current state of technology may allow for a version of a Blade Runner (1982 motion picture) *replicant*, a synthetic, bio-engineered anthropoid, in the near future, raising questions such as, how far can technological "progress" be allowed to go. Is science for science's sake, over and above ethics? The purpose of technology is to serve humankind; it is not a self-serving aim, neither a tool serving monopolies or oligarchs. We are reminded of Protagoras (c.490 - c.420 B.C.), the Greek philosopher who introduced the conception of anthropocentrism, as expressed in the radical statement "Man is the measure of all things" (Protagoras entertained the idea of relativism and stressed the need for a moral and political ideal). "Dehumanization" and "fear" are characteristics of dystopia, thus, a near future with surveillance drones, armed drones, robot-soldiers, brain transplants and the like, can only be considered as dystopic; as verified by the definition of the relative term. The ethical stakes are high, as technological "progress" is already interfering with humankind and conscience.

AI and robotics may very well be the end of life as we know it. Scientists engulfed in technological optimism are not often concerned or cannot fully comprehend the dialectics of avant-garde technology and societal implications; for them the unbridled quest for knowledge supersedes the

ontological conception of homo sapiens; clearly, a case of futurology over sociology; it is technological revolution versus biological evolution. Avoiding the issue as to whether machines will one day truly think, become conscious and self-aware, thus, probably being able to turn against humans.

Ideally, there ought to be a balance of the benefits and gains of technological advancement against the potential harm to humankind and society. The issue is whether it will enhance and improve our lives and society at large, or, potentially cause major upheavals to humankind and societal structure. Conceptual debates and judicious choices, should consider the proper place of technological practice in human life; ethically exploring the idea of technology as a social practice and as a medium of political power. Responsible research and innovation is part of the solution; needed to be imposed by a legal framework, global in scope. The Ethical Guidelines presented by the E.U., although incomplete from an ontological perspective, are certainly a step in the right direction; however, the aforementioned confirm said guidelines are ignored or dismissed. Assigning personhood, acceptable social behavior, or expecting ethical behavior from autonomous machines to facilitate their relationship with humans, is not unlike expecting humans to act like machines. For machines will never possess human qualities, like morality and ethics (as we explicated above). When humans historically have found ways to manipulate ethics (from the work-place to governments waging wars around the globe in the name of "peace", as in the case of the U.S.A., Russia or Turkey), is it possible or logical for AI machines programmed by humans to indeed be more "ethical" than humans? Has AI been deified in a global Network Society [50] which is desperately in search of the appropriate values? Have we ultimately mystified information science? Is the *New World Order* working on an agenda, *de facto* acting as our self-appointed guardians, envisioning a future for us without even asking us?

Finally, is the protagonist of the future going to be humankind or AI? Some of these quasi-philosophical questions are obviously rhetorical in nature and this forum has provided an exceptional opportunity to highlight these.

Table 1 portrays a bleak view of reality, which can only be described as dystopian. Therefore, it appears that the conception of the future during our formative years was rather naive, as life has not been rendered easier, happier or more peaceful, because of AI and autonomous robots. Unfortunately, aside from a few peaceful applications (such as the nursing home pet, or improved medical imaging), the bulk of relative research has been pursued in warfare, surveillance and corporate profit applications; brain transplants, AI and autonomous robots offer a glimpse of an ominous and pessimistic future probably gloaming over us.

We started with a quote, likewise we shall end with quotes. AI, the invention of all inventions, could spell the end of the human race. As Hawking stated, AI could be "the worst event in the history of our civilization". Therefore, it is entirely up to us to ensure that a dystopian future will not be realized. For it is not AI we should fear, but mankind itself...

> "The superficial post-war dream that technology would solve the world's social problems has transformed into a nightmare of electronically enabled global surveillance and suppression". Alejandro Garcia de la Garza, 2013.

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Quantitative Analysis Between Blackboard Learning Management System and Students' Learning

Charles Darko *

Department of Materials, The University of Manchester, Oxford Road, Manchester, M13 9PL, United Kingdom
* Corresponding author: Charles Darko, charles.darko@manchester.ac.uk

ABSTRACT:

Proper use of the Blackboard Learning Management System (LMS) motivates students to engage with their studies but the students within Material Science and Engineering (MSE) often use these LMSs to copy mathematical derivations, scientific information and submit coursework tasks without spending much time interacting with the system. Quantitatively, there is a piece of missing information on how interaction with the Blackboard LMS influences students' performances. Statistical evaluations were made by using the average times students spent on Blackboard and their final examination grades for their three-year Bachelor's degree period. There was a linear positive correlation between the time students spent on the LMS and their grades. Observations also show that students engage more with LMS at certain periods within a week. It was recognised that the more students engage with the Blackboard, the more they construct information for themselves. This result provides a quantitative analysis that gives evidence of how time spent on LMS supports students' learning.

KEYWORDS: Blackboard Learning Management System (LMS), Lecture Engagement, Material Science and Engineering students, Cognitive learning theory

1. Introduction

Learning Management Systems (LMS) are normally employed in higher education institutions to engage students [1,2]. The LMSs allow students to visualise lecture slides, interact with students and lecturers and submit their work. The influence of the time students spend online and their performances have not been evaluated quantitatively in a more relaxed and real-world approach [3,4]. Investigations on students' choice of online tools and the link between their unconscious (i.e. in a real-world environment) online hours and their final grades were made.

Previously, some studies discussed the interactions in terms of the time students spent online and their final performances were done [5,6]. Studies were made on asynchronous learning processes via an Educational Data Mining approach while using data extracted from the Moodle logs of students [5]. In that study, conclusions were made that clusters that are Task-oriented are efficient because they invested a high quantity of time in their tasks and they become high achievers than the Non-Task-Oriented Group that spent a small amount of time working on the practical task. Another investigation [6] revealed that *Consistent use students* and *Slide intensive use students* clusters who spend more time had better homework and examination grades than the *Less use students group* who spent less time. After analyzing LMS system logs in 59 computer science students during the blended learning approach [6], it was also generally confirmed that those who spent more time had better grades.

1.1. LMS and their functions

The motivation for students to access a particular LMS tool varies and links to their learning performances [7]. In that study, varied reasons for students' satisfaction were predicted based on their usage frequencies after a model of the information system was developed to evaluate students' satisfaction in terms of the quality, service and, pedagogical.

Table 1 shows a summary of the most available LMS tools with their functionality, affordability, suitability and

limitations [8-13]. From table 1, it can be observed that Blackboard LMS promotes online discussions, permits the visualization of other internet platforms (e.g. web pages, wikis, blogs, email ,etc), and analytical monitoring tools [12]. The Massive Open Online Course (MOOCs) LMS supports students' discussions, allows quizzes, and uploading of lectures materials [8]. The MOOCs LMS platforms allow forum use, lecture podcast viewing, quizzes, material downloads and assignment submissions [11, 14].

The Canvas LMS also enables students to participate in discussion forums [15] while the Accord LMS allows free accessibility and customized multicultural training for school professionals [13], It was also observed that Schoology provide teachers and students with the opportunity to set up groups, courses, administer and integrate resources, and create statistical data on students' progression [10].

Most high educational institutions universities use Blackboard LMS to engage with their students [16-18]. Previous reports on Blackboard suggest that students improve their performances when they engage more with the LMS [19-22]. While students engaged well with their peers, the staff viewed face-to-face interactions as a valuable learning experience in one of those studies [22]. The Blackboard LMS was also noticed to improve positively both students and staff interactions in a computer literacy program [21].

When Blackboard is compared with other LMSs [23-25], it was observed that Moodle was being preferred because of the ease of its [23] but Schoology was adjudged to improve communication skills, collaborations and connect with stakeholders on the same platform [25]. However, the Blackboard LMS was found to be superior *e*-learning LMS for course curriculums and students' engagement.

1.2. Purpose of the study

This work looks to improve the work done in the past that looks to find a relationship between the time students spent online and their performances [5,6,26,27] but with a real-world teaching environment. The real unconscious average time that students spent online during their entire studies were investigated and linked to their final grades. The approach of this work is to remove any barrier that inhibits a real teaching environment and statistically quantified the relationship.

There are two approaches; (*1*) investigating students' preferred online engagement, and (*2*) statistically evaluating the relationship between students' Blackboard leearning times and their final grades.

2. Method

The following survey and experimental approach were adopted;

Pathway 1: The undergraduate MSE students were surveyed and their responses illustrated under appendix A, section 1. Data collected for forms of engagements are as shown in tables 1 to 3 (appendix A). A plot of the responses were also done to vislualize students's perception..

Table 1. Examples of learning management systems and their functions

LMS tool	Functions	Limitation
Blackboard	Create online assessments, facilitate discussion and deliver high-quality training and learning content. Have a variety of blended learning capabilities, social engagement features and content authoring tools to enhance e-learning content and learner engagement. It has threads to structure online discussions and allows posting and replies. Currently, it allows videos, display of web pages, wikis, blogs, email, and analytics that monitors students' activities as well as surveys [12].	Usability does not just apply to business software or entertainment websites [17].
MOOCs	MOOCs allows videos, discussion forums, chat groups, lecture materials, quizzes, lecture viewing, and coursework submissions [8].	Needs to initiate a platform to include multiple pathways that support user activities [14].
Moodle	Features course gamification, peer and self-assessment, file management, multilingual capabilities and a shared calendar. Users can create course forums, wikis and more. Free license cost. Moodle promotes videos adaptation, chat forums, chat groups, uploading lecture resources, setting of quizzes, lecture viewing, and coursework submissions [11].	Needs proper IT architecture and manpower in place to implement and maintain a system.
Canvas	Web-based software that offers all of the core LMS functionality including course and assessment creation, and course management [15].	Does not have links to social media sites like YouTube and Facebook for informal learning.
Accord	A web-based software for schools and businesses that promotes social learning and role-based groups to engage with over 200,000 students. More affordable than *Blackboard* [13].	It has a reporting challenge.
Schoology	The objective of this free platform is to create a learning strategy for students and to motivate studying online. On this platform, teachers and students are able to develop groups and courses, administer resources, set course materials and present statistical data for students' assessments [10]. Other platforms such YouTube, Google Drive and Turnitin can be used.	While navigation can be confusing, it requires operator to allow students to unenroll.

Pathway 2: The number of Blacboard logs from previous third-year Bachelor students were investigated and compared with their grades. Tables 4 and 5 (appendix B) show the average data from sixty-nine (*69*) students in a semester-year and the entire three-year period were obtained from the e-learning person. The students' IDs

were replaced with numbers to ensure complete anonymity based on ethical reasons and that allowed the evaluation between their login times during the entire study period and their final grades.

In the statistical analysis, averages were made from the total average login times for each year (table 5, appendix B), After that, trend analyses were made to bring out a clear relationship between the students' login times and their final grades.

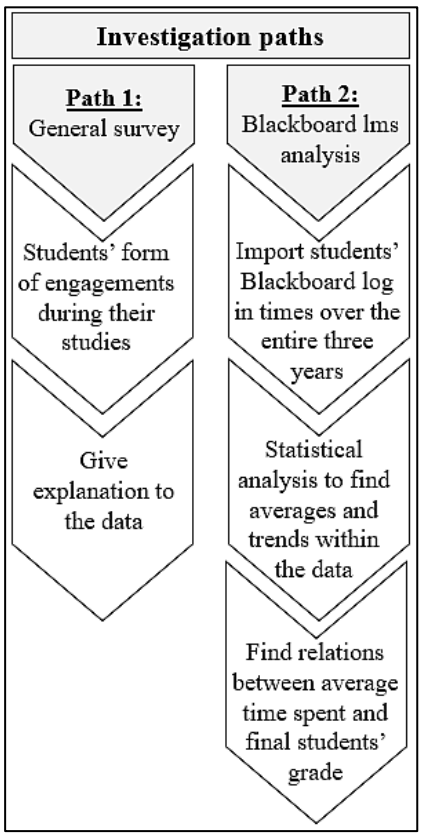

Figure 1: Investigation pathways

In the survey, the type of program, learning style, method of learning new concepts, engagement form as well as type of internal and external digital resources (see Appendix A, section 1) were investigated. Random responses from eighty-three (*83*) students that selected multiple choices were obtained. A student can select all five (*5*) options in the learning styles, three (*3*) for learning new concepts, four (*4*) for forms of engagement and two (*2*) for internal digital that support learning as shown in section (appendix A). There would be 415 if all 83 students in table 1 select all 5 options within the forms of engagements (appendix A). As a result, table 1 (appendix A) revealed a total of 212 selections for the forms of engagement that constitute 46 responses for the lecturer's feedback, 45 for Blackboard, 41 for face-to-face lectures, 39 for demonstrations, 36 for coursework, 1 for lecture sheets, 1 for podcast content, 1 for seminars, 1 for academic one-to-one engagement and 1 for going over contents for the low-grade students.

2.1. Calculating Simple Moving Average

To visualize the trend of the bivariate data between the mean time students spent on LMS and their grades, trend analysis [28,29,30] was performed using a four (*4*) point simple moving average (SMA) [31] as follows;

$$\boldsymbol{SMA = \frac{(S_n + S_{n+1} + S_{n+2} + S_{n+3})}{4}}$$

The terms S_n, S_{n+1}, S_{n+2}, and S_{n+3} are four (*4*) consecutive numbers from the table. In the trend analysis, the first 4 numbers within the column were averaged which was followed by the next 4 consecutive numbers as shown in table 6 (appendix B). The procedure was repeated until all data were used.

2.2. Calculating the Product Moment Correlation Coefficient (r)

The correlation coefficient called Product Moment Correlation Coefficient (*r*) [32, 33, 34] was used to predict the correlation between the average time spent by the students and their grades at the end of their three-year program after the SMA trend analysis. The correlation coefficient, *r*, is given by;

$$\boldsymbol{r = \frac{S_{x\,y}}{\sqrt{S_{x\,x} S_{y\,y}}}}$$

Where

$$\boldsymbol{S_{x\,x} = \sum x^2 - \frac{(\sum x)^2}{n}}$$

$$\boldsymbol{S_{y\,y} = \sum y^2 - \frac{(\sum y)^2}{n}}$$

$$\boldsymbol{S_{x\,y} = \sum xy - \frac{\sum x \sum y}{n}}$$

Note that *x* represents the variables for the total average obtained from the average times students spent over the three years, and *y*, the variables for their final grades obtained. The *r*-value can be defined as;

$$\boldsymbol{-1 \leq r \leq 1}$$

When *r* = 1, a positive linear correlation is obtained, *r* = -1 gives a negative linear correlation, and *r* = 0 predicts a no correlation data.

3. Results

In pathway 1, and since the department uses the Blackboard LMS, the survey done was to find out whether students use any other online engagements and most of them confirm the usage of Blackboard. This was followed by the statistical analysis in pathway 2 to find the

correlation between the average time spent by students on Blackboard over the three years and their final grades. The results obtained have been explained below.

3.1. Survey results

The survey results demonstrate that students rely more on lecturer feedback, Blackboard, in-person discussions with the lecturer, graduate teaching assistance (GTA) demonstrations and coursework as shown in figure 2a. It can be postulated that the MSE students deal more with mathematical derivations, theory and science definitions and they get more information from the Blackboard LMS which also enables them to have fruitful discussions with lecturers. Interactions with some of the other students revealed that they focus more on how to get better grades rather than engaging in seminars and other meetings.

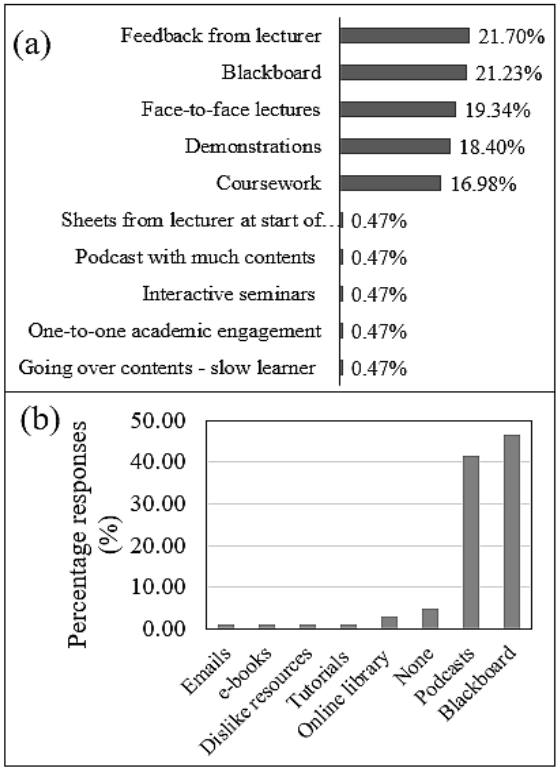

Figure 2: Survey results on the forms of engagement (a) and type of internal digital resources (b) used by the students (see table 1 and 2 in appendix A)

The survey results confirmed the use of Blackboard LMS as the most used digital resource used by the students (figure 2b) but there were also higher ratings for podcasts that can be accessed through the Blackboard LMS. In addition, there were other online platforms such as YouTube, emails, etc. also embedded in Blackboard. Meaning that the results in figure 2b are more informative and justifies why the relationship between the average Blackboard log times and students' final grades is very important.

3.2. Students' log times versus their final grades

The average login times students spent online per day for the two-semester period have been plotted against their final exam grades (figure 3). It was clear that there was a weak positive linear correlation but it was necessary to work with the exams grade since all students were examined using the same examinations process. It was believed that all students use similar exam preparation times, and exam guidelines but the information absorption might vary. The main point is that the students might have different learning styles, absorption rates, capacity of the working memories and that might influence their final grades [35,36]. In summary, the data represent perfectly the students' performances because they all received the same Blackboard LMS information.

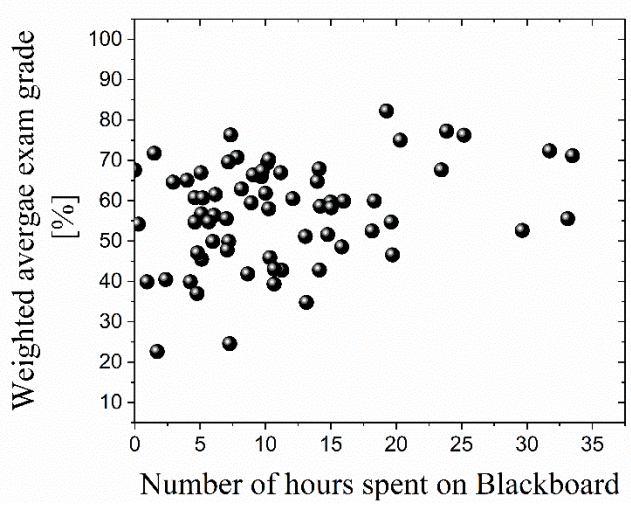

Figure 3: A plot of the average login hours per day for two semesters over three year periods versus students' final grades.

Another intriguing analysis is shown in figure 4. It was noticed that had more engagement with the Blackboard on Wednesdays and Fridays over the two semesters and this suggests that lecturers might use these two days to effectively communicate with the students. The lecturers might use those two days to set coursework deadlines. The remaining days are not suitable for scheduling assignment deadlines since students do not engage well on those days.

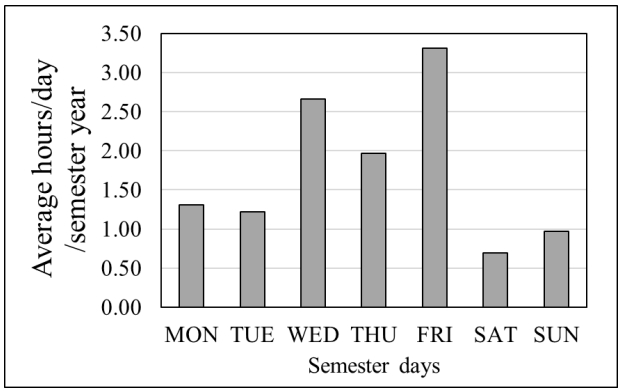

Figure 4: Average hours per day per semester-year. Data plotted from table 4 (Appendix A)

3.2.1. Finding the relationship between the average time students spent online versus their final grades

After statistical analyses of the data by using the four (4) point moving average described in section 2.1, the full

results obtained are as shown in table 6 (appendix B). The four (4) point moving process involves averaging the first 4 numbers in each column before moving to the next four (4) consecutive numbers until all data is completed.

The results after the statistical analysis of the data gave a strong positive correlation between the overall average time students spent online and their final grade (figure 5). The statistical trend analysis enabled the visualization of the relationship between this complex bivariate data. The complexity of the data stems from the fact that the accurate and effective usage of the Blackboard LMS by the students cannot be quantified perfectly but the trend analysis gives a good indication of the relationship between the data. The *r*-square value of 0.56 (figure 5) suggests a strong positive correlation after the statistical trend analysis.

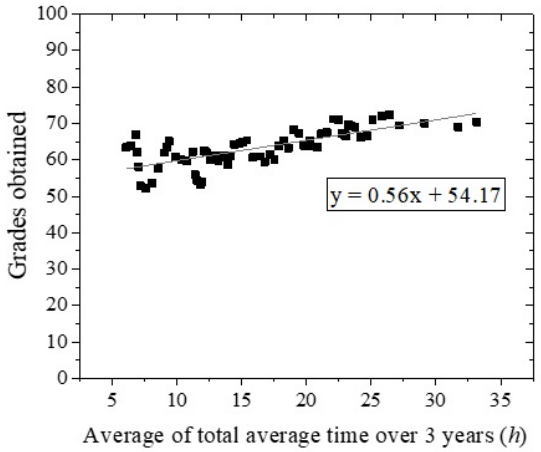

Figure 5: Statistical data plot after trend analysis of the average of the total averages time students spent over a three-year period versus their final grades (data in table 6 - appendix B).

3.2.2 Product Moment Correlation Coefficient (r)

To confirm the strength of the correlation, the treated data from the 4 points moving average were used to calculate the correlation coefficient (*r*). Using the description under section 2.2, the values in table 7 (appendix B) were generated. The values in table 7, appendix B) were calculated with;

$$\sum x = 1097.74$$

$$\sum y = 4241.70$$

$$\sum x^2 = 21044.37$$

$$\sum y^2 = 270272.92$$

$$\sum xy = 71252.63$$

The number of data used, $n = 67$.

Meaning,

$$\boldsymbol{S_{x\,x} = 21044.37 - \frac{(1097.74)^2}{67} = 3558.80}$$

$$\boldsymbol{S_{y\,y} = 270272.92 - \frac{(4241.70)^2}{67} = 1735.32}$$

$$\boldsymbol{S_{x\,y} = \sum xy - \frac{\sum x \sum y}{n}}$$

$$\boldsymbol{S_{x\,y} = 71252.63 - \frac{1097.74 \times 4241.70}{67} = 1755.86}$$

and

$$\boldsymbol{r = \frac{1755.86}{\sqrt{3558.80 \times 1735.32}}}$$

$$\boldsymbol{r = 0.71}$$

The value of *r* around 0.7 means that the square value is 0.5 (i.e. $r^2 = 0.5$) and this confirms that the perfect positive linear correlation that exists between the bivariate data is similar to that obtained from the plot in figure 5.

4. Discussions

The observations reveal that students engage more with the Blackboard LMS on Wednesdays and Fridays and it was not checked whether this is peculiar to the MSE program but the result is similar to a different study where students were found to interact more with the Blackboard at certain periods [37, 38]. It also provides substantial information that lecturers must avoid setting deadlines and actions on the rest of the days sinc students might stick more to their non-academic activities.

The very good and positive correlation obtained after the statistical trend analysis gives evidence of the fact that there were several factors at play and a clear picture could only be observed after the trend analysis. It was believed that before the trend analysis (figure 3), factors such as technology barriers [39], misconceptions because of internationalization [40]), different learning styles [41-44], and Blackboard inactivity after login [45] may have influenced the correlation. Hence, the analysis was necessary to mitigate those factors and promote a clear picture of the data.

The positive correlation predicts that the more engagements students have with the Blackboard LMS, the more they will improve their grades and the result is comparable to previous findings. Students who spent more time improve their grades and became high achievers [5, 6, 46].

The result also relates to the constructivism learning theory [47] that suggests that learning must be an active process where students construct their learning and that can be said to have happened when they engage more with the Blackboard LMS [48].

4.1. Effects of reading from the computer screen on the results

Excessive participation in online learning and discussions may occasionally inhibit students' learning since that might affect their concentration and divert them from the main issues during learning [49]. To aid effective online discussions and reduce students' search times online, content quality must be the top priority. As suggested by the cognitive learning theory, part of the reasons why students do not store information correctly is their ineffectiveness to process the acquired information via a computer screen [50]. The usage of Tablets may also pose a technological hindrance during information capturing since special skills will be required to enhance performance [51].

In the human eye, the process is such that, the retina (composed of millions of light receptors known as rods and cones that detect visible light) conveys reading information to the brain and the brain translates the information as visual objects. The act of gazing and movement of the eye in front of computer screens can predict user intentions [52]. Previous investigations suggest that gazing prompts attention and directs cognitive processes within the brain [52]. This is because our attentional orienting system quickly and automatically prioritizes salient visual events [53].

Furthermore, screen characters, contrast, colour, background, and the dynamic aspects of the screens affect readability [54]. Kim and Albers [55] noted that user motivation in searching for information, varied information, and user's knowledge of the types of information are key factors for consideration. Moreover, reading is normally done for quality but not on the reading speed [56].

4.2. Influence of the cognitive processes on the results

Sticking with the cognitive learning theory that postulated that learning is the development of knowledge and conceptual development which includes the storing of knowledge in the brain and the process of that knowledge [57, 58, 59]. In another study, Piaget was also quoted to have described learning to be the formation of new schemas (i.e. a pattern of thought) and the building on previous schemas [50]. It was also disclosed that Piaget proposed learning to be an organization of schemas and adaptation of schemas and that new information is created by absorbing and readjusting previous schemas [60]. In addition to the above, when the cognitive load is less it becomes easier and more processable than a high cognitive load because some of the working memories of users cannot process a very heavy load [35, 36].

4.3. Influence of the Blackboard screen design on the results

Designing a good Blackboard LMS screen can improve spontaneous information processing and reduce the cognitive load during learning [61]. There is a high cognitive load requirement when reading from the screen than for print because there is an additional screen navigation skills requirement [62-66]. Hence, poorly designed computer screens hinder communication [67].

4.4. Influence education level and computer usage

The education level of any student might influence their computer skills to scan through the screens and absorb information and this will have the same limitations of the required information landing on the retina before transporting it for conversion into the desired results [52, 68]. After that, the brain prioritizes salient visual events [53]. The mood of the user might also influence the required skills to scan the computer screens efficiently [69] and this has been noticed that positive moods predispose people towards using computers, while negative moods contribute to computer avoidance [70, 71].

5. The implication of this study

The students preferring the Blackboard LMS was because it was the only one adopted by our institution even though other students occasionally use other forms of engagement, they did not alter their preferences.

Some students spend much time during information absorption and this can be explained by the cognitive learning theory such that effective learning can be achieved if previously-stored information can be processed further to create new knowledge and enhance conceptual development [57, 58, 59]. The explanation suggests that spending more time on the Blackboard LMS helps to process stored knowledge and the creation of new information. Piaget's work also confirms this notion that learning is the formation of new schemas (i.e. a pattern of thought) and building upon previous schemas during learning [50]. It can be summarized under this section that students who spend much time on the Blackboard LMS have much time to absorb information irrespective of the working memory capacity and they can readjust previous schemas [60].

The screen design also plays a role in knowledge absorption and an excellent screen design promotes spontaneous processing of information and improves students' learning rate [61]. Normally, students who engage with the screen readings need to deal with a greater cognitive load than print reading since they required additional time and skills to have an effective scanning of the information [62, 63].

From another angle, the level of education might also affect their information scanning abilities because some inexperienced students may not be used to this process of fishing out information from the screen. Having positive moods enhances computer engagement [70,71] which was also confirmed by a previous study observing that the

computer skills were greatly affected by the mood of the users [69]. Consequently, this might influence the time students spent online even though it can not be justified what students do online when they log in. Furthermore, this work will have extensive studies on what students do when they log onto Blackboard LMS including any upgrade on the Blackboard software within the three years. It is noted that there might be a frequent update of the Blackboard LMS that would have affected every student during the investigations.

6. Conclusion

To conclude, the work demonstrates that students engage more on Wednesdays, Thursdays and Fridays and their engagement with the Blackboard was found to correlate positively with their final grades after trend analysis was performed on the data. It was noticed that the trend analysis supported the visualization of the pictorial correlation by minimising the complexity of the data. This result suggests that spending much time on the Blackboard LMS might help the creation of new knowledge in the schema and allows further process within the memory that may support the development of new information.

Conflict of Interest

The authors declare no conflict of interest.

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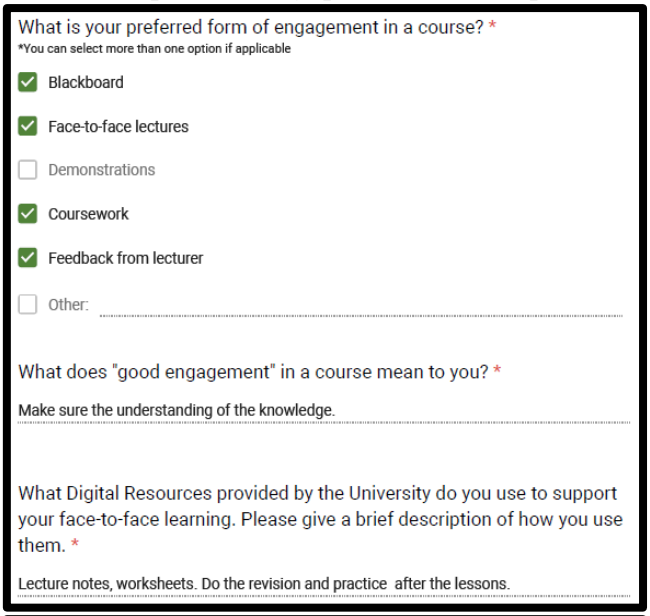
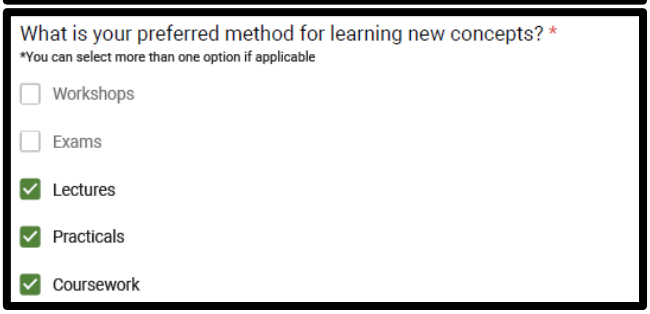
CHARLES DARKO is a lecturer in Polymer Science at the University of Manchester. He graduated with a BSc (Hons) in Mining Engineering, MSc degree in Polymer Science, Halle, PhD in Experimental Polymer Physics (Dr Rer. Nat.) and PgCert in Higher Education.

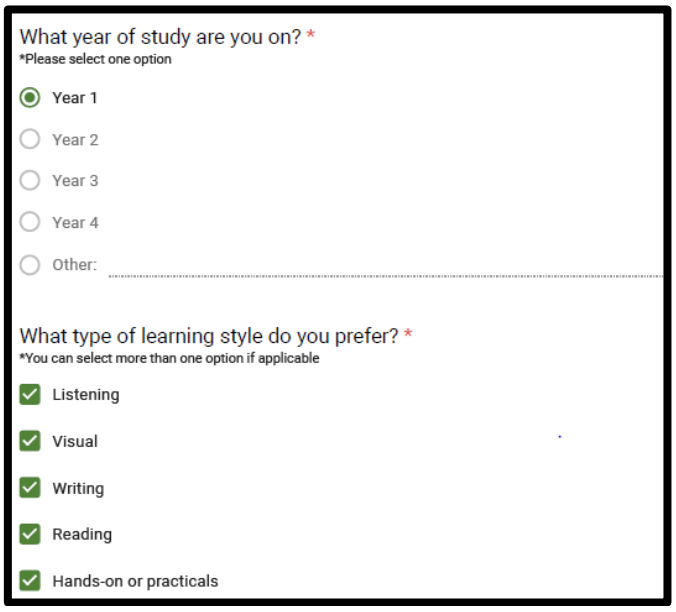
He worked on several polymer thin film researches such as Crystallization in diblock copolymer thin films at different degrees of supercooling, Kinetics in Block Copolymer Films", Laboratory testing equipment and how students' approach constructivism Learning, Blackboard Management System to Enhance Student's Learning. He is currently a Professional Member of the Institute of Materials, Minerals and Mining (MIMMM) and holds a Chartered Engineer (CEng) status.

Appendix A

1. Example of survey questions and responses







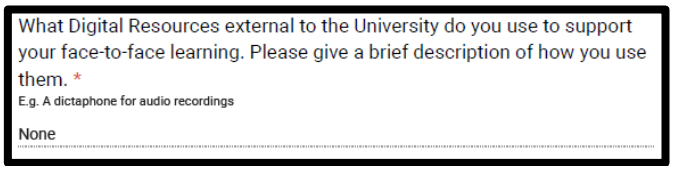


Table 1. Examples of learning management systems and their functions.

Respond topics	Number of responses
Blackboard	7
Blackboard;Coursework	5
Blackboard;Coursework;Feedback from lecturer	1
Blackboard;Demonstrations	3
Blackboard;Demonstrations;Coursework	2
Blackboard;Demonstrations;Coursework;Feedback from lecturer	1
Blackboard;Demonstrations;Coursework;Feedback from lecturer;As a slow learner I need to go over the content several times before I can consolidate everything	1
Blackboard;Demonstrations;Feedback from lecturer	1
Blackboard;Face-to-face lectures	3
Blackboard;Face-to-face lectures;Coursework	1
Blackboard;Face-to-face lectures;Coursework;Feedback from lecturer	5
Blackboard;Face-to-face lectures;Demonstrations;Coursework	2
Blackboard;Face-to-face lectures;Demonstrations;Coursework;Feedback from lecturer	4
Blackboard;Face-to-face lectures;Demonstrations;Feedback from lecturer	1
Blackboard;Face-to-face lectures;Feedback from lecturer	5
Blackboard;Feedback from lecturer	1
Blackboard;Podcast with much contents	1
Coursework;Feedback from lecturer	2
Demonstrations	2
Demonstrations;Coursework	2
Demonstrations;Coursework;Feedback from lecturer	4
Demonstrations;Feedback from lecturer	4
Face-to-face lectures	2
Face-to-face lectures;Coursework	1
Face-to-face lectures;Coursework;Feedback from lecturer	1
Face-to-face lectures;Demonstrations	2
Face-to-face lectures;Demonstrations;Coursework	2
Face-to-face lectures;Demonstrations;Coursework;Feedback from lecturer	4
Face-to-face lectures;Demonstrations;Feedback from lecturer	3
Face-to-face lectures;Demonstrations;Some form of 1 to 1 engagement with academic would be good	1
Face-to-face lectures;Feedback from lecturer	4
Feedback from lecturer;Interactive seminars	1
Feedback from lecturer	3
Sheets to fill-in in the lecture that are given out at the start of the lecture	1
Total	***83***

Note. In all there were 212 selected options since some students selected multiple choices per question as shown above. Hence, the total selected items were feedback from lecturer = 46, Blackboard = 45, face-to-face lectures = 41, demonstrations = 39, coursework = 36, sheets from lecturer at start of lecture = 1, podcast with much contents = 1, interactive seminars = 1, one-to-one engagement with an academic = 1 and going over contents because of being slow learner = 1.

Table 2. Responses according to the internal digital resources used within the University.

Respond topics	Number of responses
Blackboard	30
Blackboard, podcasts	16
Blackboard, podcasts, e-books	1
Emails	1
None	5
Online library	1
Online library, podcasts	2
Podcast	25
Dislike resources	1
Tutorials	1
Total	***83***

Note. In all there were 101 selected options since some students selected multiple choices per question. Hence, the total selected options were Blackboard = 47, podcast = 42, none = 5, online library = 3, tutorials = 1, dislike resources = 1, e-books = 1 and emails = 1.

Table 3. Responses according to the type of external digital resources used.

Respond topics	Number of responses
Books and TED talks	1
Wolfram alpha and quora	1
Mooc	1
Kahoot	1
ScienceDirect	1
Books and external videos	1
Web of science	1
Linkedin learning	1
WGSN	1
Internet	2
Wikipedia	3
Scientific journals	8
Google	11
Youtube	13
None	17
Total	***63***

Note. In all, there were 63 selected options from the students. Those who do not use external digital resources left the questions open.

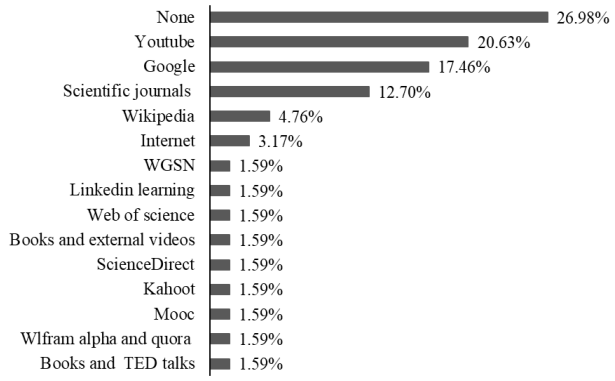


Figure 1: A plot of responses according to external devices used

Appendix B

2. Blackboard analysis

2.1. Year one semester data

Raw data from the server for students which show the average amount of hours spent on Blackboard for each weekday is as shown below (i.e. Monday → Mon, Tuesday → Tue, Wednesday → Wed, Thursday → Thu, Friday → Fri, Saturday → Sat and Sunday → Sun) during the two-semester periods for the 2017-2018 year only.

Table 4. Average hours per day per semester-year for each student

no.	MON	TUE	WED	THU	FRI	SAT	SUN
1	0.04	0.06	1.42	5.38	4.74	2.18	6.49
2	0.85	2.18	0.36	3.16	3.25	0.05	0.29
3	0.22	0.83	0.01	1.45	1.48		0.00
4	0.02	0.00	3.83	0.81	1.14	3.53	0.36
5	0.38	0.34	30.93	0.94	0.60	0.02	0.27
6	0.02	2.40	1.39	0.20	2.21	2.25	0.61
7	0.09	0.01	0.08	1.91	2.56	2.07	1.11
8	0.06	1.71	0.12	0.03	4.69	0.57	0.01
9	0.15	0.64	0.02	0.87	3.39	0.02	2.26
10	0.15	0.00	0.29	0.05	4.58		
11	3.84	4.15	7.74	0.12	4.50	0.20	2.91
12	0.38	0.35	1.84	0.68	7.73	0.04	0.15
13	0.25	0.01	3.22	3.55	2.18	0.79	0.00
14	1.93	2.33	0.06	0.03	1.62	0.05	0.05
15	0.12	0.21	0.06		9.69		0.17
16	1.03	0.32	0.84	6.06	4.94	0.74	0.03
17	0.05	0.00	1.13	0.50	2.92	0.00	0.00
18	1.57	0.02	0.31	1.36	8.90	0.74	2.10
19	1.26	0.07	0.08	1.27	4.29	0.01	0.03
20	0.30	0.34	1.10	0.15	3.19	0.00	0.04
21	0.16	0.00	1.59	1.33	1.51	0.02	1.05
22	3.12	0.00	0.37	0.01	1.09	0.01	0.00
23	1.74	1.96	4.44	0.05	5.76	0.00	0.25
24	0.07	0.36	0.39	0.13	4.26	2.89	0.07
25	7.89	2.13	0.29	4.31	1.17	0.17	0.03
26	0.34	2.54	3.75	1.71	6.42		
27	0.01	0.27	0.01	0.40	4.44	0.84	0.01
28	0.13	0.01	0.00	4.61	2.28	0.13	0.03
29	0.08		3.66	0.72	0.66		
30	0.32	0.01	3.27	1.31	7.27	0.35	0.53
31	0.17	0.00	0.01	0.20	2.53	1.88	0.00
32	0.44	0.00	0.00	6.78	1.38	0.02	0.02
33	1.76	2.12	2.24	0.54	0.03	0.73	3.25
34	0.11	0.00	2.32	4.44	4.39		
35	0.09	0.01	0.00	1.80	10.73	0.50	0.01
36	0.19	0.01	0.01	0.78	3.24	0.01	0.01
37	1.50	2.91	4.52	0.62	0.42	0.89	3.28
38		0.00		0.94			
39	2.41		1.37	0.07	3.42		
40	0.18	0.09	0.25	0.00	4.90		
41	0.22	1.91	21.33	2.71	0.83	3.21	1.52
42	6.20	5.38	4.11	2.80	0.22	0.09	0.45
43	3.14	0.06	0.26	1.40	13.46	0.00	
44	3.30	2.79	2.66	5.79	1.78	0.29	3.10
45	0.00	0.00	0.01	0.01		2.34	0.02
46	7.43	5.68	4.20	4.85	2.01	3.88	5.07
47	1.09	1.91	0.05	2.11	0.06	3.45	0.26
48	0.60	0.08	3.00	0.53	2.86		0.01
49	6.09	0.20	0.28	0.65	2.85	0.12	0.14
50	4.72	0.26	11.89	6.15	5.01	0.79	0.82
51	0.13	0.33	2.87	8.48	1.94	0.13	1.97
52	1.67	3.45	0.14	0.49	4.30	0.26	3.80
53	0.07	0.03	1.02	1.56	0.51	0.20	2.78
54		0.28					
55	1.49						
56	1.71	0.86	1.40	0.29	0.76	0.17	0.01

57	0.09	0.24	0.21	1.76	0.62	0.01	0.01
58	0.05	0.70	0.02	0.23	0.71	0.02	
59	0.09	0.40	4.57	4.72	5.21	0.01	3.15
60			0.00				
61	1.97	1.56	2.04	1.01	2.61	0.79	0.70
62	0.67	1.34	10.67	0.73	0.90	0.64	0.07
63	0.93	0.20	8.35	0.68	1.21	0.04	0.69
64	0.00	0.08	2.83	3.62	2.94	0.05	0.24
65	1.98	0.01	1.08	1.57	0.08		0.07
66	4.08	7.18	3.88	6.19	3.80	0.01	0.04
67	0.17	11.41	1.85	2.81	6.36	0.00	1.25
68	0.15	3.38	3.32	5.90	4.54	0.03	2.31
69	4.67	0.12	0.33	1.68	2.12	0.01	1.33

Note. The student at number 60 did an average login of about 0.001667 hours on Wednesday's but no login at the remaining days. It resulted to 0 when moved to 2 decimal places.

2.2. Three-year period semester data

The averages for each full years were added and averaged to give the full program averaged times of each student.

Table 5. *The a*verage of the total average times students spent on Blackboard over the three years versus their final grades.

Student ID	Total average time in year 1 (*h*)	Total average time in year 2 (*h*)	Total average time in year 3 (*h*)	Average of total average times in 3 years (*h*)	Grades obtained
1	0.00	38.07	32.41	23.49	78.90
2	0.00	29.00	11.18	13.40	77.40
3	21.37	3.98	11.31	12.22	72.70
4	0.00	23.17	53.93	25.70	72.10
5	14.44	40.70	25.94	27.03	72.10
6	20.34	24.93	19.73	21.67	71.60
7	7.90	33.18	11.68	17.59	71.20
8	28.48	15.29	12.87	18.88	71.00
9	5.76	33.07	7.90	15.58	70.60
10	13.90	0.42	14.10	9.47	70.20
11	17.03	25.33	24.57	22.31	69.60
12	19.81	39.66	25.78	28.42	69.00
13	24.71	10.30	26.96	20.66	68.60
14	13.15	4.53	15.84	11.17	68.40
15	18.32	16.48	24.91	19.90	68.10
16	21.34	14.44	33.32	23.04	68.00
17	11.99	50.96	9.58	24.18	67.60
18	36.50	30.31	45.80	37.54	67.50
19	0.00	18.76	9.15	9.31	67.30
20	13.16	39.66	15.96	22.93	66.70
21	11.24	29.10	11.27	17.20	64.90
22	0.00	3.88	22.33	8.74	64.40
23	21.78	10.72	15.67	16.05	63.70
24	11.43	10.07	14.59	12.03	63.60
25	16.09	26.08	33.22	25.13	63.30
26	27.10	14.55	21.19	20.95	61.50
27	12.77	23.02	8.12	14.63	61.00
28	16.30	14.03	10.92	13.75	60.00
29	22.67	20.51	17.98	20.39	57.20
30	13.77	16.81	38.33	22.97	56.50
31	10.02	15.58	12.27	12.62	55.60
32	10.48	13.80	21.38	15.22	54.80
33	39.29	17.62	15.06	23.99	54.70
34	15.13	13.38	13.04	13.85	54.30
35	26.80	6.85	16.76	16.80	54.00
36	9.95	7.79	9.08	8.94	52.20
37	8.73	34.03	11.98	18.25	48.30
38	10.42	5.63	5.82	7.29	47.50
39	5.06	24.11	4.33	11.16	47.20
40	1.67	31.67	2.15	11.83	22.10
41	24.25	23.48	52.77	33.50	74.70
42	24.02	16.32	36.15	25.50	81.00
43	20.75	0.19	43.40	21.45	67.20
44	0.00	16.56	20.59	12.38	56.30
45	0.00	6.98	15.42	7.47	50.10
46	0.00	15.61	41.40	19.00	63.00
47	0.00	12.19	21.31	11.17	63.80
48	0.00	7.75	9.05	5.60	54.40
49	0.00	18.53	22.41	13.65	51.40
50	0.00	6.77	44.79	17.19	55.60

51	0.00	2.96	32.58	11.85	57.30
52	0.00	19.65	23.79	14.48	69.30
53	0.00	13.03	8.05	7.03	66.30
54	0.00	3.88	15.44	6.44	66.70
55	0.00	28.85	15.95	14.93	72.60
56	0.00	52.23	7.88	20.03	67.40
57	0.00	14.65	6.30	6.98	71.20
58	0.00	0.03	5.95	1.99	24.10
59	0.00	10.46	18.49	9.65	59.00
60	0.00	13.04	21.57	11.54	69.70
61	0.00	21.10	18.77	13.29	55.20
62	0.00	9.11	18.57	9.23	63.90
63	0.00	9.97	10.75	6.90	63.60
64	0.00	10.21	6.49	5.57	68.80
65	0.00	14.65	6.52	7.06	47.30
66	31.36	0.00	38.79	23.38	75.30
67	33.13	13.07	22.55	22.92	76.30
68	22.42	38.60	21.45	27.49	64.80
69	20.79	18.62	15.67	18.36	70.90

2.3. *Three years semester data*

Table 6. Evaluation using the Simple Moving Average method. This was done using data from appendix B, table 5.

Original Data		**4 Point Moving average**		
Student ID	**Average of total average time in 3 years (*h*)**	**Grades obtained**	**4 Point Average of Time spent (*h*)**	**4 Point Average of Degree obtained**
1	1.99	24.10		
2	5.57	68.80		
3	5.60	54.40	4.90	53.50
4	6.44	66.70	6.13	63.38
5	6.90	63.60	6.48	63.98
6	6.98	71.20	6.84	66.95
7	7.03	66.30	6.99	62.10
8	7.06	47.30	7.09	58.08
9	7.29	47.50	7.21	52.80
10	7.47	50.10	7.64	52.33
11	8.74	64.40	8.11	53.55
12	8.94	52.20	8.59	57.65
13	9.23	63.90	9.05	61.95
14	9.31	67.30	9.24	63.40
15	9.47	70.20	9.41	65.10
16	9.65	59.00	9.90	60.93
17	11.16	47.20	10.36	60.05
18	11.17	63.80	10.79	59.60
19	11.17	68.40	11.26	62.28
20	11.54	69.70	11.43	56.00
21	11.83	22.10	11.60	54.38
22	11.85	57.30	11.81	53.18
23	12.03	63.60	11.98	53.93
24	12.22	72.70	12.12	62.48
25	12.38	56.30	12.31	62.05
26	12.62	55.60	12.63	59.95
27	13.29	55.20	12.92	61.13
28	13.40	77.40	13.24	59.90
29	13.65	51.40	13.52	61.00
30	13.75	60.00	13.66	60.78
31	13.85	54.30	13.93	58.75
32	14.48	69.30	14.18	61.15
33	14.63	61.00	14.47	64.30
34	14.93	72.60	14.82	64.43
35	15.22	54.80	15.09	64.75
36	15.58	70.60	15.45	65.43
37	16.05	63.70	15.91	60.78
38	16.80	54.00	16.41	60.98
39	17.19	55.60	16.81	59.55
40	17.20	64.90	17.20	61.43
41	17.59	71.20	17.56	60.00
42	18.25	48.30	17.85	63.83
43	18.36	70.90	18.27	65.35
44	18.88	71.00	18.62	63.30
45	19.00	63.00	19.04	68.25
46	19.90	68.10	19.45	67.38
47	20.03	67.40	19.83	63.93

48	20.39	57.20	20.24	65.33
49	20.66	68.60	20.51	63.68
50	20.95	61.50	20.86	63.63
51	21.45	67.20	21.18	67.23
52	21.67	71.60	21.59	67.48
53	22.31	69.60	22.09	71.18
54	22.92	76.30	22.46	71.05
55	22.93	66.70	22.78	67.28
56	22.97	56.50	22.96	66.88
57	23.04	68.00	23.08	66.63
58	23.38	75.30	23.22	69.68
59	23.49	78.90	23.48	69.23
60	23.99	54.70	23.76	69.13
61	24.18	67.60	24.20	66.13
62	25.13	63.30	24.70	66.65
63	25.50	81.00	25.13	71.00
64	25.70	72.10	25.84	72.13
65	27.03	72.10	26.43	72.50
66	27.49	64.80	27.16	69.50
67	28.42	69.00	29.11	70.15
68	33.50	74.70	31.74	69.00
69	37.54	67.50	33.15	70.40

2.4. Three years semester data

Using data from table 6 in the Simple Moving Average method, x becomes the variables for the total average of the average times students spent over three-year period and y as the variables for the grades obtained. The results from the calculations are as shown below.

Table 7. Parameters needed to calculate r.

Item	x	y	x^2	y^2	xy
	4.90	53.50	24.01	2862.25	262.16
	6.13	63.38	37.55	4016.39	388.36
	6.48	63.98	42.02	4092.80	414.68
	6.84	66.95	46.77	4482.30	457.87
	6.99	62.10	48.90	3856.41	434.25
	7.09	58.08	50.26	3372.71	411.71
	7.21	52.80	51.99	2787.84	380.71
	7.64	52.33	58.33	2737.91	399.63
	8.11	53.55	65.73	2867.60	434.16
	8.59	57.65	73.82	3323.52	495.32
	9.05	61.95	81.93	3837.80	560.76
	9.24	63.40	85.30	4019.56	585.56
	9.41	65.10	88.62	4238.01	612.84
	9.90	60.93	97.97	3711.86	603.05
	10.36	60.05	107.40	3606.00	622.33
	10.79	59.60	116.40	3552.16	643.02
	11.26	62.28	126.80	3878.18	701.25
	11.43	56.00	130.58	3136.00	639.93
	11.60	54.38	134.49	2956.64	630.59
	11.81	53.18	139.48	2827.58	628.02
	11.98	53.93	143.55	2907.91	646.10
	12.12	62.48	146.88	3903.13	757.17
	12.31	62.05	151.63	3850.20	764.08
	12.63	59.95	159.49	3594.00	757.11
	12.92	61.13	167.00	3736.27	789.92
	13.24	59.90	175.26	3588.01	792.98
	13.52	61.00	182.78	3721.00	824.70
	13.66	60.78	186.58	3693.60	830.16
	13.93	58.75	194.06	3451.56	818.43
	14.18	61.15	201.01	3739.32	866.97
	14.47	64.30	209.49	4134.49	930.67
	14.82	64.43	219.55	4150.58	954.59
	15.09	64.75	227.75	4192.56	977.16
	15.45	65.43	238.59	4280.43	1010.58
	15.91	60.78	253.26	3693.60	967.19
	16.41	60.98	269.15	3717.95	1000.34
	16.81	59.55	282.65	3546.20	1001.16
	17.20	61.43	295.69	3773.03	1056.24
	17.56	60.00	308.23	3600.00	1053.39
	17.85	63.83	318.61	4073.63	1139.25
	18.27	65.35	333.74	4270.62	1193.86
	18.62	63.30	346.80	4006.89	1178.81
	19.04	68.25	362.37	4658.06	1299.20
	19.45	67.38	378.48	4539.39	1310.76
	19.83	63.93	393.30	4086.41	1267.74

	20.24	65.33	409.84	4267.36	1322.48
	20.51	63.68	420.50	4054.51	1305.73
	20.86	63.63	435.11	4048.14	1327.18
	21.18	67.23	448.59	4519.20	1423.82
	21.59	67.48	466.31	4552.88	1457.07
	22.09	71.18	487.85	5065.88	1572.06
	22.46	71.05	504.31	5048.10	1595.56
	22.78	67.28	519.04	4525.93	1532.69
	22.96	66.88	527.31	4472.27	1535.67
	23.08	66.63	532.63	4438.89	1537.63
	23.22	69.68	539.20	4854.61	1617.90
	23.48	69.23	551.09	4792.10	1625.08
	23.76	69.13	564.57	4778.27	1642.46
	24.20	66.13	585.52	4372.52	1600.06
	24.70	66.65	610.01	4442.22	1646.15
	25.13	71.00	631.30	5041.00	1783.93
	25.84	72.13	667.59	5202.02	1863.56
	26.43	72.50	698.41	5256.25	1915.99
	27.16	69.50	737.53	4830.25	1887.44
	29.11	70.15	847.25	4921.02	2041.90
	31.74	69.00	1007.13	4761.00	2189.73
	33.15	70.40	1098.98	4956.16	2333.82
Sum	**1097.74**	**4241.70**	**21044.37**	**270272.92**	**71252.63**

2.5 *Abbreviations*

Abbreviation	**Explanation**
LMS	Learning Management System
MOOC's	Massive Open Online's Course
MOODLE	Modular Object-Oriented Dynamic Learning Environment

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Surface Defect Detection using Convolutional Neural Network Model Architecture

Sohail Shaikh*, Deepak Hujare , Shrikant Yadav

School of Mechanical Engineering, Dr Vishwanath Karad MIT World Peace University, Kothrud, Pune, Maharashtra-411038, India.
*Corresponding author: Sohail Shakil Shaikh, Pune, 9075429042, sohailshaikh133@gmail.com
ORCID Authors 1* : 0000-0001-7385-9965, ORCID Author 2: 0000-0002-0337-8709, ORCID Author 3: 0000-0002-8674-0610

ABSTRACT: With the dominance of a technical and volatile environment with enormous consumer demands, this study aims to investigate the advancements in quality assurance in the era of Industry 4.0. For better production efficiency, rapid and robust automated quality visual inspection is developing rapidly in product quality control. Deep neural network architecture is built for a real-world industrial case study to achieve automatic quality inspection built on image processing to replace the manual inspection, and its capacity to detect quality defects is analysed to minimise the errors. The primary goal is to understand the developments in quality inspection and their implications regarding finances, time expenditure, flexibility, and the model's optimum accuracy-precision compared to manual inspection. As an innovative technology, machine vision inspection offers reliable and rapid inspections and assists producers in improving quality inspection efficiency. The research provides a deep learning-based method for extended target recognition that uses visual data acquired in real-time for neural network training, validation, and predictions. The data made available by machine vision setup is utilised to evaluate error patterns and enable prompt quality inspection to achieve defect-free products. The proposed model uses all data provided by integrated technologies to find trends in data and recommend corrective measures to assure final product quality. As a result, the work in this study focuses on developing a deep convolutional neural networks (CNN) model architecture for defect identification that is also highly accurate and precise and suggests the machine vision inspection setup.

KEYWORDS: Quality Assurance, Industry 4.0, Deep Neural Network, Quality inspection, Machine Vision, Convolutional Neural Network.

1. Introduction

In this modern world, recent changes have occurred in the industrial sector in the digital transformation of the traditional production process. This new paradigm in the production process tends to drive the world towards the Industrial Revolution 4.0. Industry 4.0 ultimately came into the role to meet the growing demand for various products with better final product quality.

Quality control is the procedure in the manufacturing industry that guarantees clients receive products that are free of faults and meet their requirements. Therefore, most industries do manual inspections on the final product to be delivered, using the acceptable quality limit chart (AQL chart) so that the clients receive a high-quality product. First, a quality inspector selects random samples from the lots for inspection. Then, based on the AQL chart level, whether the entire lot is accepted or rejected for dispatch is determined. However, this method has the drawback of including defective goods that were not taken as samples in the production batch and human errors or slow inspection speed. In addition, it can endanger harm a company's reputation [1]. To counter the significant drawback, intelligent machines, storage technologies, and production facilities that autonomously share information, initiate operations, and manage each other can be adopted [2].

Furthermore, the continuous learning process can enable machines to act independently, make decisions, and develop automatically, which can be achieved by

implementing the Artificial Intelligence subfield, machine vision [3]. Object connectivity is the first stage since it collects large amounts of data, increases productivity, improves machine health, improves production line automation, and leads to defect-free manufacturing through effective data exploitation and real-time analysis [4]. Moreover, it allows control of 100% of product inspections [3].

This paper contributes to the paradigm by proposing a machine vision architecture model based on the deep Convolutional Neural Network (CNN) presented in [3]. In this study, CNN model architecture was developed by employing an early stop function for the model, as model accuracy starts to repeat the accuracy and has a higher chance to overfit the model to get better and better accuracy in the training phase, eventually which will fail in the prediction phase due to the overfit. Therefore, to overcome the drawback of overfitting, a checkpoint was set up after each run of early stops of the model architecture to store the output, which is used as a learning aid for the next run for the same model architecture. The technique incorporates detecting faulty products and continuously enhancing industrial processes by anticipating the process variables to generate a defect-free product [3]. The model architecture intends to meet Industry Revolution 4.0 objectives by appropriately exploiting and analysing data produced by the connectivity of the supply chain to progress faster, more flexible, and more effective processes that deliver first-rate goods at a low cost [3], [4].

This research intends to build a neural network model and discuss the machine vision inspection setup for the application model to detect surface flaws for the impeller dataset to speed up the inspection process of the finished product with improved accuracy in real-time. As a result, the time-consuming manual inspection procedure in the industrial sector can replace by Artificial Intelligence.

The paper's structure is the current state and relevant literature discussed in Section 2. Section 3 provides an overview of the machine vision and implementation model. Dataset used in the proposed model is discussed in section 4. The proposed model scenario describe in depth in Section 5. The virtual setup for the proposed model is described in Section 6. Finally, section 7 discusses the results of the analysis.

2. Related Works

Several research works have been conducted based on the extraction of data or data mining obtained by various integrated automation in the current manufacturing sector and various machine learning methodologies to develop an intelligent machine vision architecture system for quality inspection in the industry. As a result, the following are some remarkable achievements of machine vision architecture applications in various fields.

2.1. Machine Learning Technique for Inspection Purpose

In [5], the authors investigated the applicability and current machine learning technique for the production assembly lines. The author discussed the diverse production assembly lines and difficulties while acquiring various data and implying the methods. The challenges encountered during modelling are regularly used to optimise production assembly-line operations and mathematical and computational approaches. According to the authors, the machine learning approach has been frequently applied in numerous manufacturing fields to intensify Overall Equipment Effectiveness (OEE) comprises the indicators of quality, potential performance, and availability of setup [5]. Two significant study directions have emerged in recent years: quality control and problem diagnosis, for which the machine learning approach is effective. The author also discussed unsupervised learning, which is vastly outweighed by supervised learning because of further regression and classification problems used in production assembly lines [5]. It also demonstrates that data is plentiful in production assembly lines, and as a result, supervised learning may be leveraged to produce more accurate outcomes. The most typical tasks for quality prediction are regression and classification. According to research findings, ANN is the most commonly employed algorithm [5]. The success of neural networks in production assembly lines is presumably due to two fundamental factors. First, production assembly lines are a complicated system in which neural networks can handle the sophisticated interaction between characteristics and the dependent variable. Second, production assembly lines can produce massive amounts of data that neural networks can use and handle easily, as more extensive dataset aids in the performance of neural networks. The imbalanced datasets pose a complex problem in production processes. The majority of data points fall into one of two categories, with only a few falling into the other. Most data points do not represent this exact condition, especially in unusual cases; hence specific methods will be necessary to balance the datasets [5].

Investigation of the deep neural networks for automatic quality assessment based on image processing to overcome the drawbacks of the manual quality control process in the paper bag industry was carried out by [6]. In this study, the author explains the development and testing of the deep learning technique in real-world industrial production and its capacity to detect quality concerns [6]. A Faster Region with CNN (R-CNN) architecture was used in this work. Faster R-CNN enhances the notion of CNN architecture by eliminating wrapping and swapping it with spatial pyramid pooling

[6]. In addition, the significantly lower resolution of the feature map reduces the needed computation, allowing the method to be faster and less resource-intensive. Data were divided into two sections to develop a model: training and testing. Finally, the test data is used to determine whether or not the model correctly predicts the outcome.

The work in [7] identified that the traditional weaving mill inspection procedure relies on human visual examination, revealing 60–70 per cent of total fabric faults. Defective parts were typically thrown as waste, recycled or sold at a discount (generally 45–65 per cent off the free defect price). In [7], the authors provided a convenient automatic fault detection system that provides an alternative to replacing traditional manual fabric examination with computer vision technology that systematically analyses fabrics and ensures stable performance while highlighting the various categories of fabric faults with visual representations for each defect type. The author also describes the theoretical underpinning of principle component analysis (PCA). Following that, the principles of soft computing (particularly ANNs) has discussed as a decision-making device for data classification [7]. Finally, these ideas were used to evaluate actual samples, including sample preparation and digital imaging setup. ANN model was used for the study, for which varied network architectures have significantly different computational features, and the feed-forward and recurrent networks are the two most important structures to separate. The number of hidden layers and units per layer is critical in constructing an ANN. Since a too tiny network may not represent the required function, and too large networks, on the other hand, risk overfitting the data due to the weights present in the model, the ANN model will memorise all the cases make challenging to generalise the adequate inputs. However, each input is connected to several outputs via several weights in multilayer networks [7]. And it can be achieved by a back-propagation approach, which provides a mechanism that splits the gradient computation among the units and allows the change in each weight to be determined, reducing the error between each target and network predicted output [7].

Improving part quality in the Metal Powder Bed Fusion (PBF) process, In [8], the authors propose a unique Machine Learning (ML) methodology for producing feedback loops across the entire metal PBF process. Acceptability has considerably limited in the industry due to uneven part quality caused by incorrect product design, non-optimal process designs, and deficient process management [8]. Metal PBF feedback loop categorisation, including a generic structure and identifying critical data, and a discussion of the opportunities and problems for building the feedback loops is presented [8]. The metal PBF procedure is classified into 6 stages, for which the last stage is considered the product quality measurement. A fishbone diagram of each metal PBF method stage displayed the vital information that might be examined, managed, or quantified in each metal PBF feedback loop stage. The process developing parameters were controllable and were changed during the research work. In addition, high-performance supervised ML models that can deal with image data were established for real-time processing to aid the feedback loop [8]. Finally, the measured product characteristics are fed back into product development, process planning, and online process control phases to ensure process stability and eventual product quality. The use of machine learning methodologies in the metal PBF process allows for efficient and effective decision-making at each stage of the process, and so has a significant potential for reducing the number of tests necessary, saving time and money in metal PBF manufacture [8].

2.2. Machine Learning Techniques, Model Architecture and important factor consideration

The aforementioned literature presented techniques for Machine Learning approaches that were applied to the production assembly line, paper bag industry, traditional weaving mill, and Metal Powder Bed Fusion process to improve production quality. The image processing method is utilised to determine product quality during the process. Supervised learning or deep learning is the most common machine learning technique utilised in various fields. Human intervention is very significant in supervised learning, and the strategy necessitates more data processing for feature selection and anticipates parameter tweaking for a better algorithm setup [5]. Deep learning is a machine learning technique that learns patterns using neural networks, and supervised, semi-supervised, and unsupervised are different learning methods. Deep-learning architectures have been used in various fields and are preferred in image processing to produce results comparable to traditional approaches [6].

Model architecture, encompassing multiple layers involved in the machine learning technique, defines the vital process of converting raw data into training data sets to assist a system's decision making. An Artificial Neural Network (ANN) is a commonly employed model architecture that is complex to build due to the hidden layers and unit per layer [5]. And has a risk of overfitting the data due to weight present in the model architecture. The error between the model predicted output and each target could be reduced using the back-propagation method, where each input is connected with different outputs via various weights in multilayer models [7]. Another technique that is being used for image processing is Convolutional Neural Network (CNN) or the Faster Region CNN (R-CNN) architecture, which reduces the

computational time and resource-intensive required is low [6].

The factor that aids in the success of the model architecture is the massive amount of balanced data that contains less noise. Unfortunately, the noise present makes the dataset imbalanced, producing a complex problem while processing and predicting the faulty product [5].

In this study, CNN model architecture has been used for image processing by employing an early stop function for the model. The input data utilised was cleaned before it was split. In most of the research work, the dataset was divided into train and test sets [6], but the dataset for this study was divided into 3 sets train, validate, and test. The model was developed to achieve the time required is less for the training, validating and predicting the data, with accuracy and precision percentage and flexibility to develop the decision system further with different product input to obtain defect-free products. Mention points were considered to overcome the problem or error faced in different research work.

3. Theoretical Background

Machines have been used in manufacturing for an extended period to complete complex programmed operations. In the Industry 4.0 paradigm, machines are equipped with innovative networking technologies to become more intelligent, adaptable, cooperative, and independent in decision-making [3]. They cooperate and even function securely with humans, and the data generated is enormous, stored, and later analysed. Labour process automation directly impacts firm productivity, especially time and cost savings [9]. The proposed paradigm in this work, on the other hand, can be applied only once the product has been completely manufactured and visually inspected under the vision setup [3]. This automated quality check can replace manual inspections for the final product, enabling manufacturers to satisfy the growing demand for higher-quality products efficiently. A system must acquire data in real-time to evaluate the product and have a big storage capacity for the gathered data and a highly precise and accurate model architecture to predict product quality and decision-making.

Artificial intelligence (AI) technology allows the system to operate smartly and replace human operators to establish an automated quality inspection system [3]. AI is defined as "the science of teaching robots to perform tasks that would need intelligence if performed by humans" [10]. AI can be used to make decisions in Industry 4.0, and it promises to revolutionise the way quality checks are done by giving machines more intelligence capabilities [3]. As a result, machines will be able to detect and rectify errors, resulting in defect-free final items [11]. Many industries, including finance, health, education, and transportation, have benefited from AI. An artificial neural network solves the time-consuming, complex issue. It completely works on the input patterns and learns from them for the future prediction/work itself.

Machine learning technology is one of the most frequent AI technologies in the industry, and it's used for machine-vision inspection. Machine learning has numerous advantages and enhances system performance dramatically [3]. A machine vision inspection system is designed with sequences of algorithms to form a deep neural network model that uses digital images and videos to input the machine, identifying and classifying the object visualised. As the neural network works on the pattern and the machine vision system is built up of the neural network model, it finds the patterns in the gathered data of the final product in the form of captured images that had passed through the camera to see if it meets the threshold accuracy.

Machine vision problems, for example, necessitate the processing of a large number of computing resources (e.g., images). Moreover, the components must connect and act autonomously without the human operator's participation to implement the machine vision model, providing Industry 4.0 its unique nature. As a result, implementing a machine vision-based automated system in the manufacturing chain for detecting defective products necessitates a careful blend of Internet of Things (IoT), cloud computing, automation, big data and analytics, and artificial intelligence (AI) technologies in the manufacturing chain [3].

The Internet of Things (IoT) is regarded as automation's backbone. The Internet of Things (IoT) is a network of interconnected devices with varying levels of intelligence: sensing and actuating, control, optimisation, and autonomy, all of which supports by specialised device technologies that help transfer data and interact with the items [12].

On the other hand, cloud computing satisfies this need because of the computational power and storage capacity accessible, and it also allows practitioners in the image processing environment to collaborate [13]. But, Edge computing is a type of distributed computing that uses decentralised processing power. Edge computing allows data to be processed immediately by the device that generates it or by a local server in its most basic form. Instead of transmitting data to the cloud or a data centre [13], the goal is to process data created at the network's edge. Because data flows are processed locally in real-time, edge computing minimises bandwidth and information processing latency. As a result, edge computing is critical for integrating product inspection systems into manufacturing lines, as these machine vision systems must interpret images recorded by vision

equipment in real-time to offer quick replies without disrupting manufacturing processes [3].

3.1. Confusion Matrix Terminology

A confusion matrix is a table that commonly illustrates how well a classification model performs on test data with known values. The categorisation performance for some test data is summarised in a confusion matrix. It's a two-dimensional matrix with a specified object's actual and predicted class, as shown in Table 1 [3]. A specific confusion matrix case is frequently used for two classes, one designated as positive and negative. True positives (TP), false positives (FP), true negatives (TN), and false negatives (FN) are the four cells of the matrix in this context, as shown in Table 1 [14].

Table 1: Confusion matrix Table [14]

		Prediction	
Actual		Positive	Negative
	Positive	True Positive	False Positive
	Negative	False Positive	True Negative

Precision, Accuracy, and Recall are classification performance measures established by the classification outcomes generated by model architecture [3]. Precision refers to our model's reliability, which means how many predicted positives are actually positive and vice-versa. Recall calculates how many actual positives it can capture by labelling them as positive by the model. Accuracy refers to the percentage of times our model's predictions were correct. Finally, as per the application, the model must be developed to decrease the false positive product, which means the defective product is predicted as a non-defective product and dispatched to the market. Therefore, the precision percentage must be high for our model to determine the actually positive product among the predicted product. Equations (1) and (2) represent the mathematical formula to obtain the precision and accuracy of the model as per the Tajeddine Benbarrad [3].

$$Precision = \frac{TP}{TP + FP} \quad (1)$$

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (2)$$

The CNN model architecture of Tajeddine Benbarrad [3] obtains an accuracy of 90% and a precision of 88%. However, his work was based on the model's accuracy, not the model's precision as required by the application, where the defective product must eliminate before it is dispatched. Therefore, a deep CNN model architecture is developed and evaluated based on model precision.

4. Dataset Processing

This dataset comprises casting manufacturing products containing the image data labelled with ok(standard) and def(defective). A casting defect is an exceptionable irregularity in a metal casting process. There are many casting defects like blow holes, pinholes, burr, shrinkage, mould material, pouring metal, and metallurgical defects.

Table 2: Dataset details

Total number of images in the dataset	Train Dataset		Test Dataset	
	Ok	Not Ok	Ok	Not Ok
7348	3748	2875	453	262

Table 2 contains the dataset details used for modelling the architecture. These all are the size of (300*300) pixels grey-scaled images. The dataset is already classified into two folders for training and testing. The images used are a top view of the submersible pump impeller, as shown in figure 1.

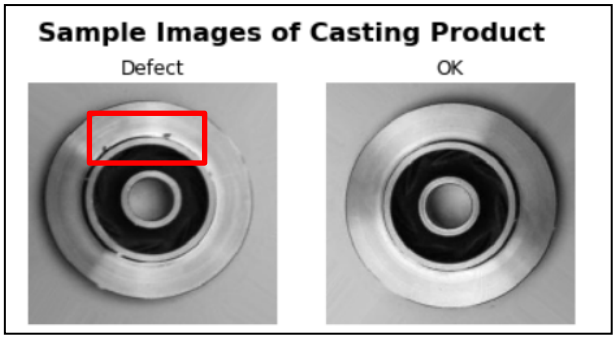

Figure 1: Impeller image in given data

This study uses the above data to verify whether the bottleneck of "manual inspection" can be evident by automating the inspection process with a machine vision model in the casting products' manufacturing process [15].

Before processing the images, multiple image processing methods to clean the images were applied to remove the noise present in them other than the impeller products. Later the image processing of the images, the training dataset was further split into the train and validation datasets. The training dataset was used to train the model, and the validation dataset was used to check the model architecture [16]. However, the test data set kept aside is to test the train model architecture to understand the model working/ prediction over entirely novel data. Since good performance in the train and validation stage has a chance to fail in the final stage of the test due to overfitting and underfitting problems, which must be taken care of by splitting the training dataset in two and

keeping the test dataset untouched till the final prediction run of the model.

5. CNN Model Architecture

Intelligent machine vision systems discover errors early in the manufacturing process and ensure that the product is of excellent quality before being delivered to the client. However, while creating an ideal machine vision architecture for inspecting defective products, the proper collaboration between the various technologies involved in the manufacturing chain should be considered. Furthermore, every data created during the production process must be used to reinforce the system and go beyond defect detection to discover failure causes and improve product quality [3]. Convolutional neural networks (CNNs) have been recommended for automated inspection tasks and have demonstrated promising performance due to this rapid growth of deep learning. It can automatically extract essential information and performance evaluation in the same network. The outcomes could be comparable to, if not better than, human performance [17]. Recent study findings suggest that CNNs are still the most effective method for tackling image classification problems with high accuracy [18].

5.1. Model Processing

Images captured by the machine vision setup are represented in the form of the pixels, which are the smallest atomic element of the digital image. Pixel ranges from 0 – 255 and is displayed in multiple channels known as RGB, which are superimposed on each other to form a colour image. Rather than working directly on the captured image's raw pixel information, which contains noise, feature extraction work is performed while working on the images to improve the efficiency of the model architecture. There are two methods to extract the feature: the manual feature extraction method and the modern feature extraction technique known as the CNN feature extraction technique. The manual feature extraction technique is less impactful than the CNN technique. In the CNN feature extraction technique, the features are from a high dimensional image and represented in the form of low dimensional without distorting the information present in the actual image.

CNN are a form of Artificial Neural Network (ANN) that works similarly to supervised learning methods in that they take in input images, detect their features, and then train a classifier. On the other hand, the features are learned automatically by CNNs, which perform all the arduous feature extraction and description work.

CNN is divided into 4 layers, as shown in figure 2: The most significant component in CNNs is the convolutional layer, always the first layer. Convolution is the process of adding each element of the image to its local neighbours, weighted by the kernel. And kernel is also known as the convolutional matrix or mask used for feature extraction used as a filter in the algorithm to extract the vital feature from the captured image without distorting it. Its purpose is to determine whether a set of features is present in the input images, which is accomplished through convolutional filtering [19].

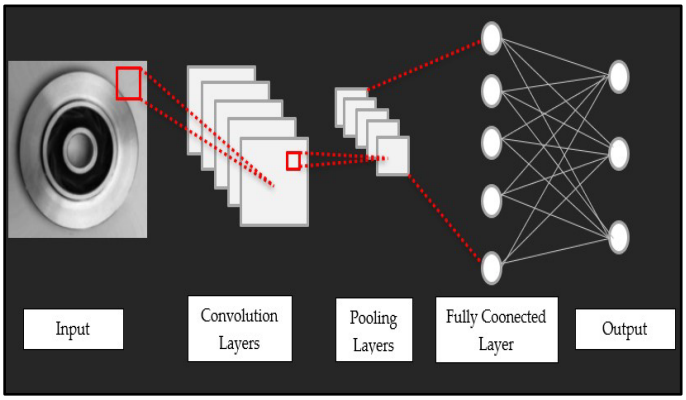

Figure 2: Common CNN layers

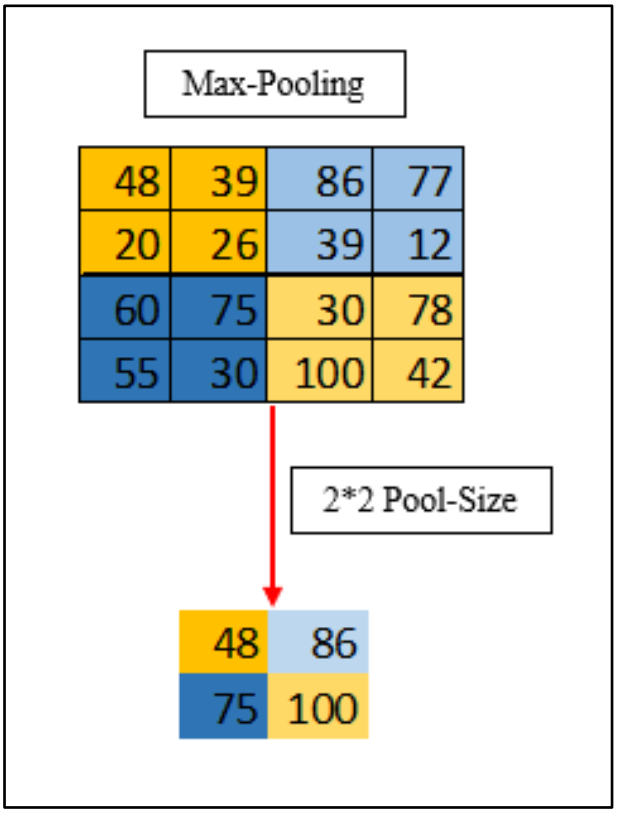

Figure 3: Max-Pooling layer

The pooling layer is usually sandwiched between two convolutional layers and receives many feature maps as input before performing the pooling function. As a result, the pooling method minimises the size of images while preserving their essential characteristics. As a result, the pooling layer reduces the number of parameters and calculations in the network, improving performance and preventing overfitting [3]. A convolutional network includes local or global pooling layers, which combine the output of neuron clusters at one layer into a single neuron in the next layer. Pooling has no learnable parameters. It

only minimises the size of the images, preserving their essential characteristics. The proposed model architecture is built using the max-polling function. For example, a window of 2 and stride of 2 take the maximum value of the window and save it in the pooling layer for further work, as shown in figure 3.

A CNN is a fully connected stack of numerous convolutions, pooling, and ReLU correction layers. Each received image will be filtered, shrunk, and rectified multiple times before being converted to a vector [3].

```
Model: "sequential"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d (Conv2D)              (None, 150, 150, 16)      800
_________________________________________________________________
max_pooling2d (MaxPooling2D) (None, 75, 75, 16)        0
_________________________________________________________________
conv2d_1 (Conv2D)            (None, 75, 75, 32)        4640
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 37, 37, 32)        0
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 37, 37, 64)        18496
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 18, 18, 64)        0
_________________________________________________________________
flatten (Flatten)            (None, 20736)             0
_________________________________________________________________
dense (Dense)                (None, 64)                1327168
_________________________________________________________________
dropout (Dropout)            (None, 64)                0
_________________________________________________________________
dense_1 (Dense)              (None, 1)                 65
=================================================================
Total params: 1,351,169
Trainable params: 1,351,169
Non-trainable params: 0
_________________________________________________________________
```

Figure 4: Model filters

The CNN model is utilised as the base model in the suggested model architecture, and the output is saved and used as the feed for the retraining of the same model to attain the best results from the previous epoch result. CNN models and frameworks can be retrained using a custom dataset for any use case, providing deep learning and more flexibility [3]. The idea is to use the knowledge gained by a neural network while solving one problem to another. As a result, transfer learning speeds up network training while preventing overfitting [17]. The model elements applied in the model architecture are listed as shown in figure 4.

The suggested architecture's training component is maintained at the local server, edge computation. The main advantage of this option is that the machine learning system can be used locally with no data storage and no flow. On the other hand, machine learning necessitates local hardware capable of handling the system's inherent surges in processing demand [20]. The issue with local hardware is that it lacks a baseline offering, and the requirements of such a system alter as new information is gained. However, local hardware is utilised for the work because these studies are only concerned with the impeller dataset. Although a wide range of items must be evaluated in real-time, for which cloud computing should be used due to the computational capacity that provides us with a lot more freedom and, as a result, much faster and higher-value computing metrics. Furthermore, cloud computing boosts the system by providing data sharing, exceptional real-time accessibility, and data backup and restoration [3].

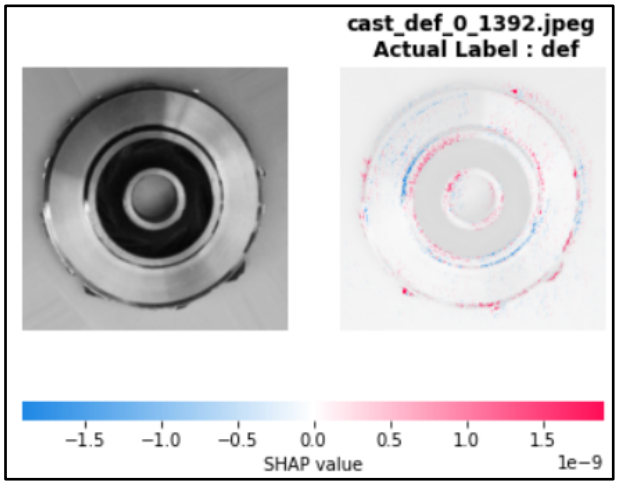

Figure 5: Defect identification

Figure 5 shows how the model interprets the images captured by the system. The left image in figure 4 shows the defective product, and the right image shows the illustrated view of how the model interprets the images for evaluating the defective or non-defective product. The colour red represents that the model is confident over the defective region, blue represents the non-defective region, and the non-colour region is confident the region is perfect. The model evaluates the input images and gets the confidence level to predict the product as defective or non-defective.

6. Virtual setup

Decision Support Systems (DSS) is a computerised information system that aids with decision-making. In most DSS, final decisions are taken by a human, but in this study, models act as the decision-maker and take the corrective decision [21].

For quality inspection, a machine vision setup can deploy in two manners. First, the setup can install after each significant process to capture the images during machining processes. If there are any defective components, they can remove during the manufacturing process.

Second, the setup can install after completing all processes by capturing the images of the product before packing. If there are any defective components, they can remove the defective product before packing the component.

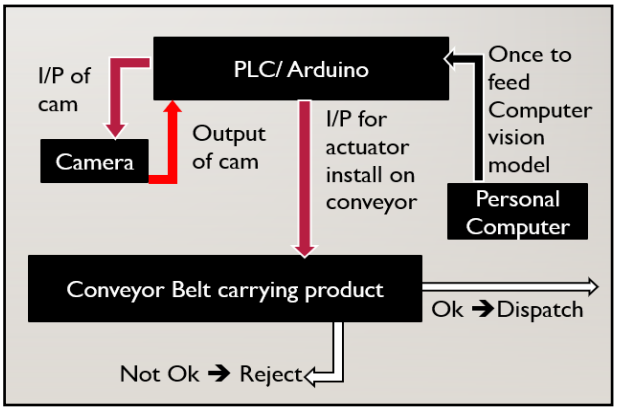

Figure 6: Virtual setup

For this study, the second setup is focused. The primary reason for utilising this setup is that it's not a complicated setup, and the capital required is also low compared to the first one. The significant devices required are a camera, PLC/Arduino and a personal computer, as shown in figure 6.

6.1. The flow of the work

The machine vision's significant role in the inspection starts after completing all the machining processes when the batch of components is sent for packing purposes. Simultaneously, the component goes along a conveyor, and the camera captures an image and transmits it as an input to the PLC, which compares it to a threshold. Thus, PLC first processes the image to decide the acceptance and rejection of the components based on the threshold set by the model architecture installed into the PLC. If the accuracy of the component is above the acceptance threshold, the component is sent for packing purposes. However, the component accuracy is below the acceptance threshold, and the component is rejected and sent for rework. For rejecting a component, the PLC sends a command to the Actuator to remove the rejected component. This complete process moves in the if loop, as shown in figure 7.

7. Results and Discussion

In this section, the result obtained from the python software of CNN models run for precision and accuracy compared with the analytical method. The precisions test is being used for surface defect detection, which checks how many are positive among the predicted positive or vice-versa. Table no. 3 shows the results of confusion matrix terminology for different models used for the work.

Table 3: Different model results of confusion matrix terminology

Model	TP	FP	FN	TN
CNN_Model_1	262	3	0	450
CNN_Model_2	262	11	0	442
CNN_Model_3	262	10	0	443

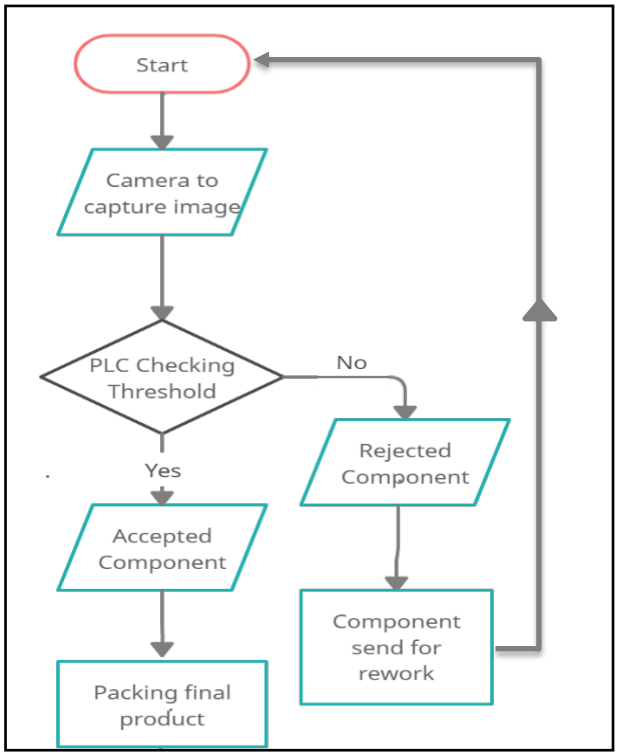

Figure 7: Process flow

Table 4: Different model results

Model	Accuracy	Precision
CNN_Model_1	99.58	98.7
CNN_Model_2	98.46	95.97
CNN_Model_3	98.60	96.32

Table 4 shows the results of different models used for the study as per equations (1) and (2).

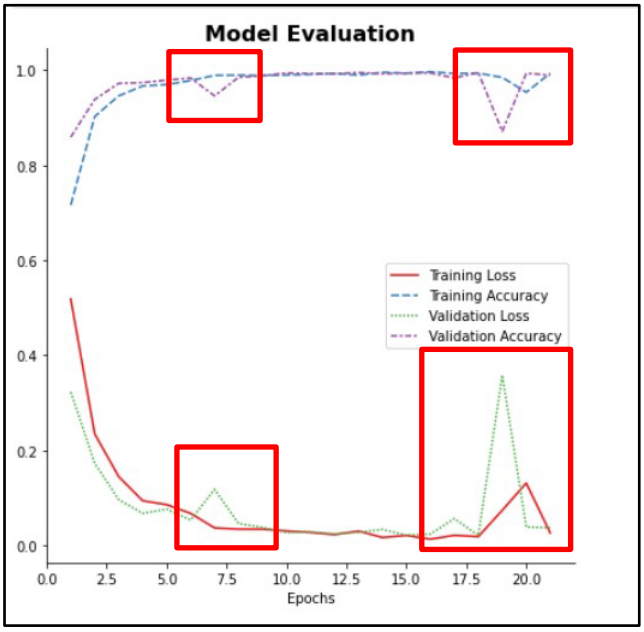

Figure 8: Model Evaluation of CNN_Model_1

Table 3 shows the classification report for CNN_Model_1, which gives an accuracy of 99.58% with a precision of 98.87%. However, the model evaluation of

CNN_Model_1 in figure 8 shows that the model is overfitting after epochs 17 to get a better result. It can be confirmed by observing the validation loss increases compared to training losses, as shown in figure 8. And the validation accuracy is decreasing as compared to the training accuracy.

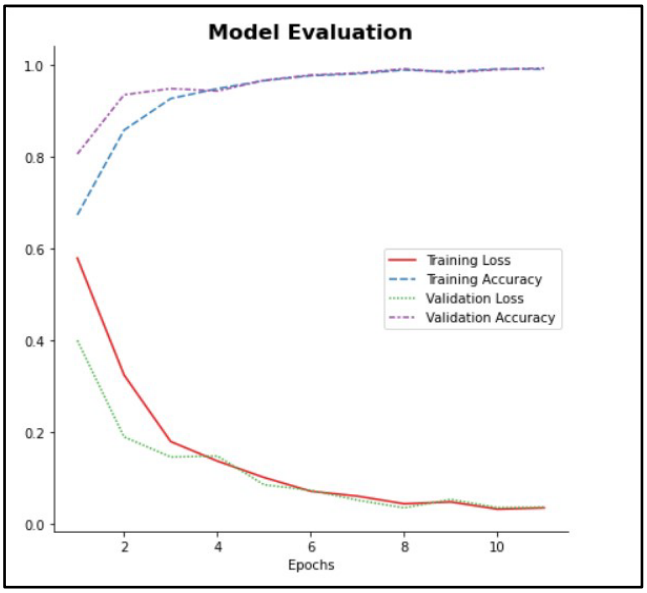

Figure 9: Model Evaluation of CNN_Model_2

In CNN_Model_2, the output of CNN_Model_1 is utilised to retrain CNN_Model_2 as a learning process for training the model to reduce the overfitting of the model. Table 3 of the classification report, CNN_Model_2, gives an accuracy of 98.46% with a precision of 95.97%, which seems promising. However, the model evaluation of CNN_Model_2 in figure 9 shows that model had stopped overfitting and stopped earlier at epochs 17, as at epoch 17, overfitting was started in the previous model. It can be confirmed by observing that the validation loss and training losses match each other after epoch 6, and the validation accuracy also matches the training accuracy, as shown in figure 9.

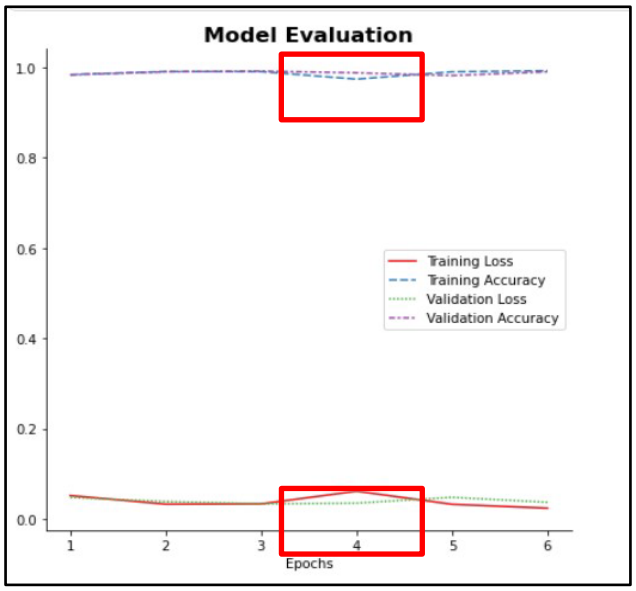

Figure 10: Model Evaluation CNN_Model_3

In CNN_Model_3, the output of CNN_Model_2 is utilised to retrain as a learning process for the training model to get better results for precision. Table 3 of the classification report, CNN_Model_3, gives an accuracy of 98.60% with a precision of 96.32%, which seems promising. However, the model evaluation of CNN_Model_3 in figure 10 shows that model had just started to get better, which has stopped just after epochs 6. It can be confirmed by observing that the validation loss and training losses match each other from the start, and the validation accuracy also matches the training accuracy, as shown in figure 10.

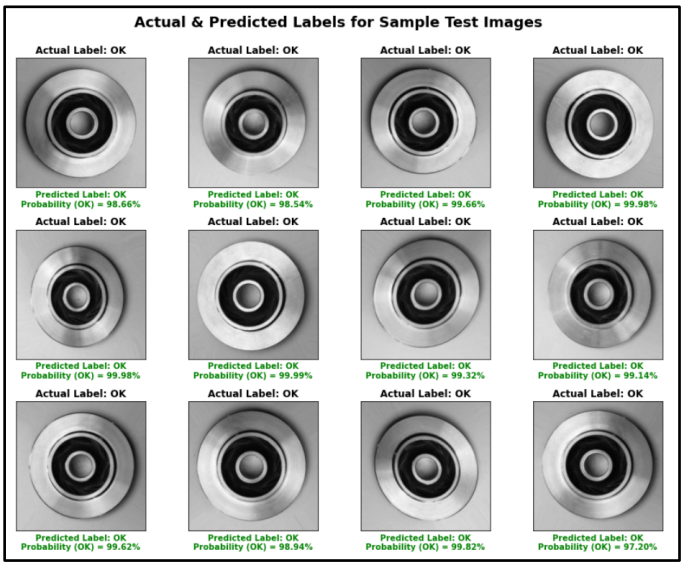

Figure 11: Actual and predicted labels for sample test images

Figure 11 shows the output results for the actual and predicted labels for test sample images which were kept aside during the training and validation of the data. The test samples were perfectly predicted and labelled with the probability of being ok products. Therefore, the probability threshold percentage for product acceptance and rejection can be set as appropriate.

For this study, model 2 architecture for inspection purposes is preferred with a precision of 95.97 % and an accuracy of 98.46%. However, since CNN_Model_1 contains many losses in the validation phase, the error rate will increase in the final test stage. And CNN_Model_3 has improved with each epoch, but the total epoch used for training and validation purposes is low. However, there is a negligible loss in accuracy and precision. But CNN_Model_2 has a good amount of epochs for the training and validation of the data with a good model evaluation with negligible loss in training and testing of data, so CNN_Model_2 is preferred.

Based on a deep CNN model architecture for product inspection, a machine vision inspection model and set up for quality assurance was developed. In which investigation based on precise model architecture was followed to reduce the defective product to be dispatched into the market at a faster rate compared to the manual

inspection, which was achieved using the proposed model in which the existing CNN model was developed based on fully connected layer and set a checkpoint to save the early stop function output of that particular run. So, that output can be used to retrain the same model to achieve high precise and accurate quality inspection model architecture.

8. Conclusion

The paper investigates the approach to detecting the defective product among the final production batch, ready to dispatch to the market using the machine vision neural network model. The focus of the study was to build a neural network and a virtual setup for the application to detect the surface defects for the impeller dataset. It is difficult for an experienced human to inspect the complete lot accurately. The evolution of the machine vision model provides a better quality accuracy of 98.46% with a precision of 95.97%. The accuracy achieved by the model is more accurate than human accuracy. Compared to the manual inspection, model architecture inspect each component in the batch. The manual inspection carried out in the industry achieves accuracy in the range of 70-80%, which is also dependent on the experience of the quality inspector [3], [6]. And the precision percentage for the CNN model architecture was more significant than Tajeddine Benbarrad [3], which had an 88% precision percentage.

There is further scope to improve the inspection detailing to assess the surface inspection and casting defect sizes, the geometry of the component, and the component's separation based on the types of defects detected. It is thus worth investigating this capability as an extra feature of the network.

Another aspect that could research is developing a system to achieve and separate the defective and perfect products during the machining process using the application machine vision model. Alternatively, create a system for separating defective components based on the defect types, geometry, or size/geometry at the last stage after completing all the machining processes.

Conflict of Interest

The authors declare no conflict of interest.

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SOHAIL SHAIKH has completed his Bachelor's Degree in Mechanical Engineering from Sinhgad Institute of Technology, Lonavala, India. In addition, he has completed Post Graduation Program in Artificial Intilegency and Machine Learning from Texas Executive Education, University of Texas, Austin. He is currently pursuing a Master's Degree in CAD/CAM/CAE from Dr Vishwanath Karad MIT World Peace University, Pune, India. His research fields are Artificial Intelligence and Machine Learning, and he is currently working in the field of the automotive suspension system.

DEEPAK HUJARE is a Professor and Associate Head of the School of Mechanical Engineering, Dr Vishwanath Karad MIT World Peace University, Pune, India. He has completed PhD in Mechanical Engineering from the College of Engineering, Pune, India, in 2018.

He has 24 years of experience in the teaching field and 3 years of experience in the industrial sector. In addition, 12 publications are to his credit in International Journals and one patent in NVH. His research areas are Vibration analysis of rotating machinery, NVH, Fault diagnosis, and Design Engineering.

SHRIKANT YADAV is working as an Assistant Professor at the School of Mechanical Engineering, Dr Vishwanath Karad MIT World Peace University, Pune, India. He has completed a Master's Degree in Automotive Engineering and is currently pursuing his PhD in Mechanical Engineering from Dr Vishwanath Karad MIT World Peace University, Pune, India.

He has 8 years of experience in the teaching field. In addition, 12 publications are to his credit in National/International Journals and conferences. His research fields are Automobile Engineering, Robotics, and Machine Learning is his current study topic.

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Design and Analysis of Dual Acting Opposed Piston MR Damper

Muhammad Aamish Khan *

Mechanical Engineering Department, University of Engineering and Technology, Taxila, Pakistan
*Corresponding author: Muhammad Aamish Khan, House Number 485 Street 13 Usman Block Bahria Town Rawalpindi Pakistan, Contact Number: +92-3365694728, Email: aamish357@gmail.com

ABSTRACT: Magnetorheological dampers are dampers filled with magnetorheological fluid, which is controlled by a magnetic field, usually using an electromagnet. Viscosity of MR fluid changes with the application of magnetic field. In this way we can directly change the stiffness and performance of MR damper based on velocity of vehicle and topology of road, thus, providing the improved damping effect. This paper deals with improvement in MR damper design. The design proposed in this paper consists of two pistons with two linear generators in such a way that each piston couples with one linear generator. Both pistons work as opposed pistons, moving directly opposite to each other. This model utilizes six forces converging system to stability, leading to more compactness. Most of the forces including in this system vary with topology of road and velocity of car so leading to better robustness. In addition to this, model proposed is self-actuating and regenerative. Thus, resolves the issue of external power supply and harvests the vibrational force to develop electricity for its running. This model is self-dependent and doesn't require on board electrical sensors and microprocessors, leading to more reliable MR damper design comprising of least components. There are multiple methods of actuation of MR damper which varies on the basis of structure and assembly, and type of generator used. Both linear and rotary generators can serve the purpose. In this paper linear actuation for this model is analyzed. This paper also deals with structural design and development of the model on the basis of certain parameters. Simulation and analysis of this model is then performed to assure the effectiveness of design. Solid works is being used for designing the structure of model and MATLAB for vibrational analysis. Simulink interface of MATLAB is used for electronic component analysis.

KEYWORDS: MR damper**:** MR fluid: MATLAB: Linear generator: Simulink

1. Introduction

A shock absorber is a mechanical device designed to absorb and damp shock impulses. It does this by converting kinetic energy of shock into another form of energy (typically heat) which is then dissipated. Dampers can be either active, passive or semi active. Passive dampers do not use any parameter to control damping coefficient in real time domain. Active dampers use road conditions and car speed as input and move damper piston up and down accordingly while semi active dampers vary damping coefficients accordingly. Shock absorbers can be of various shapes, they can be in leaf form, in torsion rod form or in hydraulic cylinder form.

MR dampers are type of damper that uses MR fluid as damping media whose viscosity can be varied with applied magnetic field thus changing damping coefficient. These dampers are very effective as they vary damping coefficient in real time according to surface of road. They generate magnetic field using electromagnets. So, by varying input current, damping coefficient can be changed. Input current is usually controlled by processing inputs like vertical speed and acceleration of chases of vehicle. MR dampers can be controlled by generators making then self-sustainable. Generator can be either linear or rotary with some changes in assembly. These regenerative MR dampers are cost effective as they don't require an additional energy source. They provide better control and better performance. Regenerative MR dampers have higher damping capacities and are more compact in size. These dampers utilize emf (electromotive

force) as an addition to other forces to converge system to stability. Among various types of regenerative magnetorheological dampers single-ended monotube regenerative MR (RMR) damper has maximum power generation capabilities [1]. MR damper finds its application from automobile industry to aerospace application. Civil structures also utilize MR dampers to prevent damage from seismic vibrations. Another application of emf force is regenerative braking system which utilizes generator for recovery of a part of kinetic energy during braking [2]. Generator generates electricity while producing electromotive force which creates braking effect. In addition to this, multiple efforts have been done, working on material science, to improve automotive, aerospace and aircraft, rail transport, and marine transport industry [3].

2. Literature review

The design MR damper in their paper considering non-Newtonian fluid and meeting device force capacity, size, and electrical power consumption [4]. They coupled non-Newtonian fluid with non-linear magnetic behavior of steel alloy to minimize power consumption. In the end, comparison between ER and MR damper is made based on power consumption.

It is developed a car model in ADAMS/Car for simulation purpose. A large bus is then tested to measure its dynamic response by the single-lane change test and the rapid stop test [5]. Simulation results were then compared to physical experiment in which several sensors were installed. The results from simulation were in good harmony with actual results. Then, they developed MR damper simulation using Magic Formula Model. Bump simulation of full car was performed. Vehicle with MR damper showed better response than vehicles with traditional passive damper.

The author studied the effect of iron particles-based MR fluid [6]. They prepared MR damper by adding iron particles in silicon oil. Then to reduce sedimentation, grease is used as stabilizer. Then sedimentation is measured under various concentrations of iron particles.

The author studied properties of MR fluid under application of magnetic field. In their paper they studied both MR fluid and FF [7]. MR fluid is modeled using Bingham model and FF is modeled using Newtonian model.

The author evaluated commercial MR damper for its application in semi-active suspension [8]. The experiments were carried out in damping force testing machine. MR damper RD-8040-1 by Lord Corporation, USA was used for testing at different values of current input. It was found that same damper can behave as under-damped system, critically damped system or overdamped system depending on the value of current supplied to it. It was also found that increase in MR damper load increases with current supplied which is studied and analyzed to develop a mathematical model of the MR damper under investigation.

The author worked on review paper which aims at a comprehensive review of development in structure and assembly of MR dampers [9]. This paper typically studies improvements of damping channels, magnetic circuit, coil number and distribution in recent years.

The author studied MR damper using SIMULINK environment in MATLAB for quarter vehicle model. Their first aim was to implement the correct control system for an active suspension system of a vehicle and a take closer look at the hydraulic cylinder and servo valve concept details and its closed-loop control system and the second aim was to gain both ride comfort and reliable road-holding by correctly tunning the PID parameters for an active suspension system to reduce the vehicle body displacement and acceleration [10]. Furthermore, the hydraulic pressure, hydraulic force, and total transmitted force to the vehicle body are compared for active and passive suspension systems. The simulation results showed that the car's body displacement and acceleration have lower amplitude compared to the passive suspension case. Hence, active suspensions can provide the passengers more riding comfort and better roadholding while traveling over harsh street surfaces for the manufacturers [10].

The author studied various types of variable stiffness and variable damping techniques for semi-active MR dampers. To provide variable damping, MR damper is used and for achieving variable stiffness, the assembly of springs either in series or parallel is used [11]. Current is used for magnetization purpose which would in turn change the viscosity of fluid as required.

The author conducted a comprehensive study on control strategies and applications of MR dampers. They also discussed some properties of MR fluid and covered the operational modes of MR fluids. They analyzed dynamic model of MR damper and found it to be highly non-linear with its property of being time variant and hysteresis, and thus an accurate parametric model is challenging to be achieved. Considering the flexible mechanical properties and the faster response

characteristics of an MR damper, a strategy combining the bionics and modern intelligent algorithm would be more suitable for controlling damping behavior of MR fluids as the approach is based on learning and ability to adapt [12].

3. Damper Components

Our proposed shock absorber consists of following parts:

- Two linear generators
- Two pistons
- Two springs
- Damper body
- Cover lid and follower rod
- Adjusting gear

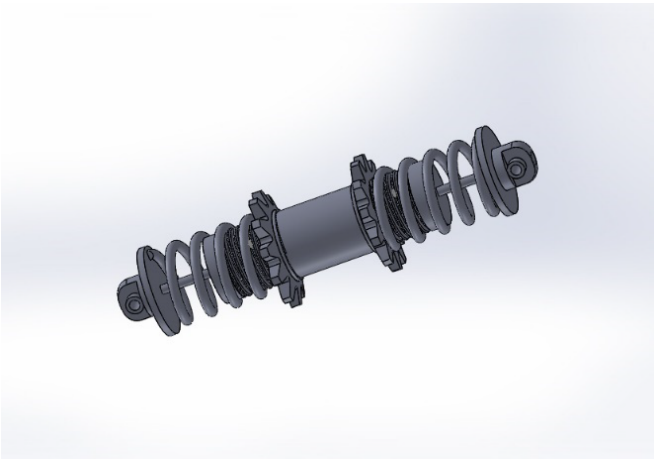

Figure 1: Damper assembly

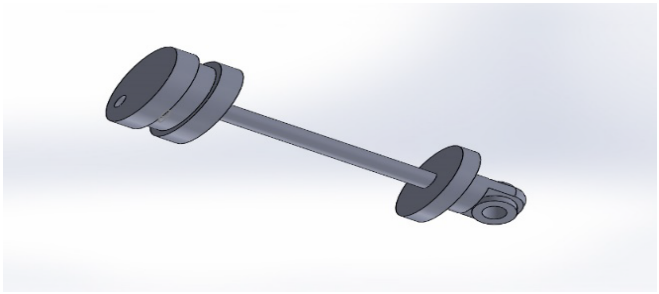

Figure 2: Lower piston

4. Feasibility of proposed project

Feasibility here means the efficiency of proposed project, whether the proposed design is better than the previously used dampers or it is useless to perform these changes. To check this out transfer function of model is calculated and compared with standard damper.

To calculate transfer function, consider each part of suspension system independently.

4.1. Lower piston

Assume that $x_d - x_1$ is motion of lower piston relative to damper body.

The other forces applied to the piston are

- Spring force
- Viscous force
- Inertial force
- Magnetic levitation force

Force balance for piston

$$m\left(\frac{d^2x_1}{dt^2}\right) = \mathrm{F(t)} - k_1(x_1 - x_d) - c_1\left(\frac{dx_1}{dt} - \frac{dx_d}{dt}\right) - \frac{n^2 i^2 \mu a}{4(L-(x_0+x_1))^2}$$

Solving $\frac{n^2 i^2 \mu a}{4(L-(x_0+x_1))^2}$

Suppose $\frac{n^2 i^2 \mu a}{4}$=B

So $\frac{B}{4}(L-(x_1+x_2)^{-2}$ can be solved as,

$$m\left(\frac{d^2x_1}{dt^2}\right) = \mathrm{F(t)} - k_1(x_1 - x_d) - c_1\left(\frac{dx_1}{dt} - \frac{dx_d}{dt}\right) - \frac{B}{4L^2} - \frac{B}{2L^2}\left(\frac{x_1+x_2}{L}\right) + neglecting\ higher\ powers$$

4.2. Damper body

A part impact force will be transmitted by piston to damper body resulting in motion of damper x_2-x_d relative to upper piston. Therefore, force analysis of damper body is as under,

$$m_d\frac{d^2x_d}{dt^2} = (k_1-k_2)x_d + (c_1-c_2)\left(\frac{dx_d}{dt}\right) - k_1x_1 + k_2x_2 - c_1\left(\frac{dx_1}{dt}\right) + c_2\left(\frac{dx_2}{dt}\right)$$

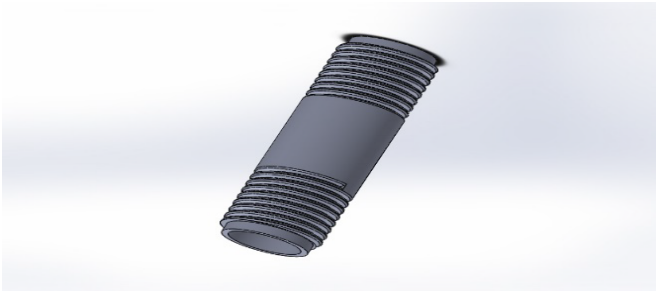

Figure 3: Damper body

4.3. Upper piston

Damper body will also transmit a part of impact force to upper piston causing piston to move displacement x_2. Resulting force balance is as under

$$m\left(\frac{d^2x_2}{dt^2}\right) = k_2x_2 - k_2x_d + c_2\left(\frac{dx_2}{dt}\right) - c_2\left(\frac{dx_d}{dt}\right) + \frac{B}{4L^2} + \frac{B}{2L^2}\left(\frac{x_1+x_2}{L}\right)$$

4.4. Using transfer function.

Using Laplace transform for all the above equations and solving them simultaneously we get,

$$X_2(s)(m_1s^2 + 1 + c_1s(s+1) + 2BL^{-3}) + 2BL^{-3} + (-k_1 - c_1s(s-1))P = F(s)$$

where,

$$\left(\frac{m_2 s^2 + 1 + 2c_2 s(s+1) + 2BL^{-3} + k_2}{K + c_1 s(s+1) - c_2 s(s+1) - m_d s^2 + O^2}\right) = P$$

$$\left(k_2 + c_2 s(s+1)\right) = O$$

$$k_1 - k_2 = K$$

Since proposed model is about to be compared with damper of constant damping coefficient. So, above transfer function is obtained while considering constant damping coefficient i.e., MR fluid is not used yet. Moreover, back emf force is also neglected in this scenario for proper comparison.

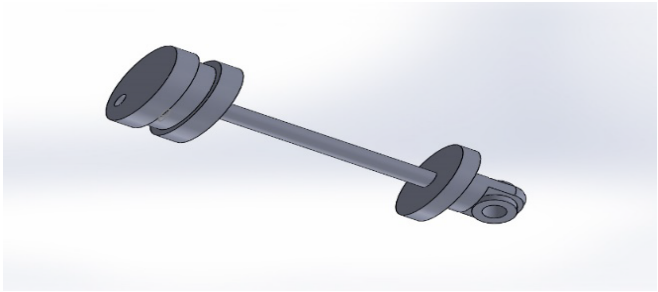

Figure 4: Lower piston

Transfer function of mass m attached to spring with spring constant k and damper with damping coefficient c is,

$$\frac{X}{F} = \frac{1}{ms^2 + cs + k}$$

For comparison

B = 1 L = 1 $c_1 = c_2 = 1$ $k_1 = k_2 = 1$

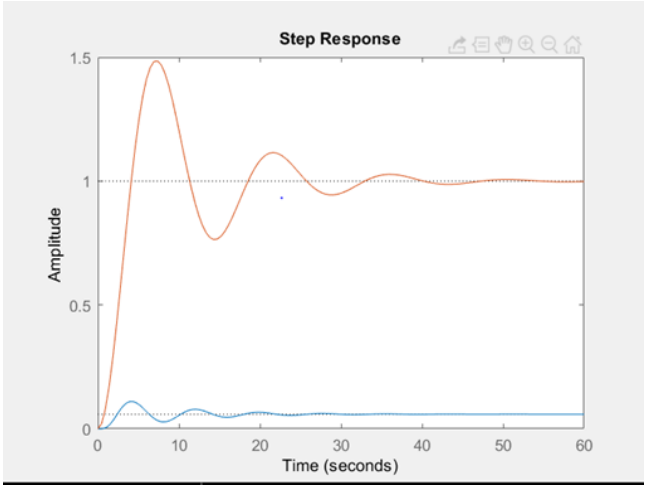

Figure 5: Step response of proposed model and traditional passive damper

Blue line represents our proposed model

Red line represents traditional passive damper.

Note that damping ability has been improved manifolds.

5. Design of damper

To design damper, first thing we did is to apply boundary conditions related to riding comfort. Optimum conditions in this case are

$$x_1 = 2x_d$$

$$\frac{dx_1}{dt} = 2\left(\frac{dx_d}{dt}\right)$$

$$\frac{d^2x_1}{dt^2} = 2\left(\frac{d^2x_d}{dt^2}\right)$$

Therefore, damper body equation becomes

$$m_d \frac{d^2x_d}{dt^2} + (c_1 + c_2)\left(\frac{dx_d}{dt}\right) + (k_1 + k_2)x_d = 0$$

Solving above equation we get

$$x_d = \frac{X}{K + m_d {w_f}^2} \sin(w_f t + \varphi)$$

5.1. Spring constant

Now we should calculate spring constants

Suppose we design for *40kg* mass and assume static displacement to be *2in* and damper body to be of *4kg*.

For k_1:

$$k_1 = \left(\frac{M+m}{x}\right) g = 29{,}302$$

For k_2:

$$k_2 = \left(\frac{M}{x}\right) g = 25{,}480$$

5.2. Damping coefficient

Now, we need to decide the damping ratio value. We want to achieve robustness and wide range of control. Therefore, we should not limit damping ratio to a single value, rather it should vary with variation in conditions.

For proper functioning

$$x_d = \frac{Y}{2}$$

where Y is amplitude of jerk

Putting values and solving we get

$$\left(3 - \left(\frac{M}{M+m_d}\right)^2 + 2\left(\frac{M}{M+m_d}\right)\right) {k_1}^2 + \left(2\left(\frac{M}{M+m_d}\right) m_d {w_f}^2 - 2m_d {w_f}^2\right) k_1 + 4\left(c_1 w_f\right)^2 - {m_d}^2 {w_f}^4 = 0$$

Putting values, we get

$$70561199 - 1528.3{w_f}^2 + 4\left(c_1 w_f\right)^2 - 4{w_f}^4 = 0$$

$$c_1 = \frac{\sqrt{1528.3{w_f}^2 + 4{w_f}^4 - 70561199.5}}{w_f}$$

Varying value of angular velocity in above equation we get following graph of required damping coefficient.

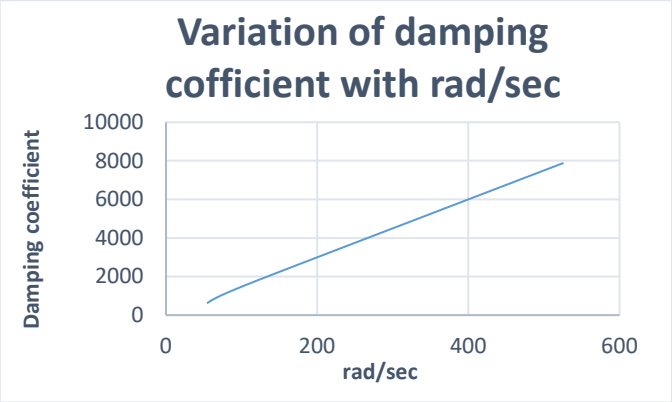

Figure 6: Variation of damping coefficient with angular velocity (rad/sec) for proposed model

5.3. Dimension of damper

The one-dimensional behavior of MR material undergoing simple shear is assumed to follow a Bingham constitutive model in which the applied shear stress is resisted by flux independent yield stress $\tau_y(B)$, and flux independent viscous stress. $\eta\dot{\gamma}$, [13]

$$\tau\left(B_g, \dot{\gamma}\right) = \tau_y(B_g)\mathrm{sgn}(\dot{\gamma}) + \eta\dot{\gamma}$$

Now by Bingham model

$$\tau_y = \tau_{y\infty} + 2(\tau_{yo} - \tau_{y\infty})(e^{-\alpha_{styB}} - 0.5e^{-2\alpha_{styB}})$$

The pressure drop across the piston, Δp, also has yielding and viscous components

$$\Delta p \approx 2.1\frac{\tau_y}{t_g} + \Delta p_N$$

where the Newtonian viscous component, Δp_N, is approximated by.

$$\Delta p_N \approx \frac{12Q\eta(2N_s)L_p}{\pi(D_p + t_g){t_g}^3}$$

where N_s is the number of spools of wire, Q is the volumetric flow rate, and D_p is the diameter of the piston.

The force generated in the device, F, is the pressure drop times the piston cross sectional area and can be expressed as,

$$F = \Delta p\pi\frac{\left(\left(D_p + t_g\right)^2 - {D_r}^2\right)}{4}$$

Here t_g is the gap between piston and damper body and D_r is the connecting for thickness. Assuming incompressibility, Q is related to the piston velocity, v_p, by

$$Q = v_p\frac{\pi}{4}({D_p}^2)$$

Thus, the device force may be obtained from the piston velocity, the device geometry, the MR fluid properties, and the magnetic flux density in the gap.

Since variation in damping coefficient and damping force is calculated so putting these values in above equations, we can calculate damper dimensions. The damper dimensions are as follow,

Piston diameter =1in

Piston thickness = 0.2in

Damper body inner diameter = 1.4in

Damper body outer diameter = 1.8in

Connecting rod of piston diameter = 0.2 in

Length of damper body = 8 in

5.4. Buckling and its remedy

In this design there is a chance of buckling as damper body is suspended between upper piston and lower piston. Upper piston is attached to car body and lower piston to tyre.

To avoid bucking follower rod is used for pistons to follow. The cover lids and follower rod attached to them are shown below

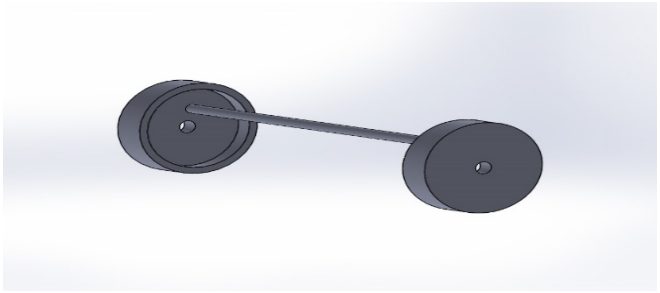

Figure 7: Follower rod with end caps

Pistons follow the follower rod and reduces chances of buckling. Multiple follow rods can be used depending upon design specifications. Above figure shows only single follower road.

5.5. Motion analysis of car body

Since upper piston is directly attached to car body. So, both will have same acceleration, velocity and displacement covered. The equation for displacement of upper piston in this case is as follow.

$$x = P\sqrt{S^2 - T^2}$$

where,

$$P = \sqrt{\left(\frac{BY}{2L^3} - \frac{k_2 X}{K+m_d {w_f}^2}\right)^2 + \left(\frac{c_2 X w_f}{K+m_d {w_f}^2}\right)^2} - \frac{B}{4L^2}$$

$$S = \left(\frac{-M{w_f}^2 + k_2 + \frac{B}{2L^3}}{(-M{w_f}^2 + k_2 + \frac{B}{2L^3})^2 - (c_2 w_f)^2}\right)$$

$$T = \left(\frac{-c_2 w_f}{(-M{w_f}^2 + k_2 + \frac{B}{2L^3})^2 - (c_2 w_f)^2}\right)$$

Solving the displacement of car body and displacement of damper body in real time domain with varying damping ratio and magnetic field throughout the jerk we obtain following curves.

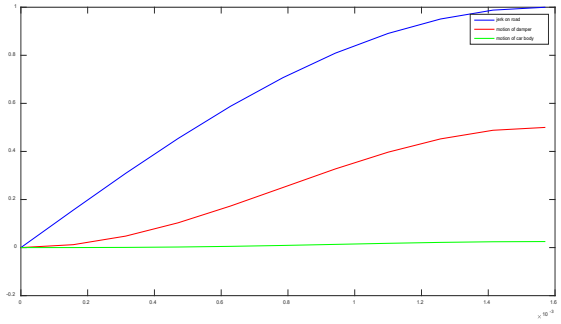

Figure 8: Displacement curve of different moving components of damper for jump on road

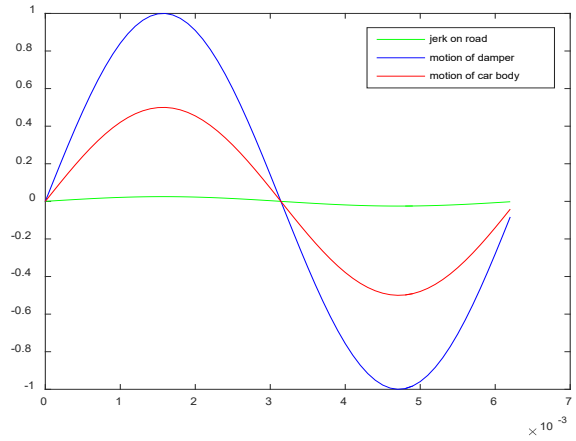

Figure 9: Displacement curves of different moving components of proposed damper for jump and pit on road

The responses show that very little motion takes place in car body and most of the jerk is absorbed by the damper.

The response is almost the same as long as magnetic field varies linearly with rpm and magnetic field produced follow the same trend as required.

5.6. Variation of magnetic field with angular velocity

Magnetic field increase with the increase in rpm and jerk velocity. For higher jerk velocity higher damping ratio and higher magnetic levitation force is required. Higher damping coefficient can be obtained by increasing viscosity. For MR fluid viscosity is the function of magnetic field and increase with the increase in magnetic field

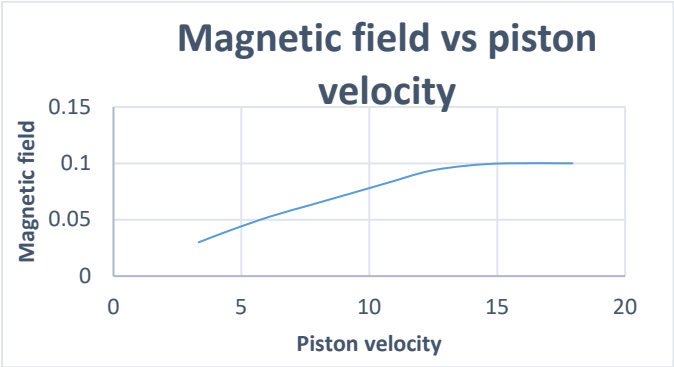

Figure 10: Magnetic field vs piston velocity for proposed model

Trend shown in above graph shows that magnetic field does not increase linearly with piston velocity throughout the range. Rather it remains linear for some period and then saturation occurs.

5.7. Variation of magnetic field with viscous force

Application of magnetic field make particles of MR fluid to arrange themselves resulting in increase in viscosity. In the beginning viscosity increase linearly with the increase in magnetic field. After that, the state comes when almost all the particles are arranged. Beyond this state further application of magnetic field would have no effect on increase in viscosity. Viscous forces increase with the increase in viscosity and piston velocity.

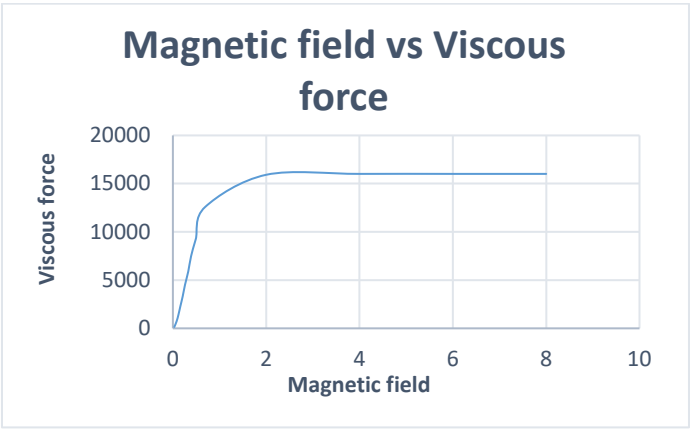

Figure 11: Magnetic field vs viscous force for proposed model

5.8. Variation of angular velocity with viscous force

Variation in viscous force required and angular velocity (rad/sec) can be seen in the following graph.

6. Mechanically actuating the damper

MR dampers can be actuated mechanically but it has its own pros and cons. The following benefits obtain by actuating the damper mechanically.

- More reliable - containing less electronic parts
- Provide back emf force to converge system to stability

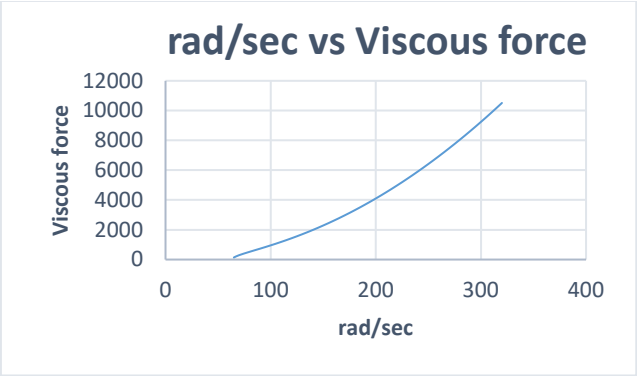

Figure 12: rad/sec vs viscous force for proposed model

This method has its own limitations also. Generators can actuate damper only within range where magnetic field varies linearly. Moreover, at high rpm values inductance also hinders the flow of current a lot. So, steps must be taken to reduce the inductance of system. Simulation is made using Simulink for mechanical actuation of MR damper. To decrease the inductive resistance within the circuit, linear generators with lower inductance are preferred over rotary generators. Since damper system works at higher rpm. So, lower the inductance in system better the system is.

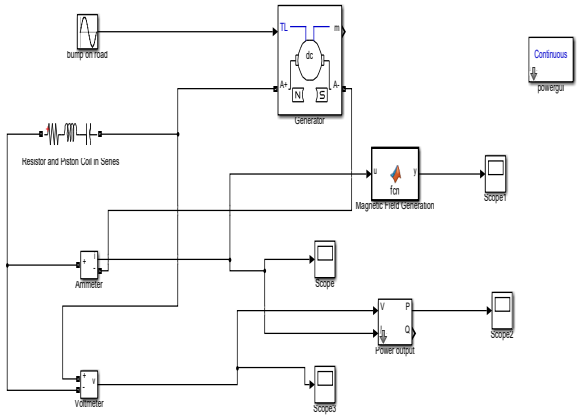

Figure 13: Simulink model for electronic components

Specifications for some main electrical components of this model are as under:

Table 1: Specifications of electrical components

DC linear generator	
Internal resistance	0.06 ohm
Inductance	0.003 H
Back emf constant	0.01 V/rpm
Magnetic coils	
Inductance	0.0125 H

Current, voltage and magnetic field variations for different rad/sec are as under

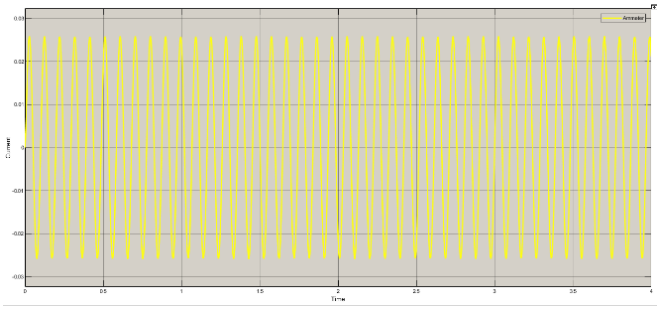

Figure 14: Variation of current at 65rad/sec

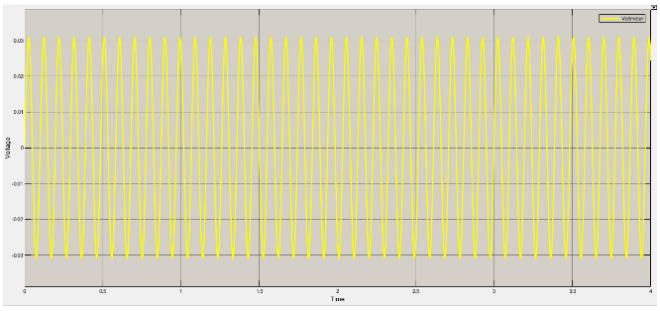

Figure 15: Variation of voltage at 65ras/sec

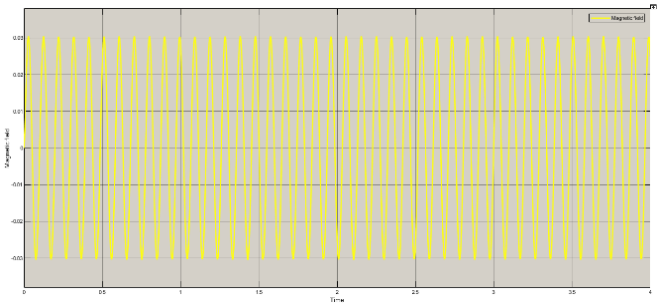

Figure 16: Variation of magnetic field at 65rad/sec

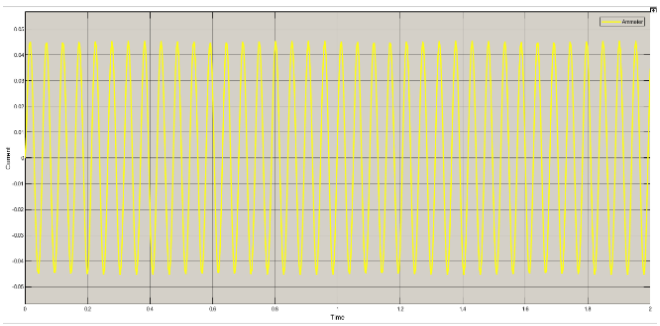

Figure 17: Variation of current at 120rad/sec

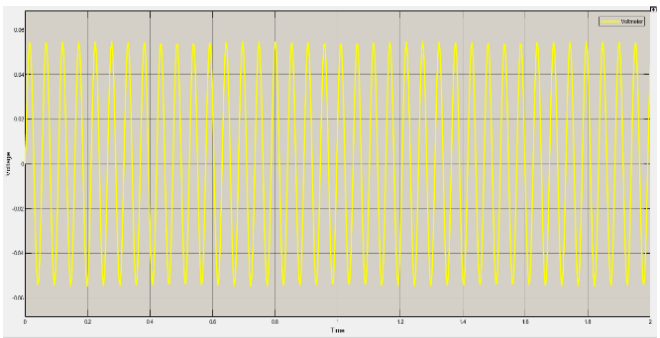

Figure 18: Variation of voltage at 120rad/sec

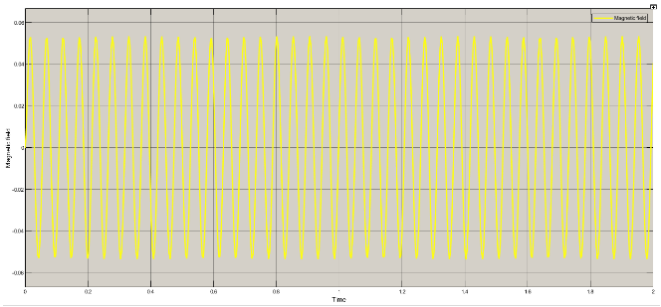

Figure 19: Variation of magnetic field at 120rad/sec

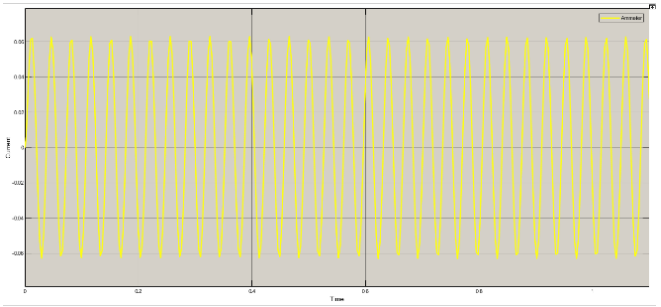

Figure 20: Variation of current at 180rad/sec

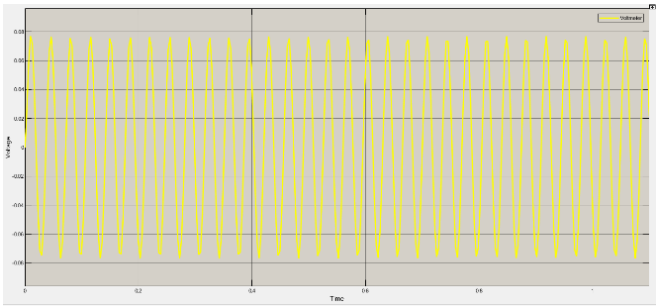

Figure 21: Variation of voltage at 180rad/sec

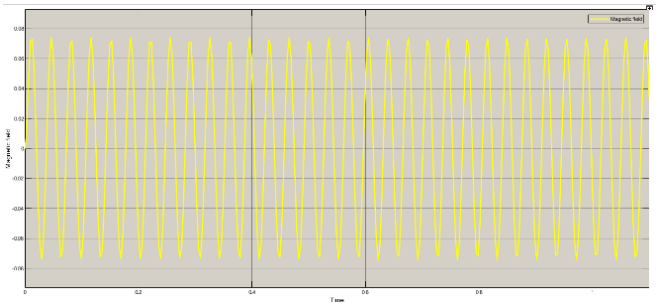

Figure 22: Variation of magnetic field at 180rad/sec

Table 2: Variation of current, voltage and magnetic field

Rad/sec	Piston velocity	current	voltage	Magnetic field
65	3.33	0.025	0.03	0.03
90	4.62	0.035	0.042	0.041
120	6.15	0.045	0.052	0.053
150	7.69	0.054	0.062	0.063
180	9.23	0.061	0.071	0.073
210	10.76	0.072	0.081	0.083
240	12.3	0.078	0.093	0.093
270	13.85	0.08	0.099	0.098
300	15.38	0.087	0.11	0.1
350	17.94	0.094	0.12	0.11

7. Conclusion

MR dampers use MR fluid and vary the viscosity accordingly using magnetic field thus their performance is improved. The design we proposed uses two pistons and respective two linear generators with damper body. Pistons move opposite to each other thus dual action is achieved. Linear generators while producing electricity for damper generate electromotive force which improves the compactness of damper. The damping effect and stability is much improved using this design. This design eliminates the need of sensors and on-board micro-processors by actuating the suspension system mechanically. Linear generators have simple assembly and lower inductances than rotary ones. The graphs we obtained showed that generator with lower inductances would produce the desired fluctuation and variation of current as needed by design. This design is self-actuating and regenerative, so, requires no additional power supply and is thus a cheaper design with better control ability. This mechanical actuation limits the peak performance to a limited band of rpm values as generators tend to saturate at very high rpm values due to their inductances and thus don't follow a linear curve. This design also faces a challenge of buckling, which is reduced by using follower roads.

Acknowledgment

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Survey on Developing a Low Cost System for Taxi Payment

Suleiman Taha, Raed Saeed Mohammad Daraghma*

Department of Communication Engineering and Technology, Palestine Technical University Kadoorie, Tulkarm, 62451, Palestine
*Corresponding author: Raed Saeed Mohammad Daraghma, Palestine, +970599707545, Email r.daraghmeh@ptuk.edu.ps

ABSTRACT: In this post, we built a small gadget that can be placed in the front of the cockpit, closer to the driver, and can be accessed by both the taxi driver and the passenger. It is simple to operate since it has a crystal display that displays a wealth of information about both the section cut and the distance's eventual cost. The piece, which is also the delivery charge, as well as the passenger card's identification card and other explanatory information, and the system, is equipped with a simple and secure payment method that is based on radio wave technology and is linked to the company database. The payment service and the taxi driver are both connected to the internet via a wireless transmission device, and the person who has the card is stored in a specific financial bank's database. Because the payment manner is easy, the primary goal of this instrument's design is to prevent passenger money from being stolen, as well as for the driver, and it is a more pleasant, softer, faster, and safe method to handle.

KEYWORDS: RFID, Smart Credit Card, Arduino MEGA

1. Introduction

Given the incredible technological advancements of the twenty-first century, as well as the significant acceleration in the trend toward integrated systems and their development in a way that allows users to complete several everyday tasks with minimal time and effort. We must keep up with the wheel of technological progress in the current period, particularly in the domain of easy-to-use automated systems and their advantages in integrity and rapidity in performing sophisticated procedures, as well as their high abilities and linking to one another through global Wireless Sensor Networks (WSNs) and the ability to enter and link with the World Wide Web. According to literature reviews, there are electronic payment gadgets that rely on people's IDs to simplify their payment procedures. Some taxi firms and organizations have resorted to electronic payment systems as a term for current and future advancement and orientation in this area, as well as their reliance on electronic payment cards. In paper [1], the author devised a way for paying a cab electronically with a traveler's card, so reducing the need to carry cash. Furthermore, he proposed and implemented such a system by repairing one or more card readers into the taxi and utilizing an individual taximeter with new characteristics. The Smart Credit Card (SCC) was used to make the payment, which was deducted from the customer's account. The information from proposed services was saved in the system and will be displayed as services. In paper [2], the author researched the current industry case, procedure structure, and styles of micropayment services in Taiwan local and international taxi services, as well as the methods that simplified success, in order to make the findings helpful, theory-based references for developers of the taxi industry's micropayment system. According to his results, the author proposed that the micropayment service's manufacturing chain was "micropayment service provider-taxi carrier-end user." Furthermore, he made the following suggestions on the use of the taxi micropayment service: A micropayment service provider needs, first, have procedures in place with appropriate subscribers; moreover, the supplier must be able to integrate the micropayment system. Before the taxi micropayment service can be effectively performed, the micropayment service provider must also fix issues in the cost-structure of taxi carriers and take the "micropayment service provider-taxi carrier-end user" relationship. Finally, this study discovered that official performing was the most active, and terminal users benefited the most from the taxi micropayment service. In paper [3], the technology of Radio Frequency Identification (RFID) and its applications

were discussed by the author, introduced RFID standards, ranked RFID tags and readers, applied frequencies, current application, as well as benefits and drawbacks. In addition, the author examined the current state of this technology's advancement and future prospects. In paper [4], the author demonstrated that RFID was not a new technology and has been used in the military, airline, public library, security, healthcare, physical activities, animal farms, and other areas for many decades. In addition, RFID was employed in various industries for various purposes such as individual outlet control, administrative shopping security, appliance tracing, baggage, fast food companies, logistics, and so on. The advancement of RFID technology has resulted in resource optimization, increased efficiency in business modes, and improved client care, as well as general refinements in business and healthcare. In addition, the author's goal was to create a sample for a mobile technology application of the motion process of hospital patients. The focus of this study, however, was on the most common RFID devices. In paper [5], the author as being used in various areas of our daily lives, including tracing production merchandises, currency, and patients to payment orders, highlighted RFID candidates such as e-ID, smart tag, and contactless smart card. He also looked at several RFID implementations, which was useful for looking into not only outstanding e-governance issues like digital recognition, distribution, and governance, but also trading-oriented application areas like supply chain.

In paper [6], Within the AIS box of high-reputation publications, the author demonstrated the current degree of understanding advancement on RFID technology, the technology at the heart of the "Internet of Things". Furthermore, the likely future research trends on RFID technology are included in this access. He conducted a survey of essays published in journals in the AIS box of high-reputation publications between 2000 and 2011. Twenty-five relevant documents were provided and assessed using the following criteria: issue date, implantation locations, people, procedure, and theories employed. Finally, a list of possible article directions was reviewed.

In paper [7], the author demonstrated that RFID was widely employed in a variety of applications, including logistics, supply chains, property tracking, healthcare, and herding, among others, attracting the attention of a number of researchers. He also offered a survey of nearly all of the cited RFID themes, focusing on implementations, security, and privacy. Using a free Python hardware, the author retrieved the top subjects and surveyed the relevant studies. In addition, the following findings were examined: The first segment dealt with implementations, which included IoT, supplier management, localization, tracking capability, and logistics, worldwide computing, medical care, and access control system; the second portion dealt with security and privacy, including authentication and confidentiality as subsections. In paper [8], during the last two decades, the author demonstrated how RFID technology has been widely used in the structure area. Finally, RFID streamlines the management of a wide range of procedures throughout the construction process, from concept to completion. He also gave a summary of RFID applications in the evolving industry, pointing out evolutions, limitations, and gaps to the audience. The author also discussed the RFID technology's foundation in four essential phases of a facility's lifecycle: planning and design, manufacturing and commissioning, and operation and maintenance.

In paper [9], the author demonstrated how RFID was one of the most enabling technologies that was still being considered in a variety of applications. In the end, a wireless system used the concept of reflected waves to communicate. In addition, the author examined the major aspects of RFID systems and reviewed the industry standard. The author also looked at a few different card designs, as well as some improved outcomes and suggestions.

In paper [10], the author stated that RFID technology has been around for a while but has not been widely used due to a lack of criteria and expensive costs. Charges have decreased because of other technologies, and standards have improved. RFID is now widely employed for a variety of purposes, including managing suppliers, tracking animals and herding, preventing counterfeiting, monitoring building outlets, and supporting automated checkouts, according to the author.

In paper [11], the author investigated the components required to execute RFID, a technology that was further advanced by the introduction of Industry 4.0. First, a foundation had been laid for this continuous advertising technology. Then, within carmakers' suppliers, current processes were considered. Those vendors focused on the flow of tire composition from the manufacturer to its final place in the gathered automobiles. This research was carried out in two stages. Initially, in light of the current state of its processes, and then, more recently, with the installation of RFID technology. The correlation between the two phases allowed researchers to conclude that using RFID technology will make procedures more efficient and secure.

In paper [12], RFID was expected to increase efficiency and sensitivity among automobile suppliers, according to the author. One of the primary hurdles to RFID adoption and diffusion in cross-company channels has been the shortage of data levels in the automotive industry. In addition, the Carmakers Industry Action Group (CIAG) was evaluating the current CIAG B-11 Item Level RFID Standard in order to develop a criterion that corresponds

to the carmakers' indicated requirements. The author put the working group's best results to a real-world business setting.

In paper [13], the findings of a review of various methods to CFC, as well as a qualitative multi-criteria evaluation of these technological alternatives, are presented in this research. Acceptability by users and operators; payment and physical infrastructure; information technology requirements; financial and human resources; and transaction and technical complexity are among the criteria.

In paper [14], Concealed cash transactions are being phased out of traditional cash-based transactions, and all economic operations will be more visible as a result. Cashless transactions make governmental control and monitoring of all forms of cashless transactions conceivable and simple.

In paper [15], for security, RFID is increasingly being used with biometric technologies. The basic principles of RFID technology, as well as its various variants, are covered in this paper.

In paper [16], author gave a quick overview of RFID technology, as well as contemporary library challenges and how RFID technology might help solve these problems. Following that, he examine the specifics of RFID technology in various aspects of library management and services, before looking at the possible benefits of RFID and identifying impediments to its adoption. Finally, based on the literature examined, he presented a critical success factor framework for RFID implementation and offer advice to librarians.

In paper [17], the benefits of establishing a contactless payment system based on RF technology are described in this article, which was developed through pilot experiments done by VISA, MasterCard, and American Express to confirm the technology's applicability in practice.

2. Methodology

The software system design, program methodologies, and system approaches utilized in the development of programming the Arduino are described in this part. Accepting and executing commands, operating operational terminals, and supporting data Input/output ports are all responsibilities of the software program. In order to construct the model, we used the Arduino program. The sensing modules are included in the programming procedure (Wi-Fi, RFID). We calculated how much time each component would take. The Arduino microcontroller is in charge of the machine's whole operation. It is worth noting that the Arduino software requires programming in the C++ language.

2.1. Mechanism for calculating the traveled distance

The first step : the system is started by the switch.

The second step : the Arduino is powered up, and the Arduino issues commands to the LED and the bell to work; the bell operates for a set period of time before stopping, and a welcome message is displayed on the LCD screen; the content of the welcome message includes the project's name and welcome.

The third step : Wi-Fi is turned on in conjunction with the previous step, and the screen displays a message indicating that the network is being connected. When the connection is complete, the screen displays a message indicating that the system is connected to the network and is also connected to the hosting company's server for this service.

The fourth step : When the engine is running, the Arduino takes the reading of the switch, and when the engine is stopped, the reading of the switch is off, which is (0 for digital input). The RFID reading is ignored here. And if the switch's reading is on, the car is moving, indicating that it is (1 for digital input), and The LCD screen shows that the car is moving and begins to calculate the distance and display it on the screen in kilometers; if the car stops during an emergency and the engine is still running but not moving, the LCD screen displays that the car is moving and begins to calculate the distance and display it on the screen in kilometers; and if the car stops during an emergency and the engine is still running but not moving, the LCD screen displays that the car is moving and begins to calculate the There is a distance that has been covered, The distance traveled before stopping is added to the distance traveled after stopping, but in the case of turning off the distance covered, we adopt the final distance traveled over the entire driving period, which appears on the screen (car is stopped), and then the fully covered distance and the cost of the fully covered distance appear on the screen.

The fifth step : The distance is computed based on the number of wheels that roll, with each 20 pulse from the speed sensor representing one turn, and each 20 revolutions representing one kilometer.

2.2. Mechanism to pay for the distance covered

The first step: The system asks the passenger to pay after computing the cost of the distance traveled, and this message appears on the screen (please pay).

The second step: When displaying the passenger card on the RFID Reader, the Arduino takes the RFID Reader's reading and sends an order to turn on the green LED and turn off the red, then the card data is added to the distance information covered and the price is sent through the Arduino of the Wi-Fi piece, so that the Wi-Fi, in turn, sends

an order to the RFID Reader to turn on the green LED and turn off the red. The information is saved as follows after sending these data to the company's server. The ID contains the card number and any provinces that follow the taxi office, as well as the passenger's name, the distance traveled, the cost, the time, and the date, which is then communicated between the Arduino and the Wi-Fi through (serial connection) in the form of (string) numbers and letters. The data is encrypted before being uploaded to the server, which then resends encrypted data to the device, which includes whether the procedure was successful or not. If the payment process was successful, the blue LED lights up in the form of blinks (linking).

The third step: The payment appears to have been successful on the screen.

The fourth step: The blue and green LEDs are turned out, and a thank you message (thank you, have a nice day) shows on the screen; the red LED then illuminates, and the meter is reset to work.

3. Hardware

3.1. Arduino MEGA

For our design circuit, MEGA is the best option. It comes with everything we'll need to get started. It has 54 digital input/output pins (with 12 of them being PWM outputs), 16 analog inputs, a USB connection, a power jack, a reset button, and other features. It includes everything needed to back up the microcontroller, as well as an AC-to-DC adapter or buttery (see Fig.1). It interprets data from sensors RFID readers, establishes a serial connection with the WIFI module, and displays additional information.

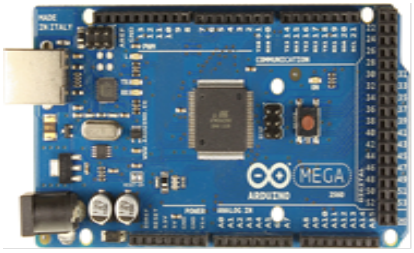

Figure 1: Arduino MEGA

3.2. LCD

As shown in Fig. 2, a Liquid Crystal Display (LCD) screen is an electronic display module with a wide range of applications. Standard HD44780 LCDs are useful for creating standalone projects.

Figure 2: Liquid Crystal Display (LCD).

3.3. RFID

RFID supply with a signal that is 2.5 cm in diameter. If the card approaches RFID, the RFID returns an 8-digit Hexa number, as shown in Fig.3. The traveler's personal information is hidden from view on the screen, but the card number is visible, and the number is encrypted, even when it is raised on the server, to maintain security and privacy.

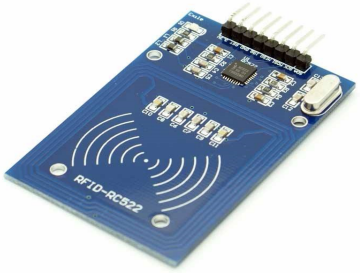

Figure 3: RFID.

3.4. Speed Sensor:

Four pins make up a speed sensor (ground, 5 volts, analog, digital). The speed sensor has two black columns, as seen in Fig. 4. One of them is the photo diode, whose job is to send a signal to a similar column. Two LEDs make up the speed sensor. If the first LED illuminates, it shows that there is power; if it does not, it indicates that there is no power; and if the second LED illuminates, it indicates that the signal has arrived; if it does not, it means that the signal has not come. A black box, which is an amplifier that converts from digital to analog, is also included.

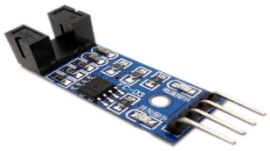

Figure 4: Speed Sensor

3.5. Wi-Fi

It is programmed using the Arduino ID program, which has its own unique code. It has a programmable input called micro, as shown in Fig. 5. Another option is a push button that works with a digital reset.

- D1, D2: is DIGITAL (input, output).
- A0: The only entrance to the analog.
- Vin= 5 volt where Wi-Fi is fed.

We achieved communication between the Arduino and Wi-Fi via a serial connection, as it works to transfer the D1 and D2 from Wi-Fi to TX, Rx, and we did so in the

Arduino Mega on two pins (2, 3) and converted it to TX, Rx.

Figure 5: Wi-Fi

3.6. LM2596 DC-DC step-down Converter

It has two entries above positive input, negative input and below there are two entries positive output as shown in Fig. 6, negative output. Inputs enter the volt, outputs display the volt step down Converter, and we enter input and the result it displays the same input or reduce it. The range (0-35) volt.

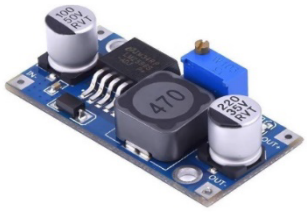

Figure 6: LM2596 DC-DC step-down Converter

4. Result

Our system is a stand-alone system that requires no other needs for the payment process; however, some applications demand the use of a smart phone with the application within its apps in order to pay through the app, which can be costly as a prerequisite for the payment process. In addition, our system sends the remaining funds to the taxi driver office, which can complete the final accounting with the drivers. Our system does not require the interception of a code, thus it is faster than systems that do. Instead of requiring the interception of a code or having steps that take longer, our system makes the payment process directly when the card is placed near the RFID reader of our system. Our system's complexity is also low because we use a simpler circuit than other systems. Our system's cost can be reduced if it is mass-produced in huge quantities with cheaper component pricing and some tweaks. A card is easier to carry and handle than cash, and it makes the payment process go more smoothly. It also can't be stolen like cash, and it eliminates the problem of losing change.

5. Conclusion

In this paper, we propose a low-cost method for taxi payment that does not require cash. The project's key goals are to save time and effort, protect people's money, and simplify the payment procedure. The cost of the distance traveled and the amount deducted are automatically computed by deducting the cost of the trip from the passenger's bank account, without the passenger being stolen or defrauded. As demonstrated in Table 1, this is done at a low cost, resulting in a low-cost system. The issues that we had to deal with. To begin with, there is no memory inside the device that retains the data that has to be transferred to the server in the case that there is no online connection and the ability to upload data later when an Internet connection is available.

Second, the information on the server and confirmation of the payment process cannot be raised if there is no internet connection or if the coverage area is not covered. Finally, we will continue to build this project based on the following suggestions: Using a global positioning system (GPS) to locate the vehicle without saving the province of the taxi office on the smartphone. Providing a memory for the system to save information about the passenger card (traveled distance, price, time, date, and province where the taxi office is located on the device) in the event of the internet being disconnected and data being uploaded to the server later when the internet connection is restored. Creating a mobile application that displays the passenger's connection fee data for each payment made.

Conflict of Interest

The authors declare no conflict of interest.

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Table 1: the cost of project and the price of each component.

No	Item	No	Price (one piece)($)	Total ($)
1	Arduino Mega 2560 with cable	1	27	27
2	Character LCD 20*4	1	14	14
3	22*10 DIY Prototype PCB	1	5	5
4	40 pcs Female to Male jumper wires 20cm	1	6	6
5	RFID card inductive module KIT	1	15	15
6	2 Pin Screw Terminal Block connector	1	0.6	0.6
7	40 Pin Straight Male Pin Header connector	3	1	3
8	40 Pin Single Row Female Header	1	1.5	1.5

9	LUA based ESP8266 development board NODEMCU	1	24	24
10	6V 4.5Ah Lead Acid Battery	1	11	11
11	5mm LED	3	0.15	0.45
12	5V Continuous Piezo Buzzers	1	0.9	0.9
13	ON-OFF 3 Pin Latching Toggle Switch	3	0.9	2.7
14	Plastic Gear Motor with Wheel for Car	1	8	8
15	Optical Coupling Module (Speed Measuring Sensor)	1	6	6
16	Resistors	3	0.15	0.45
17	LM2596 DC-DC adjustable step-down power supply module	1	7	7
18	Potentiometer 10k ohm	1	1	1
19	Plastic encoder disc	1	0.3	0.3
20	Battery Clips	2	0.15	0.3
21	Soldering wire 1m	10	0.3	3
22	Electrical plastic box	1	5.5	5.5
23	Others	1	4	4
			Total Cost=	146.7

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SULEIMAN S. M. TAHA was born in 1976 in Palestine; he received his master degree from Ulm University in Communications Technology, Germany in 2004. He has engaged in educational work many years mainly teaches Antenna and wave propagation, Electromagnetics, Sensors and Transducers etc. at Palestine technical university PTUK. His mainly research areas include antennas and electromagnetic waves.

RAED S. M. DARAGHMA was born in 1977 in Palestine, he received his master degree from Jordan science and technology in electrical and communication engineering, Jordan in 2010, he got his P.H.D degree from Anadolu University, turkey in 2016. He has engaged in educational work many years manly teaches digital communication, mobile, digital communication networks etc…. at Palestine technical university PTUK. His research interests are wireless sensor networks, FIR filters, MIMO Radar, Types of Antennas, and NBIOT. He has multiple publications in international sources. He was a Steering Committee Chair of the International Conference of SPACOMM2018. He has been a Reviewer of many publications, including Transaction on Emerging Telecommunications Technologies, Journal of Engineering Research and Science, and Journal of Navigation. He is involved in several European projects on Narrowband Internet of things.

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Offline Signature Verification based on Edge Histogram using Support Vector Machine

Sunil Kumar Dyavaranahalli Sannappa *,[1], Kiran[2], Sudheesh Kannur Vasudeva Rao [2], Yashwanth Jagadeesh [2]

[1]Department of Computer Science, Mangalore University, Mangalore, India-574199
[2]Department of ECE, Vidyavardhaka College of Engineering, Mysuru, Karnataka, India-570002
*Corresponding author: Sunil Kumar D S, Department of Computer Science, Mangalore University, Mangalore, India-574199,
Contact No: 8618366122 & Email: dssunil6@gmail.com

ABSTRACT: Investigation on verification of offline signature has explored a huge sort of techniques on more than one signature datasets, which can be amassed beneath managed conditions. However, these records will not necessarily reflect the characteristics of the signatures in some useful use cases. In this work, introduced a novel feature representation technique called edge histogram and 4 directional histograms for offline signature verification system. For classification of signature support vector machine (SVM) technique employed. Edge is a curve or point where the intensity of an image changes rapidly. Edges represent the boundary of object of an image. Edge detection is a process of detecting edges of an image. Several algorithms are available to detect edges effectively from an image. Canny, Roberts, Prewitt and Sobel are several popular available edge detectors.

KEYWORDS: Signature, Recognition, SVM, Forgery, Genuine

1. Introduction

Signatures are behavioral biometric traits of a person, used to authenticate a person. In all the legal transaction and documentations signature is required to authenticate its legality. In such cases there may be chances to forge the signature by someone to get the benefits. Therefore in order to check the genuineness of the signature, signature authentication system is required. There are several algorithms are proposed by different authors but still there are challenges to address the skilled forgery and intra class variation.

Traditional cashier examinations, bank loans, credit cards and various legal documents has become a staple of modern work. Unavoidable the side effect of signing is that it can be used to make a document look like it is genuine. As a result, there is a growing need for research on efficient automation solutions for recognizing and validating signatures. The signature verification system aims to automatically distinguish whether the biometric sample is actually from the requested individual. That is, it is used to determine whether a query signature is fake or real. Fake is usually classified. It can be divided into three types: simple, random, and clever (or simulated) fake. The counterfeiter has no information about the user or his signature when they counterfeit randomly. Instead, the counterfeiter uses his own sign. In this instance, the fake carries something else that means more than the user's actual signature. It has a completely different shape overall. It's just a fake, and the fake knows only the user's name, not the signature. In this case, especially if it is fake, it indicates that it resembles a real signature. An individual who signs with their entire name or a portion of it. In the subject Counterfeiters, counterfeiters have access to the user's name. Sign and frequently practice spoofing a user's signature. This leads to a more similar fake. It is difficult to recognize because it is an actual signature.

2. Related Work and Motivation

In [1, 2], the authors proposed a new convolutional neural network model called Large-Scale Signature Network (LS2Net), which is aimed to address the problem of small number of signature sets to train the model from large dataset. Authors introduce Class Center based Classification (C3) to classify embedded features. C3 uses class centers which are achieved by averaging in-class properties. Under these class centers, 1-nearest neighbor

classifier is derived as classification task. Authors also addressed Large-Scale recognition problem, the influence of Leaky ReLU on the performance of network is examined. Along with the addition of the C3 (Class Center for Classification) algorithm, the default network is defined as C3+BN+LS2Net called as LS2Net_v2. In [3] author has presented fusion of two methods one is Curvelet Transform (CT) and another is One-Class Principal Component Analysis (OC PCA) for Open Handwritten Signature Identification System. In [4,5,6] author has presented back propagation method of Neural Networks. If the output obtained at output layer having higher error rate then it can be propagate back to the previous layers to minimize the error by adjusting the weights of the nodes of the hidden layers, where the data processes again and gives the result at output layer. This process repeats until the desired output obtained with minimum error rate. In [7]-[9], authors has presented a Back Propagation Artificial Neural Network Matching Technique for offline signature verification. The suggested model consists pre-processing phase, codebook generation phase and matching phase. In [10], authors propose a method that uses the information from DTW cost matrix and warping paths alignments. The decision is made by the conjunction of warping path score and DTW score. In signature verification, solid signatures may be damaged up into 3 one-of-a-kind classes. In [11, 12], authors used Extreme point and stroke point for recognition. In addition, some works make a fusion of DTW with other methods. In [13], author has presented fuse the Fast Fourier Transform with DTW and the fusion system lowers the error rate by up to about 25%. In [14], authors explained how to extract a set of features for comparing DTWs based on dissimilarities between test signatures and template databases. In addition, the closest submission and majority vote will be proposed for classification. In [15] - [17], author has presented model-based approach is a generation classifier like the Hidden Markov Model (HMM). In [18, 19, 20] author has presented a neural network (NN) based signature recognition. In [21, 22] author has presented support vector machine (SVM) based offline signature recognition system. In [23] author explained the use one of the discriminating classifiers. There are also some hybrid methods that combine the various methods described above. In [24, 25], author has presented a multi-level cascade framework and multi-level decision level score fusion or a multi-expert system for signature verification has been reported in the literature. In [26, 27], author has explained several RNN-based validation methods have recently been proposed. In [28], authors propose a new descriptor called the Length Normalized Path Signature (LNPS) for feature representation, which is then fed to the GRU (Gated Recurrent Unit) network. We trained the network with the BP algorithm using triplet loss and center loss. In [29], author has explained how to extracts 23 hand-crafted time function features and uses bidirectional LSTM (long short-term memory) and a Siamese architecture GRU network to learn dissimilarity metrics from signature pairs. In [30], author has presented the distance-based and model-based approaches are the two main methods. In [31], author has explained design context and functionality and a two-step strategy for accurate online signature verification. In particular, in the first stage, shape context features are extracted from the input and the classification is based on distance metrics. In [32], author has presented the optimum feature subspace is selected according to the contribution rate. In addition, to solve the problem of large-scale DTW computation, we proposed a simple and effective modified dynamic time warping (DTW) with signature curve constraints. In [33] author has presented the DCT technique to get a compact representation of your online signature using a fixed number of coefficients. This simplifies the fitting procedure and provides an effective alternative for working with time series of varying lengths.

There are both writer-independent and writer-dependent signature verification methods in the literature. However, in the actual signature verification settings, the user Registration is very common. For this the writer-dependent method is not applicable. In Writer-independent methods, the themes for training and testing are different, so personal characteristics are not possible. It will be used. Writer-independent methods try to learn efficient representation of signatures in order to distinguish them from each other. As a person, creating a universally discriminatory expression of a signature is a challenge, not a specialty. I found an extraction method to solve this problem.

To improve the accuracy and efficiency of matching, use the edge histogram function and SVM to compare the test signature with the registered reference signature based on the extracted features. A classifier based on the symbolic representation of interval values is proposed to determine if the test signature is genuine.

The contributions of this paper are as follows:

- A fast and accurate edge histogram-based SVM method is proposed based on the fact of the imbalanced probability of occurrence of clever and random signature forgery.
- Edge histogram feature Extractor was developed to describe the global shape features of signatures for fast classification of random counterfeiting, along with basic pre-processing that applies to all records.
- SVM applied to fulfil comparison task and interval valued based representation classifier is proposed for

final decision making to achieve state of the art verification performance

- The rest of the work consists of: Section 2 reviews related work. The presented method is described in Section 3. Experiment setup and the corresponding result is Section 4. Finally, complete the work in Section 5.

3. Proposed Method

We are going to use novel approach for signature verification using Support Vector Machine classifier. Figure 1 shows the flowchart of proposed offline signature verification system. This system will use static as well as dynamic features for verification. The static functions include momentary functions and 4 direction distribution, while the dynamic functions include gray distribution and stroke width distribution.

Finally, the signature is categorized by support vector machines.

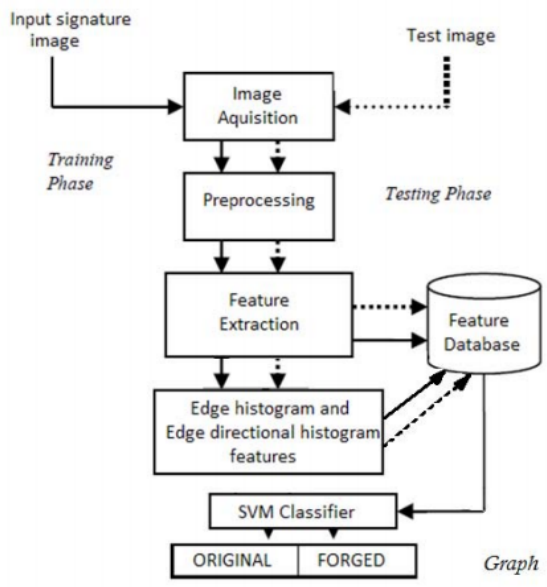

Figure 1: Proposed Offline Signature Verification Flowchart

3.1. Signature Enrolment

In the first phase, to find the parameters which characterize the variance of the signatures which are used as a reference, we use a set of signatures for reference. The extracted parameters along with the set of reference signatures are stored in the system database with unique user identification.

3.2. Preprocessing

Preprocessing stage can be divided further in five parts:

3.2.1. Noise Reduction

It's the process of removing noise from the image. It can be done by using median filters. The widely used noise type is salt and pepper noise. The noise present in the image is certainly degrades the image and it is difficult to select the exact features. To obtain usable information, noise must be removed.

3.2.2. Image Binarization

The acquired image sample may be in different colour model like RGB, gray scale or binary. The advantage of converting to binary scale is, processing will become easy because the intensity of the image will be in 0 and 1 range. There are several algorithms are available to convert, we employed Otsu's method.

3.2.3. Data Area Cropping

Image cropping is the processes where the image data area is extracted from the background area. Usually offline signature samples are acquired using a paper sheet; signatures are not spread across whole paper but on some portion of the paper. The data sample is the region of interest, so extracting only data area from the background and processing it, will helps in getting better accuracy.

3.2.4. Width Normalization

As we know signature samples are collected from different contributors, so obviously there will be more variations in the sample signatures, during pre-processing stage its necessary to normalize the data samples not only scaling but also its width. Width is one of the local features and varies from sample to sample. Normalized width will helps to get better accuracy.

3.2.5. Image Thinning

It's the process of keeping one pixel width information and removing redundant pixels. The collected samples are written on a paper, which having different pen width. Thinning operation makes uniform pixel width and also reducing pixel width will minimize the processing time.

3.3. Feature Extraction and Training the model

The study adopted HOG as a feature Extraction technology for recognition and authentication Signature image. Theoretically, the HOG descriptor method is important Occurrence of localized gradient orientation an image or part of a region of interest (ROI). Divide the image into smaller contiguous zones Calculate the histogram of (cell) and each area Gradation direction or edge direction Use pixels in cells, then gradients Receive orientation. Then discretise each Put the cells in a square bin, then the pixels in each cell gives a weighted gradient to the corresponding gradient.

3.4. Signature Verification

Let`s have an perception in SVM. Signatures are usually represented with the aid of using sparse vectors beneath the vector area model. When schooling classifiers

on huge collections of signature, each the time and reminiscence necessities related with those vectors can be prohibitive. This requires using a characteristic choice approach now no longer most effective to lessen the quantity of capabilities however additionally to boom the sparsity of vectors. We advise a characteristic choice approach primarily based totally on linear Support Vector Machines (SVMs). Linear SVM is used on a subset of schooling facts to teach a linear classifier that is characterised with the aid of using the ordinary to the hyper aircraft dividing fantastic and bad instances.

Components of the everyday with better absolute values have a bigger effect on statistics classification. Instead of predefining the quantity of maximum scoring capabilities to be protected in a classifier we practice characteristic choice that targets at a predefined common sparsity stage throughout files and classifiers for a given schooling set. After the characteristic set is determined, the version is educated on the entire schooling statistics set represented in the decided on characteristic set. The check signature is then, primarily based totally on its price for the parameters from the characteristic set, is mapped and categorized as "GENUINE" or "FORGED".

4. Experimentation

The following figure is the snapshot of Graphical User Interface for Offline Signature Verification developed using GUID tool available in MATLAB. Experiments are conducted on benchmark datasets namely CEDAR (Center for Document Analysis and Recognition) and GPDS Synthetic Signature database. The know-how repository includes the TSE capabilities extracted from each signature pattern of the records set such as each proper and professional forge signature samples. With every dataset, the signature samples are categorized into two groups: the education pattern set and the trying out pattern set with various wide variety of samples. We have achieved 4 units of experiments. With Set-1, the first 10 proper and primary ten professional fakes are selected as education samples and compared with the ultimate samples of the respective datasets. With Set-2, the first 15 samples of proper and primary 15 samples of professional fakes are considered and compared with the ultimate samples of the dataset. In Set3, we randomly selected 10 real samples and 10 randomly selected fake samples for training and tested them on the remaining samples in the dataset. Also, in Set4, there are 15 samples randomly selected from each dataset for training, the remaining samples are the sample in question. In order to overcome the influence of randomness, the experiments of Set3 and Set4 are repeated 5 times and the average results are tabulated. Achieved 97 ° and 98 ° accuracy with the CEDAR dataset.

The signature verification efficiency is evaluated by two parameters: (i) false acceptance rate (F A R) and (ii) false rejection rate (F R R). Recognition rate is one more parameter to consider when assessing classifier performance.

Type I error or False Rejection Rate (F R R):

$$\text{FRR} = \frac{\text{No.of genuine signatures identified as forged}}{\text{No.of genuine signature samples}} \times 100\% \quad (1)$$

Type II error or False Acceptance Rate (F A R):

$$\text{FAR} = \frac{\text{No.of forged signatures identified as genuine}}{\text{No.of forged signature samples}} \times 100\% \quad (2)$$

Recognition rate: The classifier accuracy is identified by this parameter, which is given by:

$$\text{Recognition rate} = \frac{\text{No.of correctly indentified signature samples}}{\text{No.of signature samples}} \times 100\% \quad (3)$$

Equal Error Rate (EER): Which is the error when false acceptance rate is equal to false rejection rate.

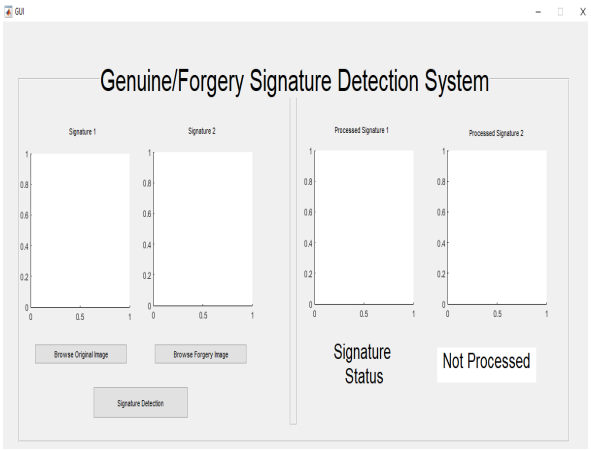

Figure 2: GUI for SVM based Signature Recognition

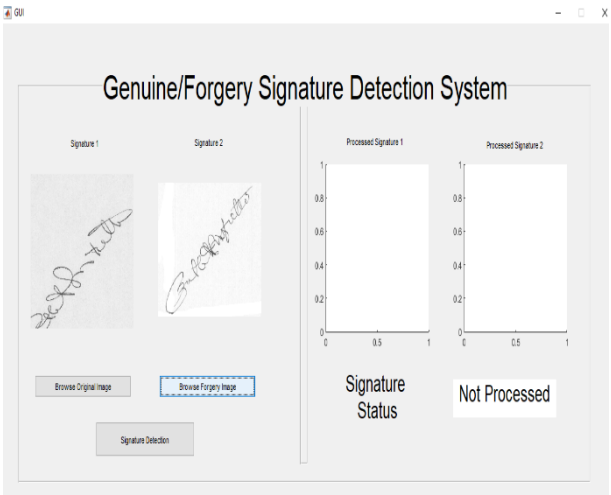

Figure 3: Reading the input forgery/genuine signature

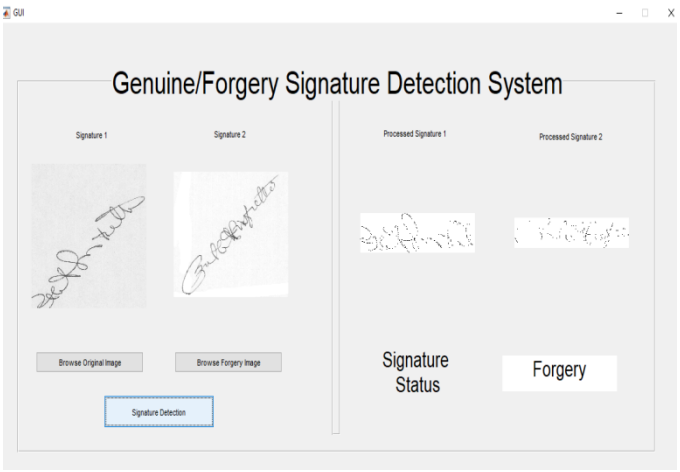

Figure 4: Feature extraction and Forgery Signature Detection Result

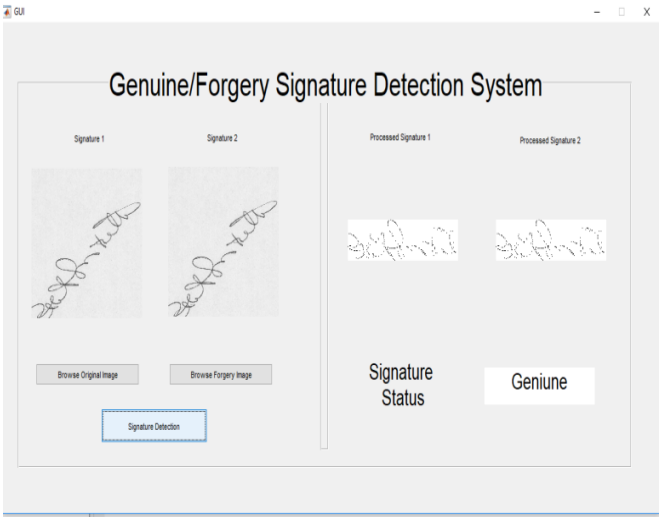

Figure 5: Feature extraction and Genuine Signature Detection Result

For testing the signature detection system. We have considering 50 signatures in that 30 signatures are genuine and 20 signatures are forgery.

Table 1: Results of proposed SVM method

Users	No. of signature	FRR	FAR	Accuracy
User1	50	5/50=10%	3/50=6%	45/50=90%
User 2	50	3/50=6%	4/50=8%	47/50=94%
User 3	50	4/50=8%	2/50=4%	46/50=92%

Table 2: Comparisons with the state-of-the-art works on database SVC2004.

Works	Method	Error Rate (%)
[28]	LNPS+GRU	2.47
[29]	GMM+DTW with SCC	2.63
[30]	DTW+ Warping path alignment	2.53
[31]	Two-stage verification	2.39
[32]	DTW with SCC	2.89
[33]	Spare representation	2.98
Proposed Work	Edge Histogram + SVM	2.37

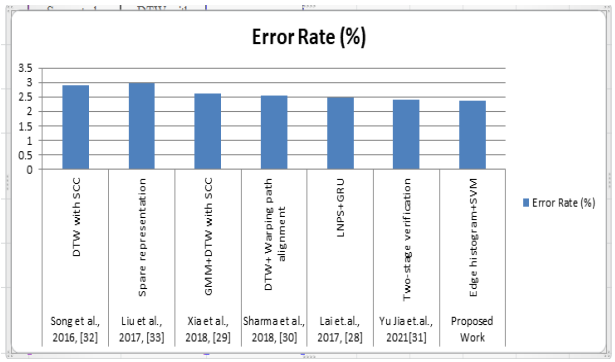

Figure 6: Graphical view of comparative analysis with existing works

Table 2 shows a comparison of the SVC2004 database with the prior art. Due to the different databases, training, tests, etc., it is not easy to make a fair comparison of online signature verification methods. Select some recently published works using the same database (SVC2004). The existing method has a slightly higher EER than our method.

5. Conclusion

Offline signature verification based on edge histograms using a support vector machine system has been proposed. Using techniques such as RGB2Gray conversion, filtering, adjustment, thresholding, and clever edge detection, the signature can be pre-processed. It has been shown here that the proposed method is more efficient and thoroughly tested to detect segmented signatures of the original image with different image processing methods. The proposed work limitation is that the classifier is retrained during the training phase. In Future work, the support vector machine (SVM) is being examined for the discovery task.

Conflict of Interest

The authors declare no conflict of interest.

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Dr. SUNIL KUMAR D S obtained his ph.d. in computer science from mangalore university, india. He was received his m.sc. in computer science from kuvempu university, india before obtaining his phd. His research area of interest is pattern recognition, machine learning and deep learning. He has published 4 research papers in highly reputed international journals and conference proceedings. His ph.d.

research work is on signature biometric. He was worked as faculty member in various institution in bangalore, india. His one of the research paper is published in the isprs international workshop "photogrametric and computer vision techniques for video surveillance, biometrics and biomedicine" -psbb17 held in lomonosov moscow state university, moscow, russia from 15th to 17th of may-2017. the international workshop is organized by isprs wg ii/5 and wg ii/10, the state research institute of aviation system (gosniias, russia), lomonosov moscow state university and the moscow state university of geodesy and cartography (miigaik, russia).

KIRAN currently working as an assistant professor in department of Electronics and Communication engineering at Vidyavardhaka college of Engineering, Mysuru, Karnataka, India. Kiran received his M.Tech in Digital Electronics and Communication Systems at Malnad College of Engineering - Hassan affiliated to Visvesvaraya Technological University, Belgaum, Karnataka, India. He is currently pursuing his Ph.D at Visvesvaraya Technological University, Belgaum, Karnataka, India. His research interests are related to Human Computer Interaction and medical Image security. He has published several research papers at national and international journals, conference proceedings.

Dr. Sudheesh K V, has received the B. E in Electronics and Communication Engineering and M. Tech in Digital Electronics and Communication from Visvesvaraya Technological University, Belagavi, INDIA. He has received Ph.D. degree in the field of Image Processing from the Visvesvaraya Technological University, Belagavi, INDIA. He is currently working as an Associate Professor in Electronics and Communication Engineering Department, Vidyavardhaka College of Engineering, Mysuru, INDIA.

His research interests include Pattern Recognition, Image Processing, Signal Processing, Machine Learning and Brain Abnormality Detection. He has published 10 technical papers in international journals and conferences. He serves as a reviewer for several international conferences.

YASHAWANTH J currently working as an assistant professor in department of Electronics and Communication engineering at Vidyavardhaka college of Engineering, Mysuru, Karnataka, India. Yashawanth J received his M.Tech in Digital Communication and Networking at The Oxford College of Engineering, Bengaluru to Visvesvaraya Technological University, Belgaum, Karnataka, India. He is currently pursuing his Ph.D at JSS University, Mysuru, Karnataka, India. His research interests are related to speech processing and networking. He has published several research papers at national and international journals, conference proceedings.

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Competency Manifestation Clues within Interactions in Computer Mediated Communication

Hocine Merzouki [1] *, Nada Matta [1], Hassan Atifi [1], Francois Rauscher [2]

[1]University of Technology of Troyes, 12 Rue Marie Curie CS 42060, 10004 Troyes, France

[2]InfoPro-Digital, 92160 Antony, France

*Corresponding author: Hocine Merzouki, Email: hocine.merzouki@utt.fr

ABSTRACT: The notion of competence is multidimensional and polysemic. Several definitions of this notion are present in the literature according to disciplines such as industry, sociology, management, psychology, etc. It often refers to the experience, knowledge, abilities, skills, behaviors, and attitudes that allow valuable action in a workplace. Beyond its intrinsic value for the individual, competence is considered in organizations as an intangible asset whose mere possession often provides very considerable competitive advantages. The manifestation of competence takes several forms and the methods of its evaluation differ, ranging from quantitative approaches to social recognition. The approach that we have developed is based on the hypothesis that interacting individuals emphasize the components of their functional competencies according to the activity they carry out and the context that surrounds it. We chose pragma-linguistic, which permits us a more in-depth analysis in comparison to statistical analysis based on text-mining or data-mining techniques that are insufficient for an accurate detection of competence. For that purpose, we have proposed an interaction analysis methodology based on natural language processing techniques to find language elements that highlight the clues of the manifestation of the competence in computer mediated communications. We have developed and implemented two algorithms for the detection and analysis of competence that we have applied to interactions from the "Ubuntu" corpus of the community of interest of the same name which deal with Ubuntu operating system issues. The results of the application of our approach are presented and discussed in this paper.

KEYWORDS: Ability, Behavior, Communication, Competence Detection, Computer Mediated Communication, Interaction

1. Introduction

The competence concept covers several disciplinary domains (sociology, industry, psychology, cognitive sciences, Human Resources Management, strategic management, etc.). It is a complex notion that is individual and collective, tacit and explicit, but often reduced to qualifications and sometimes associated exclusively with practices. Moreover, the terms used to designate competence often induce ambiguities according to usage. Thus the words 'skills', 'abilities', 'capabilities' are used almost indiscriminately to designate competence in literature where knowledge and know-how are qualified as "hard competencies" and the other categories related to attitudes, behaviors and personality traits are called "soft competencies" [1]. The methods most used by managers for competence assessment are staff appraisal, evaluation interviews, tests or references contained in curriculum-vitae [2]. Even if the results of these processes are relevant, they remain biased by the fact that they are based more on the declarations of individuals than on their real or potential capacities to act. Other competence identification systems are proposed such as the “recommender system” [3] where the authors explored the idea that the interests of an individual are strongly linked to their skills. They detect and analyze the traces of online professional activities of an individual to deduce his competencies. The notion of interest is indeed interesting, but it constitutes a simplified representation of competence. There are other automated competence identification methods from documents, based on text-mining such as the method proposed in [4] which extracts keywords from documents associated with personnel. However, these keywords generally refer to vague competence areas rather than to

explicit competencies. In [5], the authors explored an "e-learning" system which makes it possible to integrate the traces of an individual's training to deduce his competencies. But this way of doing things is flawed by its tendency to confuse competence and training or apprenticeship.

In our hypothesis, we assume that it is more likely to detect competencies by analyzing interactions around previous actions performed by people in the context of decision-making or problem-solving processes or more generally in cooperative activities. Indeed, during cooperative activities, individuals interact and exchange proposals and arguments in order to perform complex tasks. By going through the stages of an interaction, they share and merge their knowledge to create new one [6]. Therefore, the analysis of the interactions underlying a cooperative activity not only allows us to record the links between the parts of the activity, but it is particularly efficient to detect the clues of the manifestation of competence that helped to solve a problem, to make a decision or to deal with a given situation.

Communicative interactions have been the focus of many analytical studies that explored several techniques for different purposes [7]-[15]. In this article, we presented related works dealing with computer mediated communication and we proposed an interaction analysis methodology based on natural language processing techniques using a pragma-linguistics grid to identify language elements that highlight the clues of the manifestation of the competence in computer mediated communications. We chose pragma-linguistics instead of statistical analysis based on text and data mining techniques that are insufficient for an accurate detection of competence.

In this paper, we firstly present different definitions of competence, its characteristics and dimensions. We then report the interaction analysis works and we describe the approach we have developed. Finally, we discuss the results obtained from the application of our approach on a specific corpus.

2. Competences

The concept of competence is multidimensional and polysemic because its definition is not consensual [7]. It is also hegemonic and ambiguous due to its widespread use in several domains of human activity, making its meaning plural and problematic [8]. Furthermore, the meaning of the concept of competence depends on the variety of study contexts and uses. Its consensual use refers to its apparent obviousness and to the shifts in meaning, logic and underlying issues that characterize it as stated in [9]. The notion of competence replaces and engulfs the adjacent notions of know-how, behavior and qualification [10]. The relevance of the notion of competence has been an issue both in the cognitive sciences and in didactics where the concept of knowledge has been broadened in the hope of describing the action without having to refer to other concepts, such as competence [11].

2.1. Definition of competence

In [12], the author studied competence from the organizations management point of view and proposed, borrowing from research on education, a three-dimensional representation of competence as illustrated in Figure 1. The three dimensions refer to i) knowledge (data, information, knowing who, what and why, etc), ii) practices (know-how, encompassing techniques, technologies and tricks) and iii) attitudes (behaviors, motivations, identity, etc).

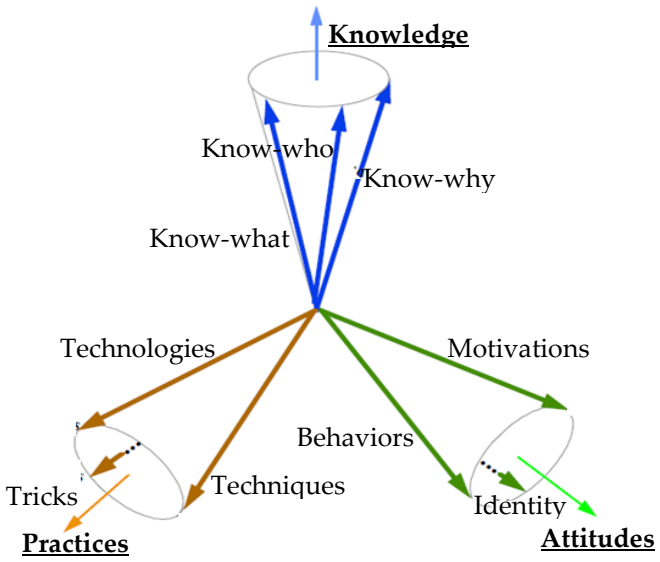

Figure 1: Competence components [12]

Five components of competence are identified in [13], namely, i) motivations, representing the stimuli of action, ii) traits, which are physical characteristics and coherent responses to situations, iii) attitudes and values of the individual, iv) knowledge, referring to the information possessed in a specific area, and v) skill reflected by the ability to perform certain tasks. In [14], the author considers the competence as a process which corresponds to the mobilization, in action, of a certain number of knowledge combined in a specific way. For him, competence is a combination of five components, (i) cognitive (knowledge and skills acquired during trainings), (ii) affective (self-image, investment and motivation), (iii) social (recognition), (iv) cultural (culture of the organization) and (v) praxeological (measurement of performance).

For the authors of [15] "the competence is the effect of combining and putting into play one's own resources (knowledge, know-how and behavior) in a given context to achieve a goal or fulfill a specified mission". This vision is close to that presented in [16] where the author considers the competency as "based on the relationship

between specific knowledge in a given domain and generic skills, with certain level of performance". In [17], the authors stated that "competence is the mobilization and dynamic organization of a set of heterogeneous cognitive resources that leads to product an acknowledged performance in the framework of a finalized activity and a particular class of situations".

In [18], the author focused on the most used competences in industrial firms and stated that "being competent requires to combine, in a relevant way, personal resources (knowledge and know-how) and environment resources (technological, material, etc.) in order to manage varied professional situations to achieve an objective and provide deliverables (tangible or intangible) to a recipient (customers, service, etc.) that help to evaluate actions' performance". The authors of [19] and [20] share the same vision and argue that "competence is the ability of a person (actor) to act and react with the relevance required to perform an activity in a work situation".

Based on an organizational approach, the competence is linked to actors' role for the author of [21]. Following the author of [22], he considers that "the competence is the ability for a person to apply his knowledge and improve his know-how in a professional situation". Thus, depending on different analysis visions, several components of the competence are to be considered.

Competence is "The combination and implementation of knowledge, know-how and know to behave to achieve a recognized performance, in relation to a given environment and as part of a finalized activity" [23], where (i) knowledge designates the mastery of varied concepts linked to a given activity domain like protocols, procedures, and standards. (ii) Know-how indicates the efficiency in executing tasks in a specific field of activity and (iii) know to behave reveals the aptitude to work on a variety of situations. Our approach is centered on detecting the manifestation of one or all of these three components.

2.2. Characterization of competence

The competence can be identified by three viewpoints; Organizational, Industrial and Individual, as depicted in Figure 2 [23].

The use of the concept of competence in human resources management derived from the reflection on the management of resources is based on the work of cognitive ergonomics [24] and its characteristics are repeated identically in [25] as shown in table 1.

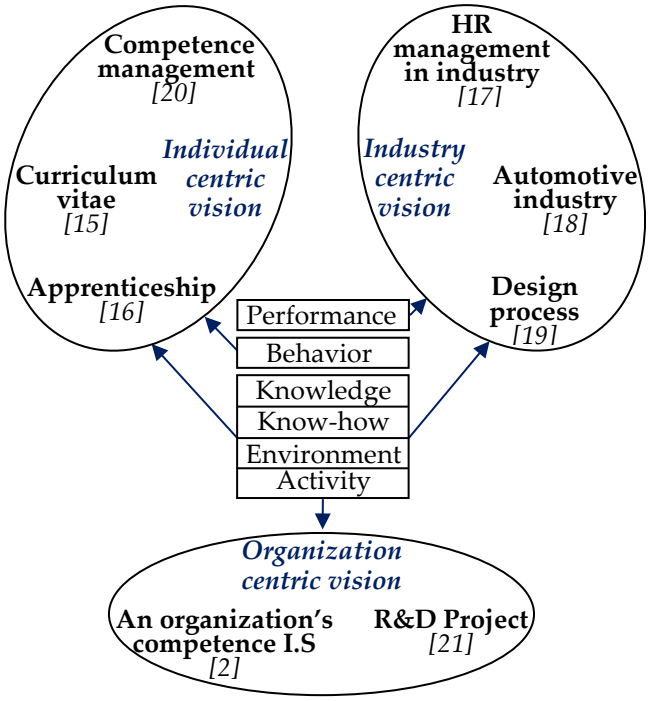

Figure 2: Different visions of the competence components use [23]

Table 1: Characteristics of competence [25]

Characteristics	Implication
Individual	It is possible to focus interest on the person competence independently of the organizational [26].
Heterogeneous	The competence is a combination of knowledge, technical know-how, behaviors, attitudes, interpersonal skills, etc. [27]. It combines diverse resources to surpass their mere possession [28].
Contextualized	Competence is inseparable from the activity through which it manifests itself [29] [30]
Dynamic	The competence is constantly developed, enriched and improved to adapt to the changing situation without departing from its associated category, in which case a new competence may emerge [28]
Objectified	Based on competency frameworks which are considered to provide an objective definition of work [31]

In the proposed work, individual, heterogeneous, and contextualized characteristics are focused. This choice is motivated by our hypothesis stating that interacting individuals emphasize the components of their own functional competencies according to the activity they carry out and its context.

Indeed, in our approach, competence encompasses three components, namely knowledge, know-to-behave and know-how, that are intrinsic to the individual and inseparable since put together they constitute the competence.

3. Interactions

Traditional vision of communication is based on the mathematical theory of communication proposed in [32], where communication is perceived as the propagation of a message from a source which encodes and sends it, as a signal, to a destination which decodes and interprets it. This vision implies that communication takes place in only one direction at a certain time. Since the 1960s, communication theory has evolved from a linear vision, centered solely on the transmission of messages, towards an interactional and contextualized one [33].

3.1. Pragmatic in interactions

Pragma-linguistic researchers study interactions to determine the logics that underlie them [34]. Indeed, the related woks to the analysis of communication, as an interactional phenomenon, has not been limited to aspects of the efficiency and precision of transmission and reception, such as those carried out in [32] but they include syntactic, semantic and pragmatic aspects [35], where (i) Syntax covers information transmission issues such as coding, transmission channels, redundancy and other statistical properties of the language; (ii) Semantics deals with the problem of meaning, insofar as the symbols have no meaning if the sender and the receiver do not agree beforehand on their meaning, which supposes a semantic convention; (iii) Pragmatic is concerned with the consequences of the execution of the utterance or its interpretation by the speakers, since communication affects behavior.

According to the authors of [36], it is necessary to specify the intended meaning of the messages exchanged. In [37], the author stated that the intention is underpinned by illocutionary acts and for the author of [38], every speech act is illocutionary and corresponds to one of the following five classes of acts : (i) commissive, where the speaker promises to perform an action; (ii) directive, when the sender expects his interlocutor to carry out an action ; (iii) representative, where the speaker commits to the truthfulness of the message; (iv) expressive, in which the speaker communicates an emotional status; (v) declarative when the speaker's message causes an alteration in the status of the referenced object such as the pronouncement of a judgment. Table 2 presents a sample of Searle's classification of illocutionary acts [39].

Table 2: Sample of illocutionary acts classification [39]

Class	Speech acts
Commissive	to affirm, to deny, to postulate, to remark, etc.
Directive	to order, to advise, to forgive, to request, etc
Representative	to promise, to invite, to guarantee, to bet, to make a vow, etc.
Expressive	to thank, to apologize, to congratulate, to criticize, etc
Declarative	to decree, to condemn, to acquit, to baptize, etc

3.2. Interactions analysis

Our review of the literature is based on interaction analysis especially on emails, discussion forums and chats.

In their works related to knowledge identification from professional e-mails in problem solving context [40], the authors used the speech act theory and the act of request by linking interaction analysis to problem context restitution. In [41], the authors have used the paragma-linguistic to detect criteria that facilitate the analysis of coordination messages during the project design stage. By referring to computer mediated communications, presented in [42], the authors used a pragmatic and action-oriented approach to digital discourse. They demonstrated that the communication medium can modify the construction of speech acts. They thus described and proposed approaches for constructing queries.

To find experts and their contact details in email exchanges, the authors of [43] proposed a message analysis methodology based on unsupervised learning. In [44], the authors developed an activity-centered automatic email classification approach, based on their observation that people are connected in groups around common activities and e-mails dealing with a given activity are often articulated around one or more subjects. Similarly, in [45], the authors focused on grouping e-mails into tasks by identifying relationships between them. To do this, they first measure the textual semantic similarities between the contents of the messages, and then they identify the links between them by exploiting the messages metadata. The results of these two steps are used in an iterative reinforcement process to refine the similarities and classify the emails by activity. Likewise, in [46], the authors focused on the analysis of illocutionary acts [38, 39], augmented with supervised learning techniques, within chat and email discussions to automatically find and classify tasks and detect commitments and their evolution from initiation to finalization or abandonment.

In [47], the authors used a text classification approach to identify "email speech acts". Their analysis is based on Searle's act classification [38] applied to multiple corpora in order to characterize a group of "email acts" that are used in the emails classification by means of machine learning techniques. For their part, the authors of [36] used the "n-grams" contained in e-mails to analyze computer mediated communications. They stated that the analysis of communication is biased if only simple words are used as features and the textual context is neglected because the latter represents a very essential linguistic aspect. To illustrate their statement, they made a comparison between the set of words "would", "you", "give" and "me" analyzed separately and the entire phrase "would you give me" that is more likely to describe a request.

4. Competency detection method

Our objective is to detect competencies from mediated interactions. The pragma-linguistic approach, illustrated in figure 3, that we developed is based on Searle's illocutionary acts classification [38, 39]. It aims to identify the communicative intentions as well as the components of the competence mobilized by the actors in their interactions. It fellows these steps:

- We select an interaction in a corpus of mediated communication and submit it to our pragma-linguistic analysis grids to identify the interlocutors' intention.
- By analyzing the intention of the interlocutors, we seek in the content of the interaction for the part which would contain a mutual aid activity which, according to our hypothesis, is the part which is supposed to provide clues of manifestation of the competence.
- We then focus the analysis on the portion of the interaction where the manifestation of competence is detected to spot the verbs and words used by the interlocutors and the class of the speech acts used to deduce the interlocutors' intention and find who would be the holder of the competence.
- We finally use the action verbs and abilities' taxonomy and the activity domains' glossary to identify the interlocutor's know-how, his behavior and his field of competence.

4.1. E-DISCO taxonomy

To develop our taxonomy of competence, we carried out a comparative study of three main systems providing taxonomies of skills and competences, which are the "European dictionary of skills and competences" (E-DISCO), the "Occupational information network" of the US labour department" (O*NET) and the Swedish "Taxonomy-DB". The results of this comparison are summarized in Table 3 [48].

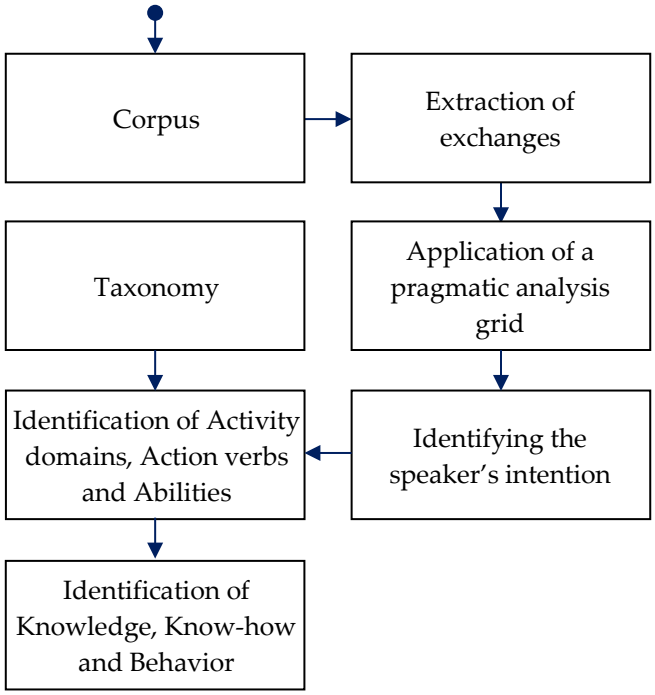

Figure 3: Methodology of competence detection

Table 3: Strengths and weaknesses of competence taxonomies [48]

Taxonomy	Strengths	Weaknesses
E-DISCO	Available in 14 languages. Similarities with the language of the job market. Easy definitions of concepts.	Some descriptors are considered as "competences & skills", even if they are not.
O*NET	Easy understanding of competences and skills.	Technical rather than common terms. Only available in US
DB-Taxonomy	Available in 20 languages. Used for labour market correspondence.	Blurred border between skills and occupations. Lack of terms explanation. Elementary classification.

In our approach, we use E-DISCO taxonomy since it is multilingual and compatible with many other nationally recognized compilations such as the French "Operational directory of professions and jobs", the Swedish "Taxonomy-DB", the German "Competences catalogue" and Austrian "AMS-Qualification classification" [48]. Its hierarchal structure provides us with a wide-ranging dictionary of skills, abilities and action verbs and it encompasses twenty-five main activity fields, broken down into multiple sub-fields. We present in Table 4 a sample of action verbs from E-DISCO. Table 5 illustrates

the four classes of skills and abilities; personal, physical, cognitive and managerial skills.

Table 4: Sample of action verbs from "E-DISCO" [48]

Action verbs
Apply / Assemble / Blend / Calculate / Collect / Create / Disconnect / Dissemble / Dismantle / Display / Draw / Drill / Examine / Exchange / Extract / Find / Fix / Follow / Glue / Identify / Implement / Install / Master / Modify / Measure / Mix / Monitor / Negotiate / Order / Organize/ Operate / Prepare / Rectify / Renovate / Repair / Restore / Represent / Select / Store / Solve / Update / Take [. . .]

Table 5: Sample of skills and abilities from "E-DISCO" [48]

Skills and Abilities	
Personal skills and abilities	Ability to work in a team / Capability to support pressure / Assertiveness / Discretion / Reliability / Carefulness / Politeness / [. . .]
Physical attributes and abilities	Agility / Dexterity / Physical strength / Absence of perception problems and allergies / Stamina / Sense of balance / Responsiveness [. . .]
Problem solving abilities and cognitive skills	Concentration and learning abilities / Inventiveness / Analytical mind / Intellectual curiosity / Application of regulations and laws [. . .]
Managerial / organizational skills	Decision-making / Coordination and organizational abilities / Multitasking capabilities / Management techniques / Operative planning / Supervision skills [. . .]

4.2. General architecture of the proposed system

To concretize our approach we proposed a system whose general architecture is illustrated in Figure 4. It's based on two algorithms that we developed and implemented using the object-oriented programming language Python. The first algorithm aims to detect the competence manifestation assumption while the second one analyzes the competence manifestation in depth to bring more information such as the competence holder, his how-know, his abilities and his competence domain.

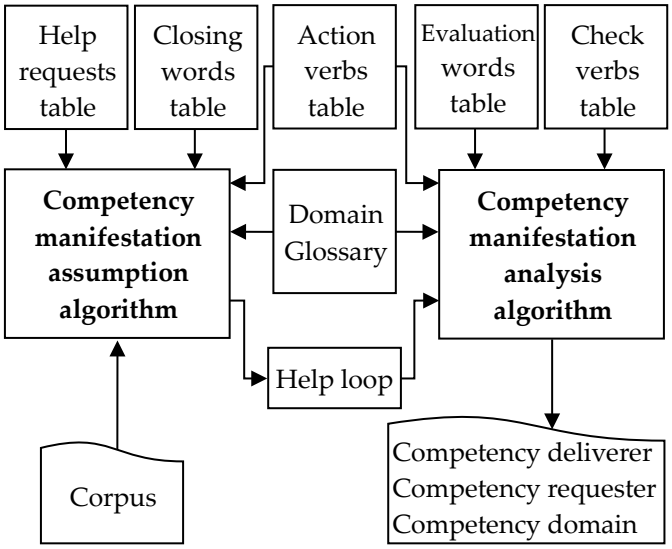

Figure 4: General architecture of the proposed system

4.3. Competency manifestation assumption algorithm

In the aim of detecting the manifestation of competence, we presume that individuals involved in a cooperative activity make proposals, share arguments and seek for explanations through questions and answers in order to make a decision or resolve a problem. We also presume that the competence manifestation is to be found in the part of the interaction between the expression of a request and the end of the response to this request. Moreover, we consider that once the interlocutor, who needs a competence, gets help, he will express an acknowledgment to the person who provided him with the required competence.

The usual expression used to ask for competence is the "help" request. We assume that if such a request exists within an interaction, it implies that there is a potential manifestation of competence that can be selected for further analysis. A request as stated above belongs to the class of directive speech acts where the speaker intends the receiver to perform an action [38]. We make a distinction between direct and indirect requests. Table 6 illustrates these types and gives a variety of expressions using the verb "help" [23].

Table 6: Help request grid [23]

Request	Linguistic form	Examples with Help
Direct request	Performative	I am asking you to help me.
	Imperative	You have to help me. Help me.
	Need / Want statements.	I want (need) you to help me. I need help.

	Obligation statements	You have to (must) help me.
Indirect request	Question about the listener's willingness to perform an action.	Would you like to help me?
	Question about the listener's ability to perform an action.	Could you help me? Can you help me?
	Statement about the speaker's will.	I would like (appreciate) if you can help me.

We use the Table 6 above as an input for the competency manifestation assumption algorithm. However, before being satisfied the interlocutors will exchange to precise the needs and to get more explanation about the subject. We assume that during this exchange they use words that belong to the domain of activity related to the issue they are dealing with. These words are selected and compared to the domain glossary and if they match a specific domain with sufficient proportion, it will be considered as the activity domain. This step is important because as we stated before there is no competence if the context does not exist.

After having obtained satisfaction or not, the interlocutor who asked for help generally thanks the one who guided him. We therefore consider the detection of a "thanks" word as being synonymous with the end of a help sequence. However, other words can signal the closing of a help sequence. We assembled the closing words in Table 7.

The aim expected from the competency manifestation assumption algorithm is to delimit the part of the interaction where the manifestation of competence is found. This part is isolated to be the input for the competence manifestation analysis.

Table 7: Closing words table [23]

Closing words
Ta
Thanks
Thanks a lot
Thank you very much
Thank you
Thank you so much
Thank you for
Thank you ever so much for
Thank you very much for
I am really most grateful for your
I am very grateful for your
It was terribly good of you to have
I appreciate your help
I am thankful for your help
Thanx
Thankyou

The algorithm we developed for the competency manifestation assumption is the following:

Algorithm 1: Competency manifestation assumption

```
Result: manifestation of competence
Select an interaction between two interlocutors;
Search for help requests terms for each interlocutor;
Find the words of the associated domain Glossary;
Search interaction closing words;
Search other forms of questions;
Find the words of the associated domain Glossary;
Find answers to questions by interlocutor;
Find action verbs;
Find the forms of speech acts "directive / informative;
Find other forms of speech acts "evaluation ;
Find words in the associated Glossary;
 if help requests and closing words exist then
   | A potential competence requester exist;
end
if directive or evaluation forms exist then
   | A potential competence deliverer exist;
end
If words match a domain glossary then
   | A potential competence in the domain exist;
end
If action verbs exist then
   | A competence exists in the associated domain;
end
```

4.4. Competency manifestation analysis algorithm

After detecting a potential manifestation of competence within a portion of an interaction, we perform a more depth analyse of this isolated part to detect who is the owner of the competence, his domain of knowledge and his know-how. To do this we rely on the supposition that the competent person will help the applicant by asking him to perform certain actions. He will then use action verbs (Table 5) in a directive form according to sealers classification (Table 2). For example, he can make suggestions in the form of instructions to follow, identify and name the problem to be solved, make a diagnosis by describing the situation or explaining the approach or solution adopted. Besides giving instructions to guide the

requester, as things progress, the competence holder will tend to control and evaluate the actions performed then he will ask to perform checking on the one hand and on the other he will assess the results of the actions by using evaluation words (evaluative act). To do this we selected from the action verbs taxonomy those generally used to perform checks (Table 8) and we constituted a bag of words that express evaluations (Table 9).

Table 8: Check verbs [23]

Check verbs
Try / check / see / look / verify/ control.

Table 9: Evaluation words [23]

Evaluation words
Good / great / right / Fine / Wonderful / Super / Nice / Success / It's working / It works / It worked.

During the part of the interaction containing the assumption of competence manifestation, the competence holder will use words in relation with his competence domain and verbs that express his know-how and how to behave. For this is, we use the domain glossary and action verbs taxonomy. The input of the competency manifestation analysis algorithm is the help-loop previously isolated and the output expected is the competent interlocutor, his how-know and his competence domain. Moreover, an annotated text file is delivered. It contains the portion of interaction represented by the help-loop with highlighted words, action verbs and check verbs and their corresponding class in Searls' speech acts classification. Based on the above, we have proposed the competency manifestation analysis algorithm as follows.

Algorithm 2: Competency manifestation analysis

```
Result: Competency requester, Competency deliverer, Competency domain
For each help request;
Determine interlocutor;
Set interlocutor_1= interlocutor;
Find in the thread of interaction the first next apparition of closing words;
Determine the interlocutor;
Set interlocutor_2= interlocutor;
if interlocutor_1 = interlocutor_2 then
    Set help requester = interlocutor_1;
    Set help deliverer = the interlocutor who answer interlocutor_1;
    Set Help-loop = the part of interaction between the help request and the closure of help;
    Isolate the Help-loop;
    Count the number of directive and evaluation answers for each interlocutor;
    Set A = the number of directive and evaluation answers of the Help deliverer;
    Set B = the number of directive and evaluation answers of the Help requester;
    Detect action verbs and words used within answers;
    if A > B then
        Set Competency requester = Help requester;
        Set Competency deliverer = Help deliverer ;
        Set Competency domain = domain Glossary related to words ;
    else
        Exit Help-loop ;
    end
end
Find the next help request within the interaction;
```

5. Results

To apply our approach, we used the Ubuntu corpus, which is made up of more than seven million statements exchanged within an interest-based community around the Ubuntu operating system technical issues. We chose this corpus because the communities of interest are characterized by the absence of hierarchy, roles, signatures and identity elements that could explicitly indicate the competences of its members. All of this renders the identification of competence difficult without operating a detailed and in depth analysis of the interaction.

5.1. First application

Our competency manifestation assumption algorithm has been applied to a selection of nearly 400 exchanges involving two participants in an interaction. The result obtained consists of 6 help-loops, one of which is presented in Table 10.

Table 10: Help loop extracted from an interaction between "Kartagis" (A) and "Ikonia" (B)

	Message	Speech acts
A	Can you help me with my problem? Ubuntu dims the display every time. I start a GUI program with dare background, like terminal	help request
B	are the video cards different	request
A	It could be, I'm not sure. can't check now because the one at work is off	Check
B	Worth checking,	informative
A	and if they are?	informative
B	well, that is where I'd start investigating	commissive
A	What codecs can I install here?	request

B	is that the one that's working (I bet not)	request
A	that's the one failing	
B	SIS videocard, terrible, lots of problems. Not surprised it's failing grep $ username/etc/passwd and let's see the result (it contains no password information)	informative
A	vetibbc.com: x: 1000: 100: BBC Vetereiner Klingi,: /srv/ www/vetibbc.com: bin/bash	informative
B	ok, so that's all. Look at the permissions on the home-dir as I suspect that's the issue. Set spot on,	directive chek
A	600, maybe that i's why?	
B	is the user the owner ? and look at the permissions on /sry and srv/www as the user needs to be able to get into them to see his home dir	directive check
A	Yes	
B	if you su - $user can you then put cd into the home-dir ?	directive
A	permission denied	informative
B	we have a winner !	
A	http:/ /pastebin .com/QbNcKSrE	informative
B	ls -la /srv/www	
A	drwx------ 3 vetbbc.com users 4096 Sep 28 23:57 vetbbc.com	
B	No, can you run "id" on the user vetibbc.com. 600 is a good permission	directive
A	uid. =.1000 (vetbbc.com) gid. =.100 (users) groups=100(users)	
B	that should be fine. can the user get into /sry ?	evaluation
A	yes, and / srv/ www too. 700 fixed it though	
B	Why do you need write-access? most odd glad your fixed	informative
A	Thanks.	Cloture

The present help-loop begins with a help request "can you help me" and ends with "thanks" (in green). It contains requests, action verbs (in blue), check verbs (in red) and terms (underlined) that belongs to the glossary of information technology (IT). All these elements suggest a manifestation of competence that we analyzed by applying the competency manifestation analysis algorithm. We got the results shown in Table 11.

Table 11: Results of the application of the competency manifestation analysis on a thread of discussion between "Kartagis" and "Ikonia"

		interlocutors	
		Kartagis	Ikonia
Number of exchanges	27	14	13
Help requests	1	1	0
Cloture terms	1	1	0
Requests	3	1	2
Directives	4	0	4
Directive with check verbs	2	0	2
commisive	1	0	1
Commisive with check verbs	1	1	0
Informative acts	7	4	3
Evaluation acts	1	0	1
Competency requester	Kartagis		
Competency deliver	Ikonia		
IT domains associated :	Software terms: 75% Computer security: 10% Apple terms: 5%		

These the results show that the help-request and the cloture term (Thanks) are exclusively formulated by "Kartagis", thus, we consider him as the competency requester. All directive acts are expressed by "Ikonia", therefore, he is the competency-deliverer. These results show, as we stated in our hypothesis, that the competency-deliverer formulates language acts attesting to his competence like orders by asking his interlocutor to perform some actions (ie. "set spot on"), or propositions by reformulating the expressions of his correspondent to make a diagnosis (ie. "Not surprised…it contains no password…"), by detailing the tasks to be executed in order to tackle an issue (ie. "If you….then put cd.."), or by assessing the actions carried out (ie. "that should be fine").

5.2. Second application

To reinforce the results obtained in the first application of our approach we selected another interaction where the interlocutor "Ikonia" who was declared competent is involved. The help loop obtained after the application of the competency manifestation assumption algorithm is presented in Table 12 bellow. Due to the duration (length) of the interaction, we only selected the top and the end of the help loop.

Table 12: Help loop extracted by applying the competency manifestation isolation algorithm on an interaction between Roasted (A) and Ikonia (B)

	Interaction	Speech act
A	Appreciate the help.	help request
B	arp will show you the mac's currently connected	Information
A	meaning it'll show me the MAC of the wireless adapter in my laptop - not the actual access point?	Request
B	try it with a different user account, see if it's your personal settings or a bug	Directive check
A	I'm almost positive it's a personal setting in the	Informative

	.thunderbird directory that KDE's existence changed.	
B	ok, well finding out for certain if it's a personal settings thing is the way to go	Informative
...	...	...
A	I've had this happen before, so I'm pretty certain that's what it is.	Commisive
B	then fix it how you fixed it before instead of asking for help	Directive
A	if I knew how to fix it, I would have fixed it instead of asking.	Information
B	if you want help - follow the advice to get the information spot on to get help, if you know the problem then work out how to fix it	Informative
B	check for certain with a different user	Directive Check
A	I'll continue asking for help since I am unsure of how to fix it.	Commisive
B	please don't be so rude as to post links to it when I've just (we don't deal with unsupported packages in here	Directive
A	I got it fixed. thanks anyway.	Cloture

In order to analyze this isolated part of the interaction, we submitted it to the competency manifestation analysis algorithm and obtained the results presented in Table 13.

Table 13: Results of the application of the competency manifestation analysis on a thread of discussion between Roasted (A) and Ikonia (B)

		Interlocutors	
		A	B
Number of exchanges	240	140	100
Help request	1	1	0
Cloture terms	3	3	0
Requests	28	23	5
Directives	22	7	15
Directive with check verbs	8	0	8
Commissive	25	22	3
Commissive with check verbs	3	2	1
Informative acts	150	82	68
Evaluation acts	0	0	0

Competency requester	Roasted
Competency deliver	Ikonia
IT domains associated	Software terms: 40.2% Business terms: 35.4% Computer security: 3.9%

This table shows that the help request sentence (Appreciate the help) and the closing words (Thank you) are expressed by the same speaker "A" who also formulated the majority (24/28) of commissive acts, so he is the requester of competency according to our hypothesis. Moreover, the majority (23/30) of the directive acts are formulated by the speaker "B" who is consequently the competency-deliverer. Through these results we notice that the deliverer of competence performs language acts to guide his interlocutor in order to help him in performing tasks (ie. "fix it") or to control his activities by directives with "check verbs" (ie. "try it with ..., see if it's your personal settings or a bug ") or to lead him to explore different paths of a process (ie. "if you want help - follow the advice …, if you know the problem then …"). The results gave the interlocutor named "Ikonia" as the holder of competence in software domain. These results were confirmed by an expert who analyzed the interaction.

6. Discussion

The results obtained by applying our method on two different interactions in which we kept one of the interlocutors unchanged showed that the latter had competence in both cases and in the same field. These results, which are confirmed by an IT expert, show that the method we proposed enables us to detect a potential manifestation of competence and to discover the competent and his field of competence. Moreover, the file obtained is annotated and makes it easy to identify the action verbs, the glossary words used and the classification of the speech acts contained in the interaction. This deliverable can be used as needed by an expert for a possible in-depth analysis. Indeed, unlike CV analysis methods, where the skills are declared by the author of the CV, our method detects the acts and the words then link them to a glossary.

7. Conclusion

In this work, we started by studying the notion of competence to adopt its definition and determine its components. We then presented the notion of interaction and elements of pragma-linguistics and led a literature review on related works on the interaction analysis. The approach we proposed in response to our hypothesis was then presented. It consists of a methodology to detect and analyze competencies in the interactions. We used pragma-linguistic concepts applied to computer-mediated communication to determine the intention of participants

in an interaction in order to detect a potential manifestation of competence and then analyze it. Two algorithms have been developed for this purpose and implemented. We applied them to interactions from the Ubuntu corpus. The application made it possible to detect the manifestation of the competence, the interlocutor who is competent and his competence field. To confirm the obtained results, we applied our method on two distinct interactions where one of the interlocutors is involved in both. For the two interactions the results gave this same interlocutor as competent and in the same field. These interactions are also analyzed by an IT expert who confirmed the results. The limit of our approach lies in the type of the interaction we selected. Indeed in our work we focused on a specialized discussion corpus, which limits the topics of discussion, whereas if the corpus deals with several topics it would be considered essential to enrich our methodology with new algorithms. Moreover, our work could be extended to analyze "soft competencies" such as attitudes which remain difficult to detect.

Conflict of Interest

The authors declare no conflict of interest.

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Hocine Merzouki, Phd candidate at the University of Technology of Troyes in France. He has done his Master degree in Information system management at University of Pau and Pays de l'Adour (France) in 2011.

Nada Matta, Full Professor at the University of Technology of Troyes. She studies techniques in knowledge engineering and management specially to handle cooperative activities as product design, crisis management, etc. She is Director of department of "Human, Environment and ICT". She assumed several responsibilities as: Director of department of "Human, Environment and ICT" for four years, Director of "Scientific group of supervision, and security of complex systems" for five years and Director of department of "Information Systems and Telecom" during two years. She is involved in the organization of several tutorials and workshops on COOP, ISCRAM, KMIS, IJCAI, ECAI, CTS conferences. She wrote several books on Knowledge Management. She is involved in scientific committees of several conferences, journals and research groups. She manages several projects on the application of Knowledge Management in several domains (consulting, design, safety, security). She completed her PhD in KE and AI at University of Paul Sabatier (France) in collaboration with ARTEMIS. She worked for 4 years at INRIA in projects with Airbus Industry and Dassault-Aviation. E-mail: nada.matta@utt.fr. http://matta.tech-cico.fr/en.

Hassan Atifi is Assistant Professor in Communication Studies at the Troyes University of Technology (France) and researcher in the Tech-CICO research group/LIST3N (Computer Science and Digital Society Laboratory). He has published several papers in the field of digital ethnography about different aspects of computer-mediated communication: Knowledge pragmatic extraction from professional e-mails, Maker's Tutorials, ordinary political discourse and online participatory communication.

François Rauscher has completed his PhD degree in knowledge management from the University of technology of Troyes in France.

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Evolution in Software Product Lines: Defining and Modelling for Management

Amougou Ngoumou *, Marcel Fouda Ndjodo

Department of Computer Science, Higher Teacher Training College, University of Yaounde I, Cameroon
*Corresponding author: Amougou Ngoumou, PO Box 47, Yaounde, Cameroon, Tel.: (237) 677 755 148, Email: ngoumoua@yahoo.fr

ABSTRACT: Evolution in Software Product Line (SPL) is claimed when there are changes in the requirements, product structure or the technology being used. Currently, many different approaches have been proposed on how to manage SPL assets and some also address how evolution affects these assets. However, the usefulness, effectiveness and applicability of these approaches are unclear, as there is no clear consensus on what an asset is. In this work, we plan to reduce complexity in SPL evolution management. For this goal, the difficulty is defining and modeling SPL evolution and we expect to propose a flexible way to manage it. However, a large variety of artifacts is considered in SPL evolution studies, but feature models are by far the most researched ones. Feature models are widely used to represent SPLs and have been greatly developed in the Feature-Oriented Reuse Method (FORM). Consequently, in our previous works, after observed that this method has a loose structure since it does not provide guidance to reuse and rigorously analyze its assets, we have extended FORM to FORM/BCS (the Feature Oriented Reuse Method with Business Component Semantics) by enveloping its assets among which feature models with business component semantics. The contribution and the novelty of this work is that, by highlighting formally the concept of software asset and revisiting feature business components, to add new information when analyzing a domain, such as clashing actions. conflicts or undesired interactions between existing features in a product line and new features due to evolution of the product line can be manage in a flexible way.

KEYWORDS: Evolution, Software Product Line, feature-orientation, domain analysis, business components, reuse

1. Introduction

The Software Product Line Engineering (SPLE) [1] is an approach that aims at creating individual software applications based on a core platform, while reducing the time-to-market and the cost of development [2]. Many SPLE-related issues have been addressed both by researchers and practitioners, such as variability management, product derivation, reusability, etc. According to authors in [3], a Software Product Line (SPL) is "a set of software-intensive systems sharing a common, managed set of features that satisfy the specific needs of a particular market segment or mission and that are developed from a common set of core assets in a prescribed way". The main benefit of defining a SPL is that the reuse of all assets can be systematically organized [4].

There are two distinct phases in SPL definition: domain engineering and application engineering. The domain engineering phase starts with domain analysis, where domain knowledge is used to identify common and variable features, and these features are then realized during domain design and implementation. Application engineering focuses on product creation, first by identifying customer needs, which are then used to guide product derivation. In this way, the cost of developing and maintaining core assets is spread across all the products in a SPL, and is not specific to each separate product [5]. Note that the domain knowledge, asset realization, product configuration, etc., can all evolve over time [6].

The concept of evolution [7, 8] is intrinsic to software, since customer requirements and needs change over time, so software must evolve to remain useful [9]. However, the software evolution process is quite challenging since a fragile balance must be maintained: software quality must be preserved but software structure tends to

degrade over time. The following challenges have been identified [10, 6] in the case of SPL evolution: 1) there are different types of assets, which are defined at different levels of abstraction and variability; 2) there is a high number of interdependencies between assets; 3) a SPL usually has a longer life-span than a single product; and 4) a SPL is larger and more complex than its individual products. Currently, many different approaches have been proposed on how to manage SPL assets and some also address how evolution affects these assets. However, the usefulness, effectiveness and applicability of these approaches are unclear, as there is no clear consensus on what an asset is. In this work, our research method consist of highlighting formally the concept of software asset and revisiting feature business components, to add new information when analyzing a domain, such as clashing actions so that we can manage evolution in a flexible way. The base is feature models[11] which are widely used to present commonality and variability (C & V) information of a product line compactly (see Figure1. for example). We have extended Feature models in the Feature Oriented Reuse Method with Business Component Semantics (FORM/BCS) [12, 13, 14, 15, 16, 17]. Each product in the product line is derived from a selection of a valid combination of features [18] —a process known as product configuration [19, 20].

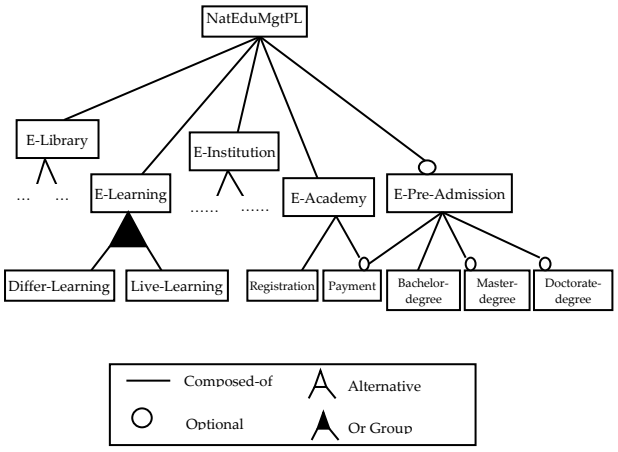

Figure 1. Partial feature model of NatEduMgtPL

Figure 1. presents an example of enterprise software for tertiary institutions of an anonymous country. The product line, referred to as National Educational Management Product Line (NatEduMgtPl), was initiated by the Ministry of Higher Education in that country. The vision of the product line is to provide software products to state universities, other higher institutions, and Enterprise Resource Planning (ERP) vendors. The educational institutions in the country implement the BMD (Bachelor, Master and Doctorate) system - which make their core operations largely the same- hence a product line.

The remainder of the paper is organized as follows. Section 2 details out research design, method, instrument and analysis technique. Section 3 highlights formally software assets and revisits FORM/BCS feature business components. Section 4 defines and models evolution in Software product Line so that we can see how evolution affects feature business components. Section 5 presents related work and section 6 concludes the work and gives perspectives.

2. Research design, method, instrument and analysis technique

Many different approaches have been proposed on how to manage SPL assets and some also address how evolution affects these assets. However, the usefulness, effectiveness and applicability of these approaches are unclear, as there is no clear consensus on what an asset is.

In this regard, we think that the first concern on evolution in SPL is to establish a clear vision on concepts and then processes. The envy to clarify software assets encourages us to first highlight formally this concept. To avoid lack of understanding and ambiguities, we specify the description of software assets using Z notation.

Secondly, knowing that the management of software product line evolution is complex and this evolution is due to requirements and needs change, we revisit the specification of feature business components proposed in the FORM/BCS method [12, 13, 14, 15, 16, 17], as it is the first software asset produced when analyzing the domain, to anticipate evolution very early. In this revision, we enrich features business components with new information such as clashing actions so that we can manage evolution in a flexible way. In the proposed analysis technique, for feature business components, the analyst must find and give, if it's possible, a clash action for all actions in that asset. These clashing actions advice on conflicts and undesired interactions between features and the analyst can avoid or correct them when new features and adaptation points due to evolution appear in user's requirements and needs.

We know that SPL is actually a continue process and we cannot think about all possible variant, but, by this contribution, we want to improve the flexibility of that process.

3. Software Assets

A software asset is composed of a set of software products derived from different activities of the life cycle. Specifically: requirements, architecture definition, analysis model, design model, code, test programs, test reports.

The different products which compose a software asset are in fact the representation of that asset at different level of abstraction (need, analysis, design, realization, texts). When the software asset is reused, each of these software assets can then be reused in the corresponding step (before, during and after coding). Specifically, test programs are strongly reusable. The person who desires

evaluate a software asset for reuse can take existing test programs to enforce the software asset in his own environment. It is important not to limit reuse at code level, but exploit all software assets.

Reusable software assets must be provided with necessary information for their reuse (the software asset description, also call « meta-information » [21]). This additional information allows facilitate software asset manipulation during his life cycle. It is in particular following elements: Classification information which allows facilitate corresponding software assets research, description of software asset which allows to understand rapidly functions and main features of the software asset, documentation of the software asset which allows to understand how enforce and customize the software asset, information related to tests and software asset qualification to facilitate his evaluation by a potential reuse stakeholder, information about software asset origin and property to obtain support or complementary information.

All these characteristics are summarised in the specification below using Z notation.

Table 1: Specification of Software Assets

SoftwareAsset = = [identifier: **TEXT**;
is_composed_of: 𝔽 **SoftwareAsset**
uses: 𝔽 **SoftwareAsset**
description: **Description**
body: **Body** |]

This schema in Table 1 shows that a software asset is made up of two types of information: the **body** (containing effectively reuse software assets) and **description** (containing information allowing reuse process support). Information of qualification and classification correspond respectively to the qualification process and the classification process.

This model also brings to light the **imbrications** of software assets, and the fact that, beside composition relations, software assets can have others types of links illustrating, for example, the fact that a software asset uses an other software asset. That means, a software asset needs, to run, functionalities of another software asset. The software asset **reuser** must then decide if he also reuses associated software assets or he is able to provide himself an equivalent implementation. Typically, a vertical software asset, if it has an important granularity, will lean probably on component techniques (for example graphical objects or a middleware).

3.1 Software Asset Description

The description of a software asset gives its intention, the engineering activity the descriptor plans to perform, its target, the concerned business and the environment that is the context. The above Z notation schema specifies software asset description.

Table 2: Specification of Software Asset Descriptions

Description = = [intention : **EngineeringActivity** ;
target : **Business;**
environment: **Context** |]

EngineeringActivity = =
AnalysisActivity | **DesignActivity** | **ImplementationActivity**
AnalysisActivity = {analyze, …}
DesignActivity = {design, decompose, describe, specify, …}
ImplementationActivity = {implement, …}

Business = = [domain: **Domain**; processes: 𝔽 **Process** |]

Details on the following concepts: Domain, Process, Business Activity, Context & Context-awareness can be found in [16].

3.2 Software Asset Bodies

A body of a software asset is composed of software products effectively reuse. These software products can be analysis models, design models, source codes, user documentation, runnable codes, test reports, test scenarios, test programs. The following schema models software asset bodies.

Table 3: Specification of Software Asset Bodies

Body = = **AnalysisModel** | **DesignModel** |
SourceCode | **UserDocumentation** |
RunnableCode | **TestReport** |
TestScenario | **TestProgram**

If we use the feature oriented reuse method with business component semantics, the body will be a feature realization if we are in the analysis stage, a conceptual realization, a process realization or a module realization if we are in the design stage.

4. Evolution in Software Product Lines

Feature models are widely used to represent SPLs and have been extended in the Feature Oriented Reuse Method with Business Component Semantics (FORM/BCS). Software product line evolution is the necessity to have in that product line new features, variability points or the death of old ones. This continuous phenomenon is due to changes in the requirements, product structure and newly emerging technologies. The integration of new features or variability points can creates conflicts or undesired interactions between them. For example when you add new features, they can enter in conflict with old ones. Let us take an example in libraries, if you want to *ensure a sufficient availability* of books and previously you *authorize long term loans*, the two features will be in conflict.

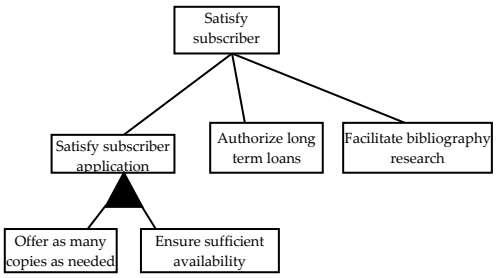

Figure 2. Feature model with a conflict

Equally, when you remove an old feature, if this feature is used by another one, you will create inconsistency. That why the management of this situation is complex. To study evolution in SPLs, we first look at the feature business component which is a software asset in which the body is a feature realization [12] to see how we can improve the specification of his constituents that are his description and body.

Table 4: Specification of Feature Business Components

FeatureBusinessComponent = = [identifier: **TEXT**;
is_composed_of: 𝔽 **FeatureBusinessComponent**
uses: 𝔽 **FeatureBusinessComponent**
description: **Description**
body: **FeatureRealization** |]

Knowing that processes are essentials in the description of feature business components, we start by revising their specification.

4.1 Processes with clashing actions

Evolution can occur in requirements or in new technologies and the first thing to observe is that, when a new variation point appears, to take it into consideration, we must guaranty that it don't create conflict with an existing feature or an undesired interaction between features in the product line. We think that, to avoid these conflicts, it is useful to anticipate them when analyzing a domain. We introduce then new information such as clashing actions when modeling processes.

Table 5: Specification of Processes

Process = = [actions: 𝔽 **BusinessActivity**;
clashingactions: 𝔽 **BusinessActivity**;
input-elements : 𝔽 **BusinessObjects** ;
output-elements : 𝔽 **BusinessObjects** ;
precision : **Precision** |]
BusinessObjects = = 𝔽 **Class**
Class = = [name: **Name**; attributes : 𝔽 **Attribut**;
operations : 𝔽 **Operation** |]
Precision
Name
Attribute
Operation

4.2. Specifying clashing tasks in business activities

To manage evolution in software product lines, it is important to decompose business activities so that we can detect antagonist tasks between them. Antagonist tasks are tasks which cannot be performed together. A business activity has a set of "mandatory" tasks, a set of "optional" tasks, a set of "alternative" tasks, a set of "or" tasks and a set of "clashing" tasks. It can be primitive or not. The following schema specifies business activities for the management of evolutions.

Table 6: Specification of Processes

BusinessActivity == [name: **Name**;
decomposition: [mandatory: 𝔽 **BusinessTask** ;
optional: 𝔽 **BusinessTask**;
alternative: 𝔽 𝔽 **BusinessTask**;
or: 𝔽 𝔽 **BusinessTask]**;
clashing: 𝔽 **BusinessTask;**
primitive: **Logic** |]

When the context is clear we write:
mandatory (ba) for *mandatory (decomposition(ba))*
optional(ba) for *optional(decomposition(ba))*
alternative(ba) for *alternative(decomposition(ba))*
or(ba) for *or(decomposition(ba))*
decomposition (ba) for mandatory (ba) $\cup$ *optional (ba)* $\cup$ ($\cup$ *(A* $\in$ *alternative(ba)))*

We say that a business activity *ba* is abstract if *decomposition (ba)* = $\varnothing$.

We define the set
Abstract_Business_Activity = {ba:Business_Activity • *decomposition (ba)* = $\varnothing$}

4.3 Business tasks

The decomposition of tasks allows detecting antagonist tasks. A business task has a set of "mandatory" operations, a set of "optional" operations, a set of "alternative" operations, a set of "or" operations and a set of "clashing" operations. It can be primitive or not. The following schema specifies business tasks for the management of evolutions.

Table 7: Specification of Processes

BusinessTask == [name: **Name**;
decomposition: [mandatory: 𝔽 **BusinessOperation** ;
optional: 𝔽 **BusinessOperation**;
alternative: 𝔽 𝔽 **BusinessOperation**;
or: 𝔽 𝔽 **BusinessOpeartion**];
clashing: 𝔽 **BusinessOperation;**
primitive: **Logic** |]

In a similar manner, when the context is clear we write:
mandatory (bt) for *mandatory (decomposition(bt))*
optional(bt) for *optional(decomposition(bt))*
alternative(bt) for *alternative(decomposition(bt))*
or(bt) for *or(decomposition(bt))*

decomposition (bt) for mandatory (bt) ∪ optional (bt) ∪ (∪ (A ∈ alternative(bt)))

We say that a business task *bt* is abstract if *decomposition (bt) = ∅.*

We define the set

Abstract_Business_Task = {bt:Business_Task • decomposition (bt) = ∅}

4.4 Evolution management functions

4.4.1. Basic functions

The decomposition of business activities and business tasks allows defining evolution management basic functions:

- *run* which given two operations return *failure* if the two operations cannot be run together in the same system or *success* if they can be.
- *clashingtasks* which given a business task provides the set of his clashing tasks.
- *conflictactivities* which given a business activity provides the set of his conflict business activities

run: BusinessOperation x BusinessOpeartion ↔ {failure, success}

clashingtasks: BusinessTask ↔ 𝔽 BusinessTask
∀bt1, bt2: BusinessTask, bt2 ∈ clashingtasks(bt1)⇔
∃(bo1, bo2) ∈ operations(bt1) x operations(bt2) •
run(bo1, bo2) = failure

conflictactivities: BusinessActivity ↔ BusinessActivity
∀ba1, ba2: BusinessActivity, ba2 ∈ conflictactivities(ba1)⇔
∃(bt1, bt2) ∈ tasks(ba1) x tasks(ba2) •
bt2 ∈ clashingtasks(bt1)

4.4.2 Evolution mechanism

The specification of processes (sub section 2.1.2) shows that a process can be seen as a set of business activities. A non primitive business activity has decomposition. This decomposition groups the set of his "mandatory" tasks, the of his "optional" task, the of his "alternative" tasks and the set of his "or" tasks. A business activity has also a set of "clashing" tasks. A clashing task of a business activity is a task which cannot run with the tasks in his decomposition.

In a software product line, evolution is the apparition of a new variation point or the disappearing of an old one. A new variation point in feature business component as specified in the Feature Oriented Reuse Method with Business Component Semantics is a new feature with his variation points. A feature corresponds to a business activity [12]. To consider a new variation point, we must check if this new variation point doesn't create a clash with the existing ones.

Each new adaptation point has a parent feature and the evolution process of a feature business component consists of inserting the new feature as part of his parent. From there, we define the two following functions which are essential in our evolution mechanism: *is_clashed* and *insert*.

Given a feature business component *fbc* and his new feature adaptation point *nap*, the function *is_clashed* returns "false" if for each feature in the solution part of *fbc*, the activity of *nap* is not in conflict with the activity of *f*.

Given a feature business component *fbc* and his new feature adaptation point *nap*, the function *insert* returns the feature business component *fbc* containing the new feature adaptation point *nap* as an adaptation point.

is_clashed: FeatureBusinessComponent × FeatureAdatationPoint ↔ Boolean
∀ fbc : FeatureBusinessComponent, fap: FeatureAdaptationPoint,
is_clashed (fbc, fap) = false ⇔ ∀ f ∈ decomposition(realization(fbc)),
activity(feature (nap)) ∉ conflictactivities (activity (f)))
is_clashed(fp, ci) = true ⇔ ¬ (∀ f ∈ decomposition(realization(fbc)),
activity(feature (nap)) ∉ conflictactivities (activity (solution (fbc))))

insert: FeatureBusinessComponent × FeatureAdaptationPoint ↔ FeatureBusinessComponent ∀ fbc : FeatureBusinessComponent, fap : FeatureAdaptationPoint,
insert(fbc, fap) = fbc • fap ∈ decomposition(solution (realisation(fbc))) ∧
fap ∈ adaptationpoints(solution(realization (fbc)))]

Given a feature business component *fbci* and a finite set of new adaptation points *NAP*, the evolved feature business component *fbco* is obtained following the algorithm below:

Algorithm: Evolution management
Result: fbco: FunctionalPerspective
fbci: FunctionalPerspective ;
NAP: 𝔽AdaptationPoint;
wfbc: FunctionalPerspective;
For each nap **in** NAP
  If no_clash (fbci, nap) **then**
    wfbc:= insert(fbci, nap);
  else
    Write ("FAILURE")
  end
end
fbco:= wfbc

5. Related Works

Stability is one of the most important properties of software. It is defined as "The capacity of the software product to avoid unexpected effects from modification of the software" [22]. Many product line approaches assume that activities in domain and application engineering can take a fairly stable product line for granted. However, real-world product lines inevitably and continuously

evolve. Managing evolution is thus success-critical, particularly in model-based approaches to ensure consistency after changes to meta-models, models, and actual artifacts. In [23, 24], several authors have stressed the importance of approaches for product line evolution to avoid the erosion of a product line, i.e., the deviation from the product line model up to the point where key properties no longer hold. Several approaches have been proposed for managing the evolution of software product lines [4], ranging from verification techniques to ensure consistent evolution, to model-based frameworks dedicated to the evolution of feature-based variability models [25]. For example, an interesting research thread proposes evolution templates for co-evolving a variability model and related software artifacts [26, 27, 28].

A model-driven product line approach that focuses on the issue of domain evolution and product line architectures is described in [29]. Authors discuss several challenges for the evolution of model-driven software product line architectures and present their solution for supporting evolution with automated domain model transformations. Such transformations could also be useful in our context to realize the update rules to support the evolution of the variability models in SPLs when applying model-driven techniques.

Another example is the work in [30], who present tool support for the evolution of software product lines based on the grow-and-prune model. They support identifying and refactoring code that has been created by copy and paste and which might be moved from product level to product line level. Refactoring of a SPL is not the scope of our work which, for the moment, is not situated at the code level. However, the work and tool are useful to support refactoring the SPL code.

A SPL evolution approach that preserves the original behaviour of evolving product lines, *i.e.*, products that could be generated before evolution can still be generated after the evolution, is proposed in [31]. This of course is only possible if restricting the removal of certain needed features, which makes the process easier but also constitutes a limitation of this approach.

To keep a configuration consistent with a feature model even after evolution of the latter, in [32] authors present an approach that automatically evolves the configuration with respect to the changes performed in the model while also taking into consideration the possible cardinalities. Such an approach is useful.

Hyper feature models are introduced in [33]. These models are capable of versioning the features and their constraints to maintain evolution traceability over time and guarantee the compatibility of one version of a feature with versions of another one. Feature traceability is thus a central concern in SPL evolution approaches, and has been shown to be essential in a feature-oriented project [34]. In [35], authors was largely inspired by this earlier work on evolving software product lines, and extended this work by considering runtime management of such evolution.

Ideas developed in this contribution enter in pioneer works on feature orientation and come from our previous articles [12, 13]. The specificity of our approach is that, by putting inside feature business components, information able to guide evolution, we give intrinsic ability, which is since his genesis, to software product lines to evolve smoothly.

6. Conclusions and Future Research

Real-world product lines inevitably and continuously evolve, then we cannot avoid the necessity of evolution in a software product line. The scientific community tries to manage evolution in software product lines but faces some difficulties link to the definition and modeling of this phenomenon in software product lines. We think that this situation is due in a large part to the fact that there is no consensus on what a software asset is. In this article after defining formally what a software asset is, we have study evolution in the first software product line asset of the feature oriented reuse method with business component semantics, the feature business component. The result is that, we find and introduce new properties in the definition of processes such as clashing actions. These new fields have allowed defining news functions for the management of evolution. This work increases the ability of software product lines to evolve in a flexible way. We plan to study erosion of a software product line which is the deviation from the product line model up to the point where key properties no longer hold.

Conflict of Interest

The authors declare no conflict of interest.

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Amougou Ngoumou is a Senior Lecturer of computer science at the Department of Computer Science of the Higher Teacher Training College of the University of Yaounde I (Cameroon). He has received Bachelor of Computer Science (1998), Master of Computer Science (2001) and PhD degree in Computer Science (2011) at the University of Yaounde I (Cameroon).

His main research interests include Software Product Lines, Domain-Specific languages and Information Systems.

Marcel Fouda Ndjodo is a full professor of computer science and the Head of the Computer Science Department of the Higher Teacher Training College of the University of Yaounde I (Cameroon). He has received a PhD in Computer Science at the University of Aix-Marseille II (France, 1992).

He coordinates besides the information systems and numerical technologies of education at the higher teacher training college. He is author of many scientific publications and has supervised many PhD thesis in information systems and software engineering.

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Hybrid Frameworks for the Multi-objective Optimization of Distributed Generation Units and Custom Power Devices with Simultaneous Distribution Network Reconfiguration

Pamela Ramsami *, **Robert Tat Fung Ah King**

Department of Electrical and Electronic Engineering, University of Mauritius, Reduit 80837, Mauritius
*Corresponding author: Pamela Ramsami, Department of Electrical and Electronic Engineering, University of Mauritius, Reduit 80837, 4037400, pamela.ramsami1@umail.uom.ac.mu

ABSTRACT: The increased penetration of renewable energy sources in the distribution system affects the stability and efficiency of the system. To account for the intermittent nature of these sources, distribution network reconfiguration and the integration of custom power devices are important. This paper aims to identify the optimum location of photovoltaic systems and unified power quality conditioners in the distribution system considering economic and technical aspects. Three metaheuristic algorithms namely nondominated sorting genetic algorithm-II (NSGA-II), strength pareto evolutionary algorithm-2 (SPEA2) and multi-objective evolutionary algorithm based on decomposition (MOEA/D) were employed. Furthermore, three hybrid algorithms were developed by dividing the population into two parts. Multi-objective particle swarm optimisation (MOPSO) was applied in the upper part while NSGA-II, SPEA2 or MOEA/D was used in the lower part of the population resulting in three hybrid algorithms: MOPSO-NSGA II, MOPSO-SPEA2, MOPSO-MOEA/D. The simulation was performed on the IEEE-123 Node Test Feeder system using the OpenDSS and MATLAB environment. The performance of the proposed algorithms was compared according to their computation time and performance metrics such as pure diversity, generational distance and spacing. It was found that the hybrid algorithms enhance the convergence of the solutions to the true Pareto front. Combining SPEA2 or MOEA/D with MOPSO also reduced the complexity of the algorithms resulting in a lower simulation time.

KEYWORDS: Hybrid Multi-Objective Optimisation, Distribution Network Reconfiguration, Distributed Generation, Custom Power Devices

1. Introduction

The traditional distribution system is radial in nature. It is fed from the main substations via the transmission network. Due to the large resistance/reactance ratio in the distribution system, the voltage drops and power losses increase. Under extreme conditions, the distribution system may be subjected to instantaneous voltage collapse resulting from poor voltage stability at most nodes. Therefore, emerging power systems are integrated with small power generating units close to the loads. These units are commonly known as distributed generation or dispersed generation (DG) [1]. To account for the depleting nature of fossil fuels and their negative impacts on the environment, DG units based on renewable energy are being favoured. Examples of such DG units include wind turbine, solar photovoltaic (PV), fuel cell, microturbine and micro-hydro generator. However, the intermittent nature of the renewable energy sources leads to fluctuations in the power output of these DG units. Also, the bidirectional power flow may affect the coordination of the protective devices [2].

Due to the deregulation in the electricity industry, it is important to ensure the reliability of the distribution system [3]. This can be achieved by modernising or substituting the current distribution lines, transformers, switchgears and other electrical components. Alternatively, spare equipment can be made available. As these solutions require large capital investments, distribution network reconfiguration (DNR) has gained much interest among utilities. It involves the opening and

closing of switches in the distribution system to alter the structure of the distribution system [4]. In addition to DNR, power electronic devices called custom power devices (CPD) can be integrated in the distribution system. CPD such as distribution static compensator (DSTATCOM), dynamic voltage restorer (DVR) and unified power quality conditioner (UPQC) help to enhance the power quality issues such as voltage sags, voltage swells and harmonics generation [5]. While DVR can address a maximum of two power quality problems, UPQC has the ability of considering several power-related issues simultaneously. It aids in load balancing, harmonics eradication, voltage sag reduction and power quality enhancement [6].

Optimisation is needed to identify the most appropriate parameters of the DG unit, CPD and DNR. To ensure the best performance of the power system, it is expected to consider the maximum number of objective functions. As the formulated problem involves more than one objective function, it is known as a multi-objective problem. In contrast to single-objective optimisation, multi-objective optimisation generates a set of solutions called Pareto-optimal solutions or non-dominated solutions [7].

To assist engineers and power system operators in the proper planning of the future power system, various research works have been performed using multi-objective optimisation. The state-of-the-art reveals that meta-heuristic algorithms are favoured over analytical and classical techniques of DG optimisation. The optimal size and location of DG units have been identified considering technical, economic and environmental factors. The technical aspects considered are mainly power loss, short circuit current and voltage stability. The economic factors were based on net present cost, annual worth, life cycle cost and levelized cost of energy. The environmental considerations were related to the emissions of carbon dioxide, oxides of nitrogen and sulfur dioxide [2]. Some studies used weighed sum approach to combine the objective functions to a single objective [3], [8]. Examples of meta-heuristic algorithms used to identify the optimal sizing and location of DG units include ant lion optimization technique [9], PSO, genetic algorithm, bacterial foraging algorithm and cat swarm optimisation, grey wolf algorithm (GWO), krill herd algorithm, invasive weed optimisation [2]. Particle swarm optimisation (PSO) has also been hybridised with modified gravitational search algorithm [8] and analytical method [10], grey wolf optimisation [11] and fuzzy systems [12]. The optimisation was performed considering power loss, voltage deviation, voltage stability and reliability [8].

The CPD used in the optimisation studies were mainly UPQC and DSTATCOM. Multi-objective particle swarm optimisation (MOPSO) [13], cuckoo optimisation algorithm (COA) [6], GWO [13] and sine cosine approach [14] were employed. The objective functions include power quality, power loss [15] and voltage stability [15]. Reference [16] used SPEA2-MOPSO for the allocation of photovoltaic-integrated UPQC. Reference [17] and reference [18] further proposed the simultaneous location of DG and DSTATCOM.

The algorithms used in the optimisation of DNR includes genetic algorithm (GA) [3], modified bacterial foraging optimisation algorithm [19] and binary cuckoo search algorithm [20]. The objective functions considered were mainly load balancing, power loss minimisation, voltage profile enhancement and reliability. Some papers combined DNR with DG allocation [21]. Reference [22] proposed DG sizing and location with simultaneous DNR to minimise real power loss using a hybrid algorithm based on binary particle swarm optimisation and shuffled frog leap algorithm. The hybrid algorithm performed better than other optimisation algorithms. The results proved that simultaneous DNR and DG optimisation reduce power loss while also enhancing the voltage profile.

Although there exist possible interactions among the network structure, DG units and CPDs in the power system, the addition of DG units and CPDs with simultaneous DNR have been barely explored. This paper is an extension of the work originally presented in the 2020 3rd International Conference on Emerging Trends in Electrical, Electronic and Communications Engineering (ELECOM) [23]. In [23], the multi-objective optimisation of PV systems and UPQC was performed with simultaneous DNR using non- dominated Sorting Genetic Algorithm-II (NSGA-II), Strength Pareto Evolutionary Algorithm-2 (SPEA2) and Multi-objective Evolutionary Algorithm based on Decomposition (MOEA/D). Three objective functions were considered namely active power loss, voltage deviation and total cost liable to constraints. The optimisation was performed using the following seven different cases: (1) DNR only, (2) UPQC only, (3) PV systems only, (4) UPQC and PV systems, (5) UPQC and DNR, (6) PV systems and DNR, (7) UPQC, PV systems and DNR. It was found that the most desirable solution was obtained in case 7 whereby the voltage and power loss profile were improved at a low cost. Each of the proposed optimisation algorithms proved to have their own advantages and disadvantages. However, the possibility of hybridising the optimisation algorithms was not attempted. To account for the limitations and promote the benefits of the individual algorithms, this paper aims to identify the optimum size and location of PV systems and UPQC along with the optimum network structure using hybrid algorithms. The population is divided into two parts to reduce the risk of premature convergence. To prevent global solutions from being caught in local minima, the proposed algorithms must compromise with the exploitation and exploration. NSGA-II was utilised in

the exploration phase using the upper half of the population to identify the global solutions. On the other hand, MOPSO was applied to the remaining population for the exploitation phase so that the particles in the neighbourhood converge towards a global solution. NSGA-II and MOPSO were chosen due to their different search mechanisms. Keeping MOPSO to exploit the search space, the simulation was repeated by replacing NSGA-II by SPEA2 and MOEA/D in the exploitation process.

The main contributions of the paper are as follows:

- The novelty of this paper is the multi-objective optimisation of DG units, CPD and DNR simultaneously. Although CPD and DNR can help to address the challenge of integrating renewable DG units in unbalanced distribution systems, optimisation is required to satisfy the economic and technical constraints. The most appropriate network structure as well as the size and location of the DG units and CPD must be identified to improve the efficiency of the power system at reduced cost.
- With reference to the No Free Lunch theorem [24], there is always the chance of developing novel algorithms for solving optimisation problems. Furthermore, the literature review revealed that there is scope for proposing new hybrid multi-objective algorithms. Therefore, the authors employed three hybrid algorithms namely NSGAII-MOPSO, SPEA2-MOPSO and MOEA/D-MOPSO to solve the problem. In each of the hybrid algorithm, the population was divided into two parts. MOPSO was used in the exploitation of the upper half of the population. NSGA-II, SPEA2 and MOEA/D were applied for the exploration of the lower half of the population in NSGAII-MOPSO, SPEA2-MOPSO and MOEA/D-MOPSO respectively.
- The performance of the algorithms was evaluated based on the computation time and performance metrics such as pure diversity, spacing and generational distance. The variation in the number of non-dominated solutions in the external repository at the MOPSO stage and in the Pareto front at the final stage is plotted. In addition, the Pareto front was plotted to provide a visual interpretation of the three objective functions for each of the non-dominated solution.

The paper is organised as follows: Section 2 describes the optimisation algorithms. Section 3 deals with the methodology. Section 4 highlights the results obtained while section 5 provides the conclusion.

2. Literature review

2.1. Multi-objective optimisation

It is desired to have a power system which can satisfy the consumers' demand while optimising the technical, economic and environmental factors simultaneously. Therefore, power system optimisation problems are multi-objective in nature. A multi-objective optimisation problem simultaneously considers several objective functions subject to equality and inequality constraints in a suitable region D as illustrated in (1). The objective functions can either be maximised or minimised.

$$\text{Optimise } f(x)= \{f_1(x), f_2(x), \dots , f_m(x)\} \quad , x \in D$$

$$\text{Subject to } g_j(x) \leq 0 \; ; j=1, 2, \dots, n$$

$$h_l(x) = 0 \; ; l=1,2,\dots,e \tag{1}$$

where f(x) is the objective functions' vector, m is the total number of objective functions, n is the number of inequality constraints and e is the number of equality constraints.

2.1.1. Multi-objective Particle Swarm Optimisation (MOPSO)

Particle Swarm Optimization (PSO) is an algorithm which mimics the conduct of birds and insects in their hunt for food or new places for habitation. It is based on a population in which each member moves in its own direction and velocity looking for a suitable place in the search space. All the members are in contact with each other to transfer data so the population is directed to the good locations in the search space. Each member indicates a particular solution and its position is upgraded in relation to its memory of the good locations (the local best) or the memory of the whole swarm. PSO was initially proposed to solve single-objective problem. Later, multi-objective particle swarm optimisation (MOPSO) was developed. The limitations of MOPSO include the formation of local fronts and the poor diversity in the Pareto front [25].

Algorithm 1: MOPSO

Result: Swarm fitness calculation and determination of global best member
Initialization of position and velocity for each particle in the swarm randomly;
For each particle in the swarm
  Evaluate the fitness function
  If fitness of particle exceeds personal best fitness
    New fitness of particle = personal best fitness;
  End
End
From all particles in the population, choose the global best solution
For each particle in the swarm
  Update the position of each particle
  Update the velocity of each particle
End

2.1.2. *Non-dominated Sorting Genetic Algorithm II (NSGAII)*

In Non-dominated Sorting Genetic Algorithm II (NSGA-II), the members of the population are located in several fronts depending on their extent of dominance. The crowding distance of the member is then found individually. Subsequently, the member having the larger crowding distance is selected from the primary front. The process is continued for the subsequent fronts. Following the selection process, crossover and mutation operations are carried out to generate the new population.

The positive aspects of NSGA-II include elitism, non-dominated sorting and crowding distance which improves the diversity and spread of the solutions. Nonetheless, the convergence may deteriorate due to the crowding operation. As the population size increases, the simulation time increase as the population requires sorting in each generation [26].

Algorithm 2: NSGA-II

Result: Generation of Pareto front
Initialise population;
Evaluate objective functions;
Rank population
while *maximum iteration is not reached*
  Perform selection, crossover and mutation to generate child population;
  Evaluate each individual;
  Combine child and parent population;
  Non-dominated sorting process
  if *maximum iteration is reached* **then**
    Generate Pareto front;
  end
end

2.2. SPEA2

In SPEA2, the initial population is generated randomly and an empty external archive is created. Each member is allocated a strength value with reference to the quantity of members it dominates in the external archive. The raw fitness value R(i) of a solution is computed by summing the strengths (σ^k) of every solution which dominates it in both the archive and the population. The members are then retained by the k^{th} nearest neighbor method according to the density D(i) as shown in (2) and (3). This conservation approach enhances the diversity of the solutions. The fitness F(i) of an individual is identified from the density D(i) and raw fitness value R(i) as indicated by (4). The nondominated solutions are collected in an exterior archive until the latter is completely filled [27].

$$D(i) = \frac{1}{\sigma^k + 2} \quad (2)$$

$$k = \sqrt{N + \bar{N}} \quad (3)$$

where N is the population size and $\bar{N}$ is the archive size

$$F(i) = R(i) + D(i) \quad (4)$$

Algorithm 3: SPEA-2

Result: Identification of members of Pareto front
Initialisation of initial population randomly;
Creation of an empty external archive;
while *maximum iteration is not reached*
  Calculate fitness value of each individual;
  Copy all non-dominated solutions to external archive;
  Compute fitness value of each solution;
  Conserve the solutions based on KNN method;
  Perform selection, crossover and mutation;
end

2.2.1. *MOEA/D*

In MOEA/D, the multi-objective problem is split into several single-objective small problems. The commonly-used decomposition techniques are the Tchebycheff technique and the weighed sum technique. The subproblems are then accumulated by the predefined weights. Finally, they are optimised simultaneously using evolutionary algorithms. The population is initialised randomly and the objective function value is computed accordingly. To generate a new member in the population, two parents are chosen indiscriminately from the surrounding. The information is transmitted based on the relationship among the neighbours. The neighbourhood mechanism used in MOEA/D enhances the convergence of the algorithm. However, the size of the neighbourhood must be selected properly to prevent the search from attaining local minima without causing any complexity burden [28].

2.2.2. *Hybrid algorithms*

MOPSO has a remarkable exploitation capability. However, the particles in MOPSO tend to be confined to local optima. This issue can be addressed by using MOPSO together with NSGA-II, SPEA2 or MOEA/D. This results in three hybrid algorithms namely MOPSO-NSGA-II, MOPSO-SPEA2 and MOPSO-MOEA/D. The population is divided into two parts. Half of the population is solved using NSGA-II, SPEA2 or MOEA/D to generate solutions. Due to its elitism, sorting and crowding distance computation, NSGA-II produces solutions with a wide spread and diversity. MOPSO then exploits the search place to identify better solutions in the surrounding driving the low-rank solutions to the global optimum.

The optimal solutions in NSGA-II, SPEA2 or MOEA/D are stored in an external archive whereas those in MOPSO are stored in an external repository. After each

iteration, the solutions in the archive are merged with that of the repository and eventually kept in the archive [29].

2.3. Test system

2.3.1. The Distribution system

The simulation was carried out using the IEEE-123 Node Test Feeder System which is an unbalanced distribution system consisting of constant power, constant impedance and constant current loads. Figure 1 shows the IEEE-123 Node Test Feeder System. The distribution system, DG units and custom power devices were modelled by separate scripts in the Electric Power Research Institute's (EPRI) open-source software 'Distribution System Simulator' (OpenDSS). The PV system and the UPQC were used as DG units and CPD respectively. Monte Carlo Simulation was done to cater for the uncertainty in the weather data [30].

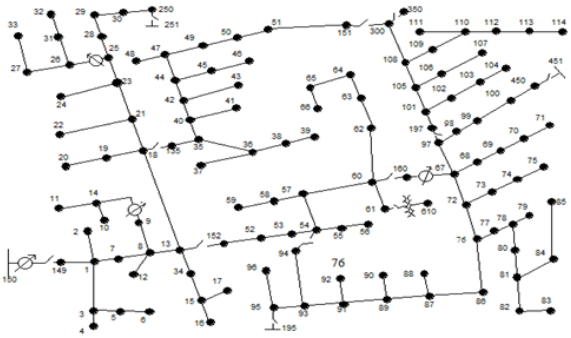

Figure 1: IEEE-123 Node Test Feeder System [31].

Table 1: Switches in IEEE-123 node test feeder system [31]

Switch	Node A	Node B	Status
Switch 1	13	152	closed
Switch 2	18	135	closed
Switch 3	60	160	closed
Switch 4	97	197	closed
Switch 5	151	300	open
Switch 6	54	94	open
Switch 7	150	149	closed
Switch 8	61	610	closed
Switch 9	250	251	open
Switch 10	450	451	open
Switch 11	300	350	open

Table 1 illustrates the location and status of all the switches in the IEEE-123 Node Test Feeder System. From Figure 1 and Table I, it can be deduced that only six switches (Switch 1 - Switch 6) can modify the network structure. From the switches utilised, three loops namely L1, L2 and L3 can be obtained. L1 is arises from the closure of switches Switch 1, Switch 2, Switch 3, Switch 4 and Switch 5 whereas L2 is formed by closing Switch 1, Switch 2, Switch 4, Switch 5 and Switch 6. Meanwhile, L3 results from the opening of all the switches except Switch 3 and Switch 6. To maintain a radial network structure, one switch must be in the open state in each loop. Radial configuration is important for the proper management and protection of the system. 1. From the 64 possible switch combinations, only the 48 combinations which generated a radial network structure were used in the simulation [23].

2.3.2. PV system

The PV system contains semiconductor materials which convert solar energy to electrical energy. Figure 2 illustrates the PV system model. The active power output in the connection node at time t is obtained by multiplying the PV array output P(t)and the inverter efficiency eff(P(t) as shown by (5).

$$P_{out}(t) = P(t) \times eff(P(t)) \quad (5)$$

For simplicity, it is supposed that the inverter locates the maximum power point (MPPT) of the panel rapidly. Equation (6) represents P(t) in terms of the rated power output at MPPT (P_{mpp}), the base irradiance $irrad_{base}$, the per unit irradiance at t irrad(t)and the correction factor (c).

$$P(t) = P_{mpp} \times irrad(t) \times irrad_{Base} \times c \quad (6)$$

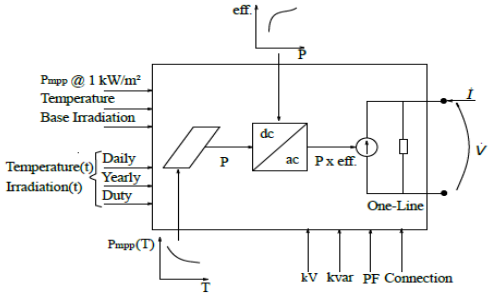

Figure 2: PV system model in OpenDSS [32].

The PV array is designed using the irradiance data, temperature data and the PV array power curve while the inverter is designed using the efficiency curve as illustrated in Figure 2 [32].

2.3.3. Unified power quality conditioner

UPQC is a single-phase device which manages the voltage and reactive power. It is added on the secondary side of a transformer and can function in three modes namely mode 1 (voltage control), mode 2 (power factor correction) and mode 3 (voltage control and power factor correction). Fig. 3 illustrates the model of UPQC in OpenDSS.

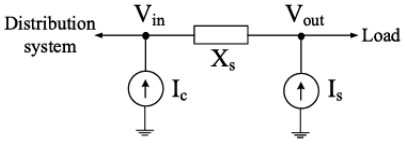

Figure 3: Model of UPQC in OpenDSS. [33]

The current source Ic is calculated using (7).

$$I_c = \frac{V_{out}}{I_S \times V_{in}} \quad (7)$$

where the impedance Xs and the current source Is represent the Thevenin equivalent of the voltage source in series [33].

3. Methodology

3.1. Formulation of the problem

Operating the power system at minimum cost results in poor voltage and power loss profile. On the other hand, it is too expensive to only enhance the quality of the power supply. Therefore, the problem was formulated as multi-objective based on three objective functions namely the active power loss, voltage deviation and total cost. The objective functions were minimised simultaneously taking into account the uncertainty associated with DG units based on renewable energy.

3.1.1. Objective functions

1. Active power loss

Minimisation of the active power loss helps to make the system more efficient. Active power loss includes the copper loss of the transformers and the loss in the lines [34]. In OpenDSS, it is computed by solving the circuit in the snapshot mode.

2. Voltage deviation

The voltage deviation is minimised to enhance the security and power quality in the system. The voltage deviation index (IVD) was computed by comparing the final node voltages with initial node voltages as shown in (8). The node voltages were found by the load flow analysis in OpenDSS [35].

$$\text{IVD} = \sum|V_{AD} - V_A| + \sum|V_{BD} - V_B| + \sum|V_{CD} - V_C| \quad (8)$$

where V_A, V_B and V_C are the initial node voltages,

V_{AD}, V_{BD} and V_{CD} are the node voltages in the presence of PV systems

3. Total cost

The total cost is equivalent to the sum of the capital cost and the replacement cost. The capital cost is computed from the net present cost (NPC) and the capital recovery factor (CRF) using (9) and (10) [36].

$$\text{Capital cost=NPC} \times \text{CRF} \quad (9)$$

$$\text{CRF} = \frac{i(i+1)^L}{(i+1)^L - 1} \quad (10)$$

Table 2 illustrates the NPC and the lifespan for the PV system, switch and UPQC [37] [38].

Table 2: Net present value and lifespan of each device

Device	NPC (USD)	Lifetime
PV	1330 /kW	25
Switch	2581	15
UPQC	$C_{UPQC} \times S_{UPQC}$	15

The NPC for the UPQC is found from the polynomial cost function given by (11) and the size of the UPQC (S_{UPQC}) [39].

$$\text{NPC}_{\text{UPQC}} = 0.0003S_{UPQC}^2 - 0.2691S_{UPQC} + 188.22 \quad (11)$$

The Fisher equation calculates the real interest rate (i) using the nominal interest rate (j) and the inflation rate (f) as shown by (12).

$$i = \frac{j-f}{1+f} \quad (12)$$

The nominal interest rate and inflation rate are set to 3.5% and 1.5% respectively in this study. The replacement cost is calculated based on (13) [38][40].

$$\text{Annualised replacement cost} = \text{NPC}\frac{i}{(1+i)^L - 1} \quad (13)$$

3.1.2. Constraints

The power flow constraint was utilized as equality constraint. As the power flow calculations were integrated in the procedure to calculate the total feeder losses, the satisfaction of this constraint was not checked. The convergence of the power flow computation revealed that the equality constraint was satisfied [41]. The size and number of the DG units and CPD were used as inequality constraints.

1. The size of the DG unit lies between 5 kW and 500 kW as given by (14).

$$5 \text{ kW} < DG_{size} < 500 \text{ kW} \quad (14)$$

2. The size of the UPQC ranges from 5 kVAr to 100 kVAr as shown in (15).

$$5 \text{ kVAr} < CPD_{size} < 100 \text{ kVAr} \quad (15)$$

3.2. Optimization algorithm

3.2.1. Chromosome model

OpenDSS was linked with MATLAB through the Component Object Model (COM) server Dynamic-link library (DLL) for optimisation studies. A compatible PC (CPU Intel Pentium 2.10 GHz 2GB of RAM) with 32-bit operating system was used for the simulation. The optimization algorithms depend on a group of artificial chromosomes which are assigned fitness values depending on their capability to solve the problem. Each chromosome is a potential solution to the problem. Figure 4 shows the chromosome model in which the first two numbers in the string refers to the size and location of the first DG unit respectively. The following two numbers indicate the size and location of the first CPD respectively. The letter n denotes the total number of DG units and CPD used. In this case, n has been set to three. The last number in the string denotes the network structure based on switch SW1 to SW6.

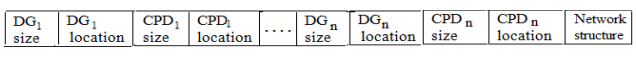

Figure 4: Chromosome model

3.2.2. *Parameters of optimization algorithm*

Table 3 illustrates the parameters of the optimisation algorithms. The parameters were kept constant for all the three algorithms. To account for the heuristic nature of the optimisation algorithms, the simulation was performed over 50 independent runs by using varying random number seeds for each run. Each run consisted of 100 iterations to guarantee the convergence of the algorithms. The population size, crossover probability and mutation probability were chosen by a trial-and-error method such that a reasonable number of solutions were found without increasing the complexity of the algorithms.

Table 3: Parameters of optimisation algorithms

Number of members in population	50
Probability of crossover	0.3
Probability of mutation	0.05
Maximum iteration number	100
Number of runs	50

3.3. *Performance metrics*

The efficiency of the algorithms was evaluated using the performance metrics such as pure diversity, spacing and generational distance.

1) Pure Diversity (PD)

Pure diversity indicates the spread and uniform spacing of the non-dominated solutions in the objective space. It is calculated utilising (16).

$$PD = d_p + d_q + \sqrt{\frac{1}{|n|-1}\sum_{i=1}^{|n|-1}(d_i - \bar{d})^2} \quad (16)$$

where d_p and d_q represents distances between the nearest non-dominated solutions and the two extreme solutions on the Pareto front, d_i is the Euclidean distance between two succeeding non-dominated solutions and $\bar{d}$ is the mean of the distances d_i and n is the sum of the number of non-dominated solutions [42].

2) Spacing (SP)

Spacing indicates the standard deviation of the distance between the non-dominated solutions in the Pareto front and is given by (17). A spacing of zero is obtained when all the solutions in the Pareto front are equally spaced.

$$SP = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\bar{d} - d_i)^2} \quad (17)$$

3) Generational distance (GD)

Generational distance shows the smallest Euclidean distance d_i from all the vectors in the Pareto front to any vector in the reference Pareto front. It is calculated using (18) [43].

$$GD = \frac{\sqrt{\sum_{i=1}^{n} d_i^2}}{n} \quad (18)$$

3.4. *Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)*

TOPSIS is a decision-making approach proposed by Yoon and Hwang in 1980. It evaluates each alternative according to its Euclidean distance from the best and worst solutions. The decision matrix (R) is constructed using the normalised performance ratings as shown by (19).

$$R = \begin{bmatrix} r_{11} & r_{12} & .. & r_{1n} \\ r_{21} & r_{22} & .. & r_{2n} \\ : & : & : & : \\ r_{m1} & r_{m2} & .. & r_{mn} \end{bmatrix} \quad (19)$$

The weight of the attributes (w_j) is then associated with the normalised performance ratings (r_{ij}) using (20) to form the weighed normalized preference ratings (v_{ij}).

$$v_{ij} = w_j \times r_{ij} \quad (20)$$

The weighed normalised decision matrix V is then constructed as shown by (21).

$$V = \begin{bmatrix} v_{11} & v_{12} & .. & v_{1n} \\ v_{21} & v_{22} & .. & v_{2n} \\ : & : & : & : \\ v_{m1} & v_{m2} & .. & v_{mn} \end{bmatrix} \quad (21)$$

The positive-ideal (A^+) and negative-ideal (A^-) solutions are then identified by computing the maximum and minimum of the weighed normalized values using (22) to (25).

$$A^+ = \{v_1^+, v_2^+, \ldots v_n^+\} \quad (22)$$

$$A^- = \{v_1^-, v_2^-, \ldots v_n^-\} \quad (23)$$

$$v_j^+ = \text{Max } v_{ij} \quad (24)$$

$$v_j^- = \text{Min } v_{ij} \quad (25)$$

where i = 1,2,…….,m and j = 1,2,…….,n

S_i^+ and S_i^- shows the distance of each alternative from the positive-ideal and negative-ideal solution respectively. They are found from equations (26) and (27).

$$S_i^+ = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^+)^2} \quad (26)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2} \quad (27)$$

The preference for each alternative, P_i is calculated using equation (28).

$$P_i = S_i^- / (S_i^+ + S_i^-) \quad (28)$$

The alternatives are ranked in descending order of the value of the preference [44].

4. Results

Figures 5 to 7 show the number of non-dominated solutions stored in the external repository used by the MOPSO section in the NSGAII-MOPSO, MOEA/D-MOPSO and SPEA2-MOPSO respectively. It was found that the repository was never full after the application of

MOPSO. In NSGAII-MOPSO, the maximum number of non-dominated solutions identified in the lower portion of the population was 18 at iteration number 29 and 85. It amounts to 30 in MOEA/D-MOPSO and occurred at iteration number 72. For SPEA2-MOPSO, the number of non-dominated solutions in the repository reached a peak of 29 at iteration 14.

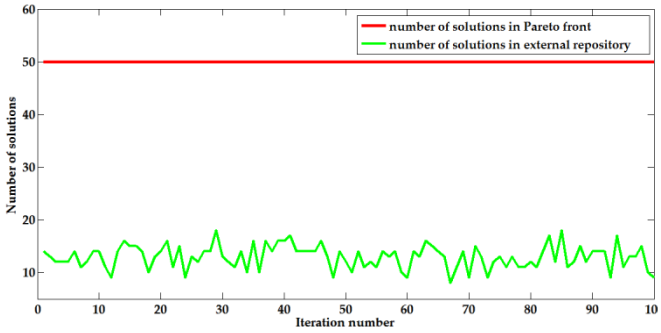

Figure 5: Number of solutions generated by NSGAII-MOPSO

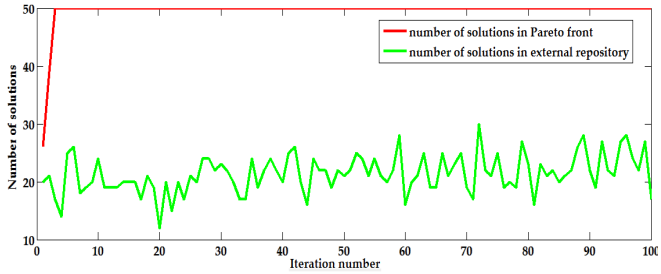

Figure 6: Number of solutions generated by MOEA/D-MOPSO

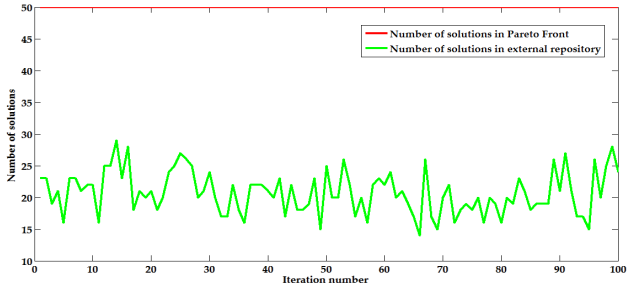

Figure 7: Number of solutions generated by SPEA2-MOPSO

Figures 5 to 7 also reveal the number of non-dominated solutions located in the Pareto front of in the NSGAII-MOPSO, MOEA/D-MOPSO and SPEA2-MOPSO respectively. The maximum allowable number of solutions in the Pareto front was 50. If the number of non-dominated solutions in the front exceeded 50, they were ranked so that only the first 50 solutions were kept. For NSGAII-MOPSO and SPEA2-MOPSO, it was found that the number of solutions in the Pareto front remained constant throughout the 100 iterations. In MOEA/D-MOPSO, the number of solutions in the Pareto front changed in the first two iterations. It then stabilised to 50 for the remaining iterations. The Pareto front was completely filled quickly due to the small size of the search space. It can be inferred that all the 50 solutions identified by NSGA-II, SPEA2 and MOEA/D from the upper half portion of the population in their respective hybrid algorithm dominates the solutions identified by MOPSO in the lower half section of the population.

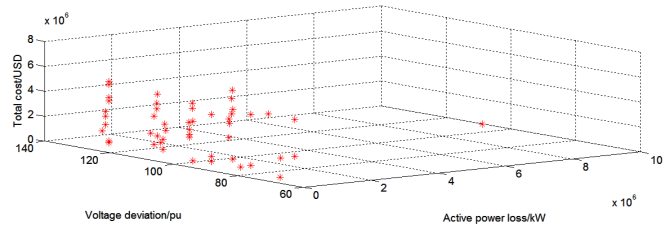

Figure 8: Solutions in the search space in NSGA-II-MOPSO

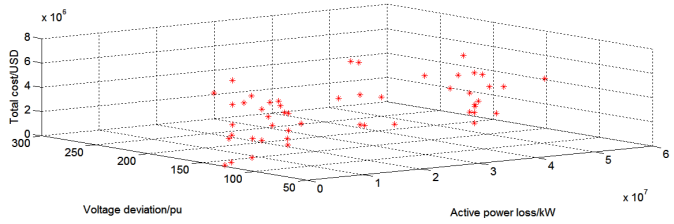

Figure 9: Solutions in the search space in SPEA2-MOPSO

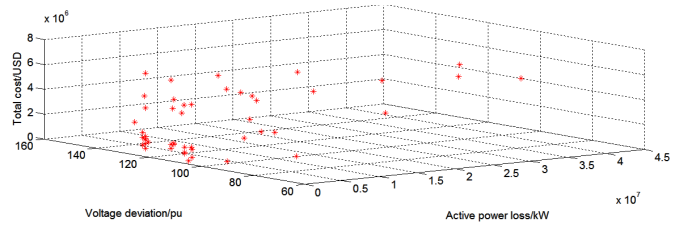

Figure 10: Solutions in the search space in MOEA/D-MOPSO

Figure 8 to Figure 10 illustrates the solutions in the search space of the hybrid algorithms at the start of the MOPSO stage. It can be observed that the search space is quite small. This explains why the Pareto front was rapidly filled. Figure 8 to Figure 10 also reveals the great exploration capability of NSGAII, SPEA2 and MOEA/D. These algorithms produce a diversity of solutions which are used by MOPSO during the exploitation phase.

Figure 11 to Figure 13 shows the three-dimensional surface plot superimposed on the scatter plot generated by SPEA2-MOPSO, NSGAII-MOPSO and MOEA/D-MOPSO respectively. The figures illustrate the compromise among the three objective functions. There is no solution which generates the best value for all the three objective functions. It is up to the engineers to choose the solution depending on the needs of the power system at that time.

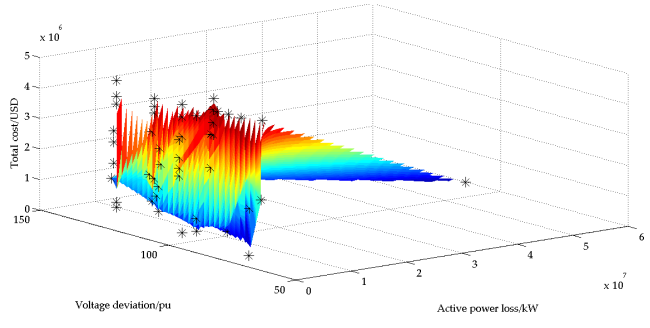

Figure 11: Surface plot generated by NSGAII-MOPSO

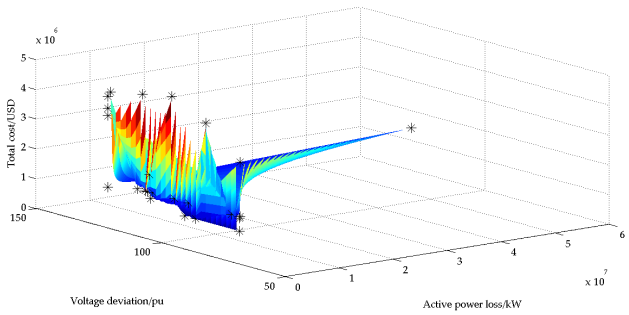

Figure 12: Surface plot generated by SPEA2-MOPSO

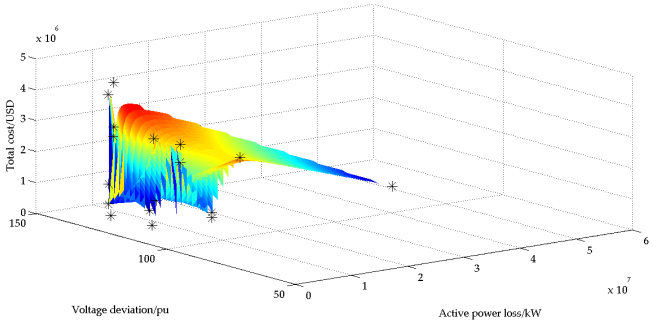

Figure 13: Surface plot generated by MOEA/D-MOPSO

Table 4 illustrates the best compromise solution produced by NSGA-II. It shows the optimal size and location of the three PV systems and UPQC as well as the optimal status of the six switches. As no solution in the Pareto front minimises the three objective functions simultaneously, TOPSIS was used to identify the optimal solutions. Equal importance was given to each objective function.

Table 4: Best compromise solution produced by NSGA-II

PV sizes	47 kW, 25 kW, 83 kW
PV locations	node 24, node 46, node 76
UPQC sizes	9 kVAr, 85 kVAr, 100 kVAr
UPQC locations	node 83, node 110, node 4
Status of switch SW1 to SW6	open, open, closed, closed, closed, open

Table 5 shows the mean simulation time for all the algorithms used. NSGA-II is the fastest algorithm as it computes the crowding distance of each solution objective-wise and then adds them to find the overall crowding distance. On the other hand, SPEA2 computes all the Euclidean distances in the objective space, generates clusters and then calculates the distance between consecutive clusters. MOEA/D has a lower mean simulation time than SPEA2 because each sub-problem in MOEA/D is solved using information from the neighbouring sub-problems only. NSGAII-MOPSO has a larger simulation time than NSGAII. This may be due to the fact that hybridization increases the memory requirement of the algorithm. SPEA2-MOPSO and MOEA/D-MOPSO have an average simulation time which is 49 % and 55 % less than that of SPEA2 and MOEA/D respectively. Therefore, MOPSO helps to accelerate the optimal solutions produced by SPEA2 and MOEA/D to particular search space regions.

Table 5: Mean simulation time of the different algorithms

Algorithm	Mean simulation time/s
NSGA-II	**2 795**
SPEA2	24 943
MOEA/D	20 222
NSGAII-MOPSO	6613
SPEA2-MOPSO	12 684
MOEA/D-MOPSO	9 010

Table 6: Minimum value of active power loss, voltage deviation and total cost produced by each algorithm

Algorithm	Active power loss/ kW	Voltage deviation/ pu	Total cost/ USD
NSGA-II	**2252.5**	**63.22**	**80 394**
SPEA2	2310.7	63.29	83 289
MOEA/D	2308.2	63.44	139 700
NSGAII-MOPSO	2394.4	63.33	103 160
SPEA2-MOPSO	4214.3	68.20	108 630
MOEA/D-MOPSO	3728.4	71.58	185 490

Table 6 shows the minimum values obtained by the optimisation algorithms for each objective functions. It was found that NSGA-II produced the lowest value for all the objective functions (shown in bold). However, the data in Table 6 is not enough to evaluate the performance of the optimisation algorithms. Due to the stochastic nature of the latter, it is vital to find the statistical significance of the obtained solutions. The quality of the results can be determined from the convergence and diversity of the optimal solutions.

Table 7: Mean value of the performance metrics for the different algorithms

Algorithm	SP	PD	GD
NSGA-II	0.2480	**6.3461**	0.0900
SPEA2	**0.2104**	4.9366	0.0842
MOEA/D	0.3336	5.9259	0.0954
NSGAII-MOPSO	0.3841	4.1899	0.0838
SPEA2-MOPSO	0.3295	4.7661	**0.0733**
MOEA/D-MOPSO	0.3374	4.4552	0.0746

Table 7 showcases the performance metrics for the different optimisation algorithms. As the data was of different orders of magnitude, it was normalised before the computation of these metrics. It was observed that the hybrid algorithms improve the generational distance metrics. The lowest mean GD was produced by SPEA2-MOPSO. The average SP value for all three hybrid algorithms was close to zero indicating that the

neighbouring solutions were almost evenly arranged. The GD values are reduced by nearly 6.9 %, 12.9 % and 21.8 % in NSGAII-MOPSO, SPEA2-MOPSO and MOEA/D-MOPSO respectively relative to their corresponding non-hybrid algorithms. This reveals that the Pareto front generated by the hybrid algorithms is closer to the true Pareto front. This may be due to the local search performed by MOPSO in the hybrid algorithms. The high PD values in the results generated by NSGA-II indicate that the solutions were more scattered. The diversity in the results produced by all the three hybrid algorithms was almost similar. However, it was less than that of the non-hybrid algorithms.

5. Conclusion

The integration of renewable DG units in the distribution system poses several technical challenges. The use of UPQC and DNR are potential solutions to the problem. Thus, multi-objective optimisation is needed to boost the efficiency of the power system at reduced costs. The novelty of this research is the multi-objective optimisation of PV systems, UPQC and DNR simultaneously using MOEA/D, NSGAII and SPEA2. These optimisation algorithms were further combined with MOPSO resulting in three hybrid algorithms namely NSGA-II- MOPSO, SPEA2-MOPSO and MOEA/D-MOPSO. The hybrid algorithms produced solutions with better spacing and generational distance metrics at the cost of a degradation in the diversity of the solutions. In addition, hybridizing SPEA2 or MOEA/D with MOPSO helps to reduce the simulation time. Using TOPSIS, the optimal network structures as well as the optimal size of the PV systems and UPQCs were found.

This research produces insightful findings so that policy makers and engineers can introduce new incentives and regulatory measures. It shows that hybridisation of multi-objective optimisation algorithm is promising. Future works may include techniques to improve the diversity of the solutions generated by hybrid algorithms. Also, the multi-objective optimisation based on a larger number of objective functions may be investigated. The effect of varying the population size, repository size, crossover parameter and mutation parameter can also be analysed.

Conflict of Interest

The authors declare no conflict of interest.

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PAMELA RAMSAMI has done her bachelor's degree in Electrical and Electronic Engineering from University of Mauritius in 2014. She is currently working towards the Ph.D. degree at the University of Mauritius.

She has presented her research works in ELECOM 2018, ELECOM 2020, 2021 IEEE PES/IAS Power Africa,

CIYCEE conferences. She won the best presentation award at the CIYCEE 2021 Conference. She also serves as reviewer in two leading journals. Her research interest includes multi-objective optimisation, neural networks and distributed generation.

ROBERT T. F. AH KING holds B.Tech. (Hons.), M.Phil. and Ph.D. degrees in Electrical and Electronic Engineering. He is an Associate Professor in the Department of Electrical and Electronic Engineering at the University of Mauritius. He is a Registered Professional Engineer in Mauritius and a Chartered Engineer (UK). His research interests includes power systems, computational intelligence and optimisation. He is a member of the Institution of Engineers (Mauritius), Institution of Engineering and Technology (UK) and Institute of Electrical and Electronics Engineers (USA). He is a Technical Committee Member on Soft Computing of IEEE Systems, Man, and Cybernetics Society. He was the General Chair for ELECOM 2016, ELECOM 2018 and ELECOM 2020 conferences. He has been on the Technical Programme Committees of several conferences and has served as reviewer for several leading journals.

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Evaluating Project Complexity in Construction Sector in India

Amit Moza, Virendra Kumar Paul, Sushil Kumar Solanki*

School of Planning and Architecture, New Delhi, 110002, India
*Corresponding author: Sushil Kumar Solanki, Contact: +917828253917, Email: sushilsolanki@spa.ac.in

ABSTRACT: Evaluating complexity, in order to manage it effectively, has been stressed by many researchers as one of the key areas of project management. This, as literature shows, has been done using different methodologies and assessing it from different perspectives resulting in measures that differ in their characteristics, their application, and their relevance with respect to location or typography. Since no such quantitative study with respect to Indian construction sector was found in literature, the aim of this research is, therefore, to develop a model for evaluating complexity in projects in Indian construction sector with aim of enabling informed interventions at the planning stage to manage the complexity better. A comprehensive literature study enabled identification of 23 such determinants initially which were grouped under 7 components of complexity, each component representing a different type of complexity. Using a two-stage Delphi process, the determinants were narrowed down to 21 and were weighed using mean rank weightages. The results of the survey were used to develop a framework for evaluating complexity which was further idealized into a model in the form of Project Complexity Index that could provide a single quantitative value of complexity at any stage of the project and highlight the areas of concern. Application of the developed model was demonstrated on two case studies of similar infrastructure projects. The framework made it possible to evaluate the complexity as well as highlight the areas needing attention on the basis of component complexity scores thereby indicating that the framework was robust.

KEYWORDS: Construction, Complexity, Architecture, Infrastructure

1. Introduction

The success of a construction project has been often measured as performance achieved on three parameters of time, cost and quality. In order to improve the probability of achieving this performance, numerous established techniques like time scheduling, cost scheduling, risk assessment etc. have been used extensively by project managers. However, despite this, a large number of projects still fail to achieve performance criteria on these parameters and many other parameters of project success put forward by different researchers from time to time. One of the reasons for this, cited by many researchers, is not understanding the project complexity and its implications on project planning and execution, even though it is a commonly held opinion that the reason for the poor performance is the design and construction process being particularly complex for several reasons [1–3] such as complex processes of communication among project stakeholders, ambiguity and equivocality related to project performance criteria, complex construction techniques etc.

Consequently, a lot of research has been carried out on complexity in projects and it has been acknowledged that construction projects must be viewed as complex and planned accordingly. For example, in [4] authors opined that construction problems are complex, the elements of the problem are numerous and the interrelationships among the elements are extremely complicated. In [5] author reinforced this by stating that construction is more than a straightforward linear process that can be managed top-down. Many researchers [1–3] stressed on the need to not only acknowledge construction projects as complex but also to understand this complexity so that it could be managed effectively. Therefore, it follows that for achieving project success, managing complexity gains significant importance. However, in order to drive the project complexity management efficiently, it is imperative that the project complexity is clearly defined and measured beforehand [6] This has been reinforced by many empirical studies in the construction field which reflect that project complexity would affect the project duration, cost, and quality and should be objectively

measured in order to provide continuous feedback to help control the process of project development [1], [7], [8].

The importance of measuring project complexity has been widely acknowledged, but there are not many universal objective measures available for assessing it. Researchers have attributed this to complexity being largely connected to the subjectivity of the observer [9], [10] which suggests that the measurement of complexity in context of projects too will differ among various project stakeholders.

Considerable research has been carried out on identification of factors that contribute to complexity and also on methods that can be used for measuring such complexity in a project. Several authors have looked at the problem of managing projects from the complex systems' point of view. While analyzing the complexity, they have often used a specific angle. For example, characterizing complexity as structural uncertainty and uncertainty in goals and methods only [11] or complexity being a function of how social systems work in projects [12]. The basic premise of all such studies has been that managing complexity needs to be viewed separately from traditional project management approach. As a result, the factors proposed have been different from those that reflect the general character of a project or those which are used often in project management vocabulary by people managing projects.

Other studies have tried to view or identify complexity in a project from within the existing characteristics of a project by simply analyzing the usual project parameters of cost, design, quality standards, specifications etc. [13]. The premise behind these studies is that it is possible to gather simple project complexity factors which are often encountered and dealt with at site level and thus are familiar to people managing projects. However, such studies are often specific with respect to various factors and local nuances like type of project, project delivery mechanism, country specific factors etc. affecting their management. Thus, a uniform approach having a universal implication on complexity management has not evolved, though the studies do provide insights into various methodologies used. Since such methodologies are often geographically specific and take into account the local nuances, very little research is available on objective quantification of complexity in India construction industry scenario thereby indicating that research on methodology for evaluating complexity in projects in an Indian context needs attention. This would enable informed interventions by project managers for reducing the complexity and managing project outcomes efficiently.

It can be argued, basis study of existing literature as mentioned above, that by simply analyzing the usual project parameters of cost, design, quality standards, specifications etc., it is possible to gather simple factors that make a project complex. For example, a project using only an established schedule of items with no additional items specific to the project can be termed as non-complex because the established items have fixed specifications and there's nothing peculiar about them as far as executing the specifications or even cost of item is concerned. At the same time, however, project will be considered complex if knowledge of processes involved in executing the project is new and requires higher skills or professional delivery.

Therefore, by considering the premise already established in the literature [13] that complexity can be established from within project parameters and fine-tuned to the geographical or locational peculiarities, evaluation of complexity can be made simpler. Also, in India though some studies have been carried out on issues of project complexity, for example, finding measures of complexity but limited to engineering design projects [14], while some studies explore complexity in governance of projects [15], others explore complexity in project interfaces [16], but no significant study on an objective evaluation of complexity in projects in Indian Construction Sector can be found in literature,. Therefore, this study was carried out to identify determinants that contribute to project complexity from the existing project parameters like design, quality, location etc. using existing available research and establishing a framework, based on identified determinants, for evaluating the same. The methodology for such a framework shall be such as can be easily applied by project professionals without prior expert knowledge of complexity modelling and complexity measurement techniques.

The study aims to develop a framework that can objectively measure complexity of projects in Indian construction sector so that project managers can make managerial interventions at appropriate stages for effective project management.

To achieve the above-mentioned aim of the study, the following are the objectives to be met:

1. To identify determinants of complexity and characterize project complexity determinants (factors) and establish key interrelationships between them.

2. To develop a model for effectively measuring project complexity as an index for assisting project managers in evaluating complexity.

3. To validate the model by testing its application to a case example generally perceived to be complex.

2. Research Method

This study tries to look at complexity using an approach wherein complexity is considered a general characteristic of a project rather than application of complexity theory and is based upon following successive

steps, which are a modified combination of methodology used by researchers [17] and [18] in their respective studies on measuring complexity.

- Reviewing literature in order to provide documentary evidence of the subject matter and to provide a wider understanding of the key issues.
- Determining, from reviewed literature, key factors contributing to complexity and group them under relevant heads to form a preliminary framework for complexity evaluation.
- Carrying out validation and refinement of preliminary framework through a questionnaire survey using Delphi method.
- Analyzing the results of the Delphi survey for the purpose of refining the framework and assign weights to each determinant.
- Idealizing the refined framework into a model to determine the complexity index of a project so that areas needing improvement through managerial interventions are highlighted.
- Testing the model by applying it to analyze a few real-life projects.

3. Background Study

A common view that one comes across often when dealing with the construction industry is that construction is a complex process, and it continues to get more and more complex with projects employing sophisticated technologies to serve diversified requirements of varied end-users. In [1], the author opines that the building projects have become progressively more complex since World War II. Although Project complexity has not been clearly defined [19] it is regarded as one of the critical project characteristics that determine appropriate actions to result in successful project outcomes [1]. The fact that project complexity influences project performance and affect the success of a project has been widely recognized by various researchers in the past [20–23]. Despite this and years of research on the concept of complexity, there has been a lack of consensus on what project complexity means. Many researchers have suggested that processes comprising innovative operations and conducted in an uncertain situation are complex. On the other hand, complexity of a task is defined as being the degree of difficulty in the search process, in performing the task, the amount of thinking time required and the body of knowledge in existence [24–26]. In [27] the author presented a view that a large number of elements in a process did not make it complex but the complexity was in the interactions between elements. This seems to fit well with the construction sector with its wide variety of disciplines, varied project types, organizational structures etc. For example, just by differing methods of procurement used may result in high or low levels of subcontracting [28] adding to the problems of integrating numerous, diverse organizations. Having no general definition of complexity, the difficulty in defining it is mainly circumvented by defining its key drivers. But according to authors in [29] defining those key drivers is not easy because those drivers depend on the environment and context of the project and reiterate that "when modelling the complexity of the design process it is first essential to determine the context" (work context, time context, motivational context and social context). They also suggest that there is very little information on the interrelations between these drivers due to a lack of consensus on project complexity drivers themselves. Project complexity is therefore difficult to define as a whole in general. As a result, many researchers have tried to express project complexity as composed of different kinds of complexity. That way they could easily define and explore the drivers of that particular aspect of the project which had the potential of making it complex. For instance, in [1] the author explores project complexity as a function to two distinct complexities depending upon the nature of organization and technology used and called them organizational complexity (number of hierarchical levels in organization, the degree of interaction between the project organizational elements, etc.) and technological complexity (number and diversity of inputs/outputs, number of interdependencies between tasks, etc.). The benefit of such a differentiation or breaking up of total complexity into components is that managing complexity becomes simpler to some extent as project managers can fine tune their approach if they know the kind of complexity they are dealing with. Consequently, complex projects have been defined by various researchers depending upon different characteristics they could possess. For example, lack of clarity on the goals of the project [30] dynamism in overall project methodology [31] direct or indirect communication among project elements [32] uncertainty in events [11], though simply having uncertain events during project lifecycle does not constitute complexity as some amount of uncertainty is always present in a project [33], and uniqueness of project [34]. These characteristics have been used by various researchers while propounding different complexity models with a view to assess and manage complexity in projects. For example, in [30] the authors having developed a 'Goals and Methods Matrix' classify projects using two parameters: How well defined the goals are, and how well defined are the methods of achieving those goals. They suggest that if methods are uncertain, the fundamental building blocks of Project Management like, tasks required to complete the job etc. will not be known. This model addresses the 'Uncertainty' aspect of complexity but does not address the interdependence of the elements in a model. Similarly, in [11] the author extends the model presented by Baccarini by adding one more dimension of Uncertainty to two components of 'No.

of elements' and 'Interdependence of these elements' presented by Baccarini. The uncertainty could be that of Goals or it could be in Uncertainty of methods. This model was further modified by researchers in [35] by including social interactions as one of the major determinants of complexity. According to them, the previous models neglected the effect of social interactions and their contribution to Complexity. Their model, therefore is an extension of William's model which in itself is a combination of Baccarinis's and Turner & Cochrane's model of uncertainty. Based on the source of complexity the authors in [36] suggest four types of project complexity

- Structural complexity: Arises in large scale projects which are broken down into smaller parts
- Technical complexity: Arises in projects "which have design characteristics or technical aspects that are unknown or untried"
- Directional complexity: found in change projects, "when it is clear that something must be done to improve a problematic situation, but it is unclear what this 'something' should be." [36]
- Temporal complexity: results in projects where there is a high level of uncertainty regarding future constraints like change in laws, guidelines etc.

This was further developed by researchers in [37] by stating that structural complexity is compounded by uncertainty increased by constraints. These constraints could be either environmental constraints, resource constraints or constraints of objectives.

Reviewing these models, it is clear that every model looks at complexity from a different perspective. While some of the key factors like structural complexity, uncertainty, technical complexity and clarity of goals seem to resonate in different models, yet it cannot be concluded that one model shall fit all the project scenarios. The researchers [38] in their study on complexity model conclude that existing models of project complexity do not suffice for an overall definition of project complexity. However, these models provide a base for identifying complexity measures particularly for infrastructure projects in the context of Indian construction industry.

Given the fact that project complexity is hard to be quantified precisely, many researchers focus on identifying factors/aspects relating to the project complexity while others focus on identifying specific variables and rating systems to quantify the project complexity. For example, in [39], the author classified construction projects based on scale of complexity into three categories of normal, complex, and singular. Classification is done on the basis of ten groups of variables and each variable is quantified on a 10-point Likert scale, and the average rating is then calculated to obtain the complexity category. However, no weights have been provided for these variables according to their relative importance. In [7], the author on the other hand worked on a construction complexity index (CCI) using ten variables that define the project complexity. The CCI is calculated as the sum of products of weight coefficients and complexity rating scores which are calculated using factor analysis and cluster analysis respectively, carried out with respect to an opinion survey. This is a robust model; however, it only focuses on measuring the complexity of the construction process only and does not focus on entire or all phases of project and also limits the study to building projects only. The model, however, does provide a working methodology for quantifying complexity in different project types carried out in different geographies. Researchers [13] further this methodology by presenting a complexity index consisting of six key measures of complexity for building projects in China. They use a three-round Delphi questionnaire survey for identifying key parameters and based on their relative importance and weightages, they calculate an index for quantifying complexity under each parameter. However, the study is restricted to building projects in PRC only. Therefore, it would not be appropriate to use the same variables for construction projects in India.

It can be concluded that there is no consensus on the identification of complexity measures for construction projects. Researchers assess the project complexity from different perspectives. The identified measures include not only specific characteristics of construction projects but also conceptual aspects relating to the theory of complex system. Furthermore, considering that the complexity in this study is defined as the degrees of difficulty when delivering projects, the complexity measures would vary in different geographical locations due to their unique market conditions. Therefore, in order to meet our objectives, it was evident that any new proposed framework must have specific measures or determinants that usually come across in a project and could be easily identified and quantified by a regular project manager. The determinants must further be able to be grouped under different heads for the purpose of classification of complexity into various components which again correspond to different aspects of project management.

4. Proposed Framework of Project Complexity

Having carried out a detailed literature study on issues related to complexity and analyzing different complexity models proposed by researchers, the next step involved listing the measures that could be used to assess complexity in an infrastructure project. While doing so it was imperative that all aspects of project complexity are captured keeping the above mentioned two main objectives in mind. As a whole, a very large number of possible project complexity measures can be identified when structuring a literature review. From among these, a

set of measures were identified after discussions among researchers which were objective in nature and corresponded to the denominations commonly used in field. The measures listed are presented in Table 1.

The measures were then further classified and grouped according to the type of complexity they attribute to. This grouping was carried out through a new model of complexity wherein overall complexity has been proposed to be of three main types and each type to be composed of different components each of which can be evaluated through measures listed above and grouped under each such component.

Accordingly, the proposed framework classifies overall complexity into three main types with each type composed of different components:

1. Complexity with respect to Scope
    a. Functional Complexity
    b. Technical complexity
2. Complexity with respect to Context
    a. Environmental complexity
    b. Social complexity
    c. Institutional complexity
3. Complexity with respect to Organization
    a. Vertical organizational complexity
    b. Horizontal organizational complexity

The primary objective of evaluating complexity under these three heads is to clearly differentiate between complexities that are either stemming directly out of the project and inherent to it or arise as a result of interactions that the project is going to have with external environment and stakeholders or those complexities that are not specific to project but are associated to it on account of the organizational structure of the project proponent or client organization.

A summary of these three types is presented in Table 2 below followed by proposed new framework as Figure 1 .

Table 1: Listed Measures of Complexity

S No.	Complexity Determinant	Description
1	No. of elements or work packages	More no. of elements in a project or more number of work packages would make a project more complex to deal with due to a large number of interactions between these elements
2	No. of stakeholders	If stakeholders are larger in number, it involves more complexity as one has to manage large no of diverse interests these stakeholders would bring with them.
3	Diversity of Stakeholders	Stakeholders coming from different cultures and different geographical regions are more difficult to manage as it poses difficulty in understanding mutual concerns.
4	Uncertainty in goals and methods	Uncertainty leads to complexity. Uncertainty in goals might arise due to various stakeholders having different expectations and goals from the project or when the scope is poorly defined.
5	Workspace/Site location	Difficult locations or constrained site conditions make a project more complex. Difficult locations would mean far away locations removed from resources, in difficult terrain, hostile terrains etc. Similarly constrained workspaces would involve more complexity.
6	Project Duration	The Urgency of Schedule or an accelerated schedule makes a project more complex. A project with fast-track schedule is more complex.
7	Project Size/Scale	Bigger projects are usually more complex than the smaller ones
8	Buildability of design	To construct the design requires complex procedures and techniques making the project more complex
9	High degree of overlap between design & construction	Overlapping stages of design and construction makes it more complex to manage the project. This can happen for various reasons like no. of interactions required between the two phases, non-availability of drawings at the right time, close monitoring required for both stages to be in sync etc.
10	Multiplicity of technologies	Too many technologies or new unused technologies makes a project more complex. This would include use of new or advanced equipment and techniques of construction.
11	Non-standard specifications/ BOQ items	If project requires too many non-standard items, it is more complex than a project which runs on standard items/specifications
12	Environmental Impact	Requires high degree of environmental clearances and procedures for mitigation of adverse effects
13	Resources Affected	If a project involves affecting too many natural resources and people, it becomes more complex due to mitigation and rehabilitation processes getting involved which increase the elements and consequently interactions between these elements to be managed.
14	Interaction with surroundings	Negative interactions with public/surroundings make it more complex to handle a project as interactions now fall outside the regular or envisaged scope of the project.
15	Geopolitical Factors	Adverse geopolitical factors make a project more complex. This includes projects coming up in politically unstable locations, disturbing territories, violence prone areas etc.
16	No. of approvals or permits	Too many and varied approvals required for project make it more complex to handle
17	No. and variety of sources of funds	More number and different types of funding make a project more complex from a financial perspective.
18	Unstable laws/ policies	High probability of frequently changing laws or policies related to a project make a project more complex
19	Conflicting Laws	Laws or policies not conducive to project execution make it more complex, for example, too many restrictions on methods of disposal of waste, methods of construction etc.
20	No. of departments within a client organization	More departments mean more interactions hence more complexity.
21	Reporting Structure	Complex and a long reporting structure delays decision making and hence is more complex to deal with.

22	Roles/Tasks with no known procedure	Roles or tasks without precedence or known procedure can cause a high degree of organizational complexity
23	Variety of MI Systems	Too many and varied management information systems are more complex to deal with.

Table 2: Summary of types of Complexity

Complexity	Definition	Objective	Details
With respect to Scope	Complexities associated with the project's deliverables and the work required to create those deliverables.	To have a measure of complexity which is inherent to the project due to its structure so that interventions required for mitigating its effects are identified	It includes aspects like basic structure of project, project size and scale, execution methodology, technologies used etc
With respect to Context	Complexities arising out of interactions of project with its environment in a specific context	To have a measure of complexity that arises due to external factors affecting project and also management actions in response to such factors.	It includes aspect like environmental impact, geopolitical factors, effect on resources/populations, interactions with statutory and other bodies
With respect to Organization	Complexities arising out of the organizational structure of project organization	To identify and optimize the organizational structure for the project so that organizational differentiation is minimized.	This is characterized by depth of hierarchical and reporting structure and Number of departments or formal organizational units across organization

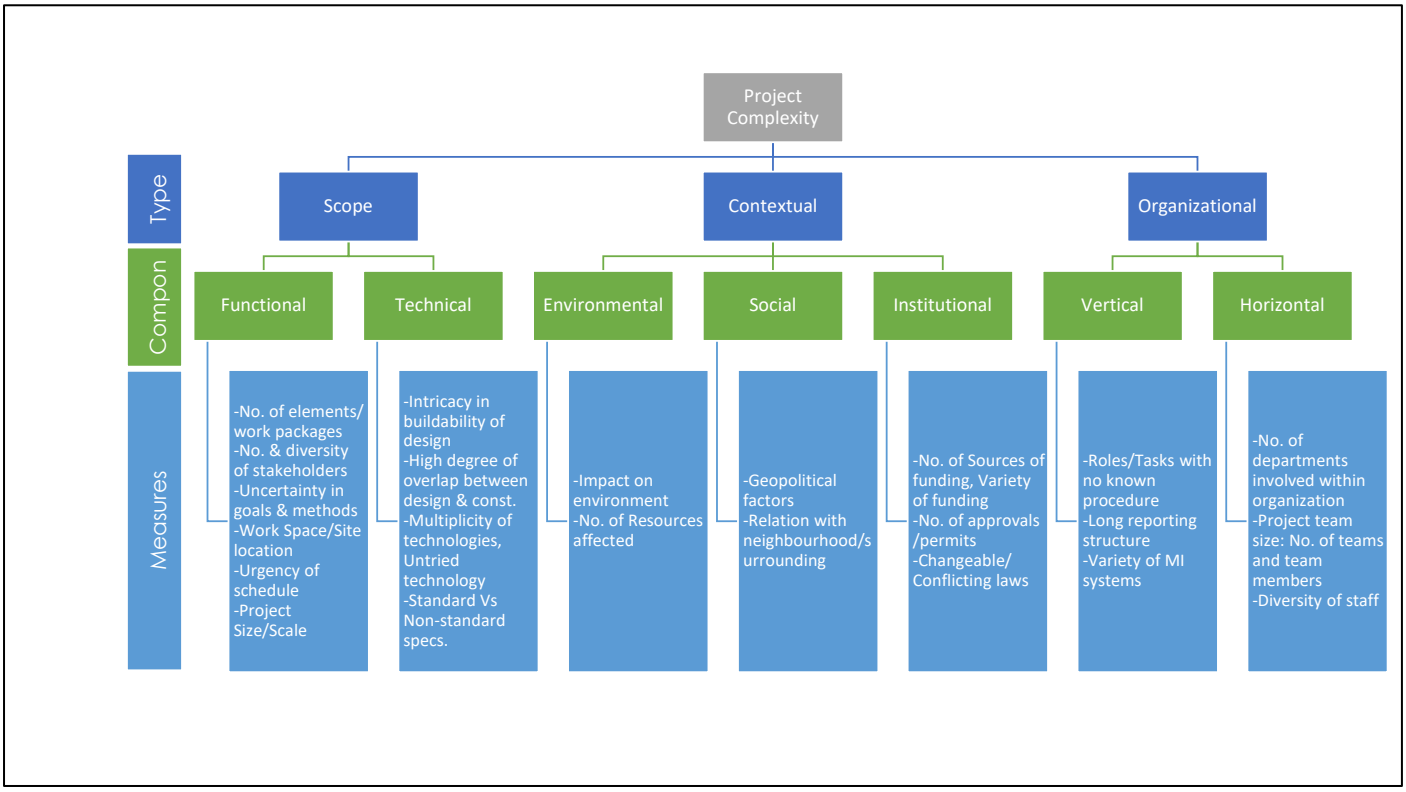

Figure 1: Proposed framework for evaluating project complexity

4.1. *Survey Design*

The methodology adopted in this research is based on the work done by researchers [13] who used three rounds of Delphi survey to finally calculate a complexity index for building projects in China. The Delphi Process is a unique method of eliciting and refining group judgment, based on the rationale that two heads are better than one when exact knowledge is not available [40]. It has proven over the years to be a very popular tool for framework building, forecasting, issues prioritizing, decision-making, etc. [41]. The Delphi method is used in this study as it is designed to obtain the most reliable consensus from a panel of experts basis several rounds of questionnaires with each subsequent round supplemented by controlled feedback [13].

As a first step of Delphi method, an expert panel was chosen for responding to the questionnaire. As suggested by researchers in [41] the experts selected should have enough knowledge and experience, willingness and time to take part in the survey, and good communication skills. Based on these features, a panel of 20 experts was selected to perform Delphi process, 18 of them belonging to construction industry while as 02 of them being academicians in the field of construction projects management. 5 out of 18 industry Practitioners were visiting academic faculty teaching construction projects management. The selected experts represent a wide spectrum of construction professionals and provide a balanced view for the Delphi study. All the experts have sufficient experience and expertise in building projects. Figure 2 depicts the details of the experience of the experts

in construction industry, number of projects handled by them and their role in the construction industry.

Fifty-Eight percent (58%) of the panel members had experience of more than 15 years in construction industry while as 26% of respondents had an experience of 5-15 years. Only 16% had less than 5 years' experience in construction industry. Almost all the respondents had acceptable backgrounds and experience in construction projects.

Thirty-seven percent (37%) of the respondents were either the owners or clients of the projects. These included public bodies like CPWD, PWD, DDA and other public sector units. More than half of the panel of respondents were consultants or architects. Almost 50% of these were both consultants as well as academicians and thus were very well versed with nuances of construction projects.

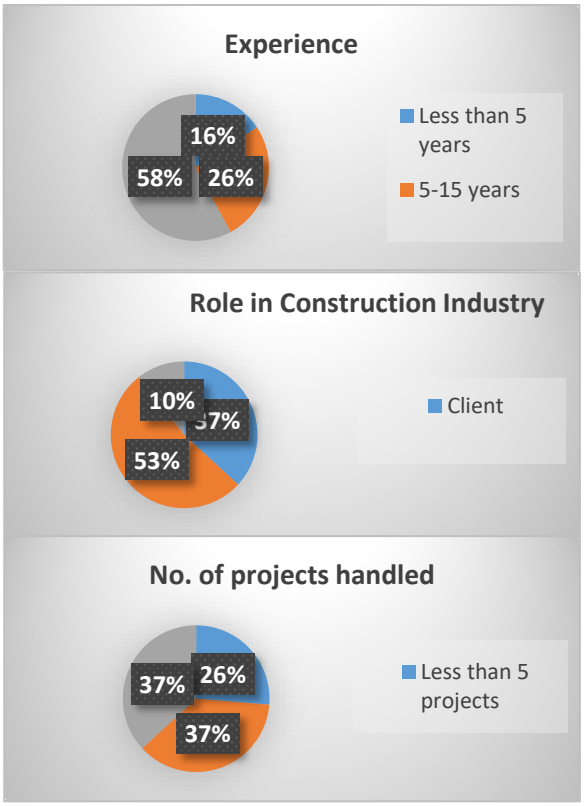

Figure 2: Details of experts selected for Delphi survey

The balance 2% of the respondents were academicians who specialized in field of construction and project management.

Because of the purpose of this research, the number of completed projects is more important than the number of years a respondent has worked. 70% of the experts had participated in more than 5 projects and out of these 50% had carried out more than 15 projects.

The questionnaire besides recording the personal details of experts as described above, also had a section where in all 23 measures classified into 7 groups were presented to experts with a brief description for each measure. Respondents expressed their opinion on the importance level of each measure on a five-point Likert scale under categories of "1" means not important at all, "2" means little important, "3" means moderately important, "4" means very important, and "5" means extremely important. For measures to be important from a respondent's perception means that the importance level should be significantly higher than three. Also, an applicable measure with mean value should be higher than three for it to be included in the framework.

4.2. Survey -Results & Analysis

The purpose of the first round of the questionnaire survey was to finalize the list of measures of complexity and also begin the process of building consensus among the experts. A list of 23 complexity determinants or measures were provided to experts in the form of a questionnaire, and they were required to record their responses against each one as per the scale explained above and were also asked to provide any other measure along with its importance on liker scale, which they felt was necessary for inclusion in the framework. In all 19 out of 20 experts selected for the panel returned their responses. In this research, the mean score of 3.0 was adopted as a cut-off point. Only the measure regarded as 'Important' remains for the re-evaluation in round 2. Table 3 below shows the results of round 1 of the Delphi questionnaire survey.

Table 3: Results of round 1 of survey

Determinants	N	Mean	Std. Deviation	Mean Ranks	Rank
No. of elements	19	4.05	.621	14.63	4
No. of stakeholders	19	4.26	.653	16.00	2
Diversity of stakeholders	19	3.79	.535	12.11	13
Uncertainty in goals & methods	19	4.42	.769	17.24	1
Workspace/Site location	19	3.84	.898	12.63	10
Urgency of schedule	19	3.47	.905	10.03	20
Project size/scale	19	3.16	.688	7.61	23
Buildability of design	19	3.89	.658	12.95	7
Degree of overlap design & const	19	3.79	.631	12.66	9
Multiplicity of technologies	19	3.74	.991	12.50	11
Non-standard specifications	19	3.53	.964	10.66	18
Impact on environment	19	3.58	1.071	10.82	17
No. of resources affected	19	3.63	.895	11.21	15
Interaction with surroundings	19	3.21	1.084	7.87	21
Geopolitical factors	19	4.00	.882	14.00	5
No. of approvals	19	3.16	1.068	7.76	22
No. of sources of funds	19	3.74	.733	11.45	14
Unstable laws/policies	19	3.84	.688	12.74	8
Conflicting laws	19	3.84	.688	13.00	6
No. of departments	19	3.63	.831	11.11	16
Reporting structure of client org	19	3.58	.607	10.13	19
Tasks/roles with no known procedure	19	4.11	.567	14.74	3
Variety of MI systems	19	3.74	.806	12.18	12

Based on results in table 4-3, it can be observed that lowest average score against a determinant is 3.16 for 'No. of approvals' and 'project size/scale' which is still slightly above the cut off score of 3.0. Therefore, all of the twenty-

three determinants were carried to the second round of the survey for re-evaluation.

Though mean standard deviation of all the responses is 0.7 which is moderately high, standard deviations of many responses are quite high, in a few cases going well beyond 1.0. This indicates that an acceptable consensus has not been achieved. This is confirmed by a low value of 0.161 of Kendall's Coefficient of Concordance (W) calculated with the aid of the SPSS software.

Therefore, a second round of survey was carried out for allowing the respondents to re-evaluate their ratings on the basis of consolidated results of round one with the aim of building a reliable consensus.

In the second round of the Delphi survey, the experts were asked to re-assess their ratings. For this purpose, they were provided a copy of the consolidated results of the first round of survey along with their individual ratings. The consolidated results included median ratings and standard deviations of each determinant. It also presented percentage responses received against each rating for a particular determinant. The purpose of providing these details was to provide the experts with enough data to assess their ratings vis-à-vis the entire panel.

Finally, all 19 experts returned back the second-round questionnaire. Most of the experts had reconsidered their ratings and had accordingly made adjustments in their ratings. From the results it was observed that two determinants had got an average value less than the cut-off score of 3 meaning that they are not considered important in determining the complexity of a project. The two determinants are 'interaction with surroundings' and 'number of approvals. Consequently, these two determinants are dropped from the list of determinants for further analysis.

Furthermore, it is also observed that these two determinants had received very low ranks in the round 1 survey and had only one determinant ranked below them.

After these two determinants were removed from the data, further statistical analysis was carried out to find out the mean ranks and the weightage of each determinant. Mean Ranks have been used instead of statistical averages because the rating scale is not a purely equal interval scale and hence doesn't justify usage of the averages for calculating weights.

On the basis of ratings provided by experts, mean ranks were calculated using SPSS software. Based on the mean ranks so calculated, similar to [13] the weightages of each determinant were computed.

Table 4-4 consolidates the results of the 2nd round of the survey. It can be observed that when compared to the results of round 1 survey, all the standard deviations have reduced and are now less than 1. The mean standard deviations too are calculated for the entire framework and found to be 0.56 which is lower than 0.7 obtained after the first round of survey. This indicates that a reasonable consensus has been achieved.

Table 4: Consolidated results of second round of survey

Complexity Determinant	Avg Rating	Std. Deviation	Mean Ranks	Weight	Rank
No. of elements	4.05	.405	13.05	0.057	5
No. of stakeholders	4.42	.507	15.79	0.068	2
Diversity of stakeholders	3.79	.419	10.58	0.046	11
Uncertainty in goals & methods	4.68	.478	18.08	0.078	1
Workspace/Site location	3.79	.713	10.42	0.045	14
Urgency of schedule	3.58	.607	8.89	0.039	18
Project size/scale	3.11	.459	4.61	0.020	21
Buildability of design	3.89	.567	11.63	0.050	7
Degree of overlap design & construction	3.79	.419	10.76	0.047	10
Multiplicity of technologies	3.79	.787	10.50	0.045	13
Non-standard specifications	3.89	.658	11.82	0.051	6
Impact on environment	3.53	.697	8.08	0.035	20
No. of resources affected	3.58	.692	8.92	0.039	17
Geopolitical factors	4.11	.658	13.24	0.057	4
No. of sources of funds	3.58	.507	8.47	0.037	19
Unstable laws/policies	3.89	.459	11.53	0.050	8
Conflicting laws	3.79	.631	10.55	0.046	12
No. of departments	3.74	.733	9.92	0.043	15
Reporting structure of client org	3.63	.496	9.26	0.040	16
Tasks/roles with no known procedure	4.16	.501	13.82	0.060	3
Variety of MI systems	3.84	.501	11.08	0.048	9

To verify this and to find out the degree of variance in the rankings, Kendal's coefficient of concordance is once again calculated and is found to be 0.291. The value of coefficient of concordance obtained is not substantial, but when compared to the result of first round, the value has almost doubled. This means that a reasonable consensus has been built up. Also, a low value of coefficient can be attributed to the fact that experts were asked to rate each determinant on a rating scale of 1 to 5 and were not required to rank the determinants directly. The rankings were calculated based on these ratings. Consequently, what it means is that the experts believe that some of the determinants are equally important in the evaluation of complexity of a project. This is corroborated by the fact that many determinants have values of mean ranks very close to each other. The presence of a rating scale allowed them to do so. Had they been required to rank each determinant from 1 to 23, it would have been unlikely that two or more determinants would have same mean ranks which would have resulted in a far improved value of the coefficient of concordance.

From Table 4 it can be observed that only five determinants have average scores above 4 which means that respondent experts feel that these five are extremely important in evaluating complexity. Furthermore, all

three complexity types of Scope, Contextual and Organizational are represented in these top five determinants. 'Uncertainty in goals and methods' has been ranked as the highest determinant of complexity followed by 'number of stakeholders involved'. Both of these determinants have their genesis in complexity related to Scope. Though they are ranked as top two, there is no significant correlation between the two as suggested by a low value of coefficient of correlation (0.2) between the two.

In order to understand better the relationships between the identified project complexity factors, a correlation analysis has been performed by calculating Spearman Rank correlation coefficient. The aim is to check for possible existing correlations between factors in the answers of the experts.

The correlations above critical values of the Spearman Rank for the value of 19 pairs have been highlighted in Figure-3.

	No. of elements	No. of stakeholders	Diversity of stakeholders	Uncertainity in goals & methods	Workspace/Site location	Urgency of schedule	Project size/scale	Buildability of design	Degree of overlap design & const	Multiplicity of technologies	Non standard specifications	Impact on environment	No. of resources affected	Geopolitical factors	No. of sources of funds	Unstable laws/policies	Conflicting laws	No. of departments	Reporting structure of client org	Tasks/roles with no known prcedure	Variety of MI systems
No. of elements	1.000	.169	-.260	.098	-.151	-.156	-.335	-.484*	-.260	.065	.031	-.100	-.277	-.226	.123	-.228	-.170	-.137	-.173	-.035	.051
No. of stakeholders		1.000	.179	.121	.085	.023	.274	-.416	.179	-.063	.101	.409	-.011	-.132	.511*	.438	.077	.095	-.012	.190	.266
Diversity of stakeholders			1.000	.205	.205	-.139	.398	-.086	.050	-.013	-.061	-.027	.407	.292	.083	.166	.241	.153	-.127	-.092	.368
Uncertainity in goals & methods				1.000	-.045	.232	.174	-.126	-.073	.399	.347	.164	.391	-.070	.109	.349	.516*	.022	.420	.201	.484*
Workspace/Site location					1.000	.390	.054	.128	-.308	.256	.536*	.360	.511*	.289	.339	.221	.337	.380	-.043	.231	.216
Urgency of schedule						1.000	.194	.219	.111	.513*	.332	.625**	.169	.486*	.057	.370	.407	.001	.353	-.167	-.268
Project size/scale							1.000	-.173	.398	.391	.260	.341	.319	.348	.192	.316	.270	.238	.196	.428	.048
Buildability of design								1.000	.129	.047	-.026	-.094	-.118	.025	-.166	-.057	.125	.255	-.146	-.134	-.054
Degree of overlap design & const									1.000	.038	-.305	-.134	-.144	-.106	.083	.166	.067	.013	.141	-.092	-.184
Multiplicity of technologies										1.000	.633**	.210	.088	.142	.292	.195	.399	.246	.385	.233	.026
Non standard specifications											1.000	.438	.370	-.139	.339	.174	.569*	.473*	.154	.431	.170
Impact on environment												1.000	.422	.288	-.044	.493*	.548*	.120	-.034	.029	-.134
No. of resources affected													1.000	.259	-.054	.458*	.661**	.189	.022	.347	.421
Geopolitical factors														1.000	-.022	.228	-.087	-.273	.112	-.019	-.143
No. of sources of funds															1.000	.274	.022	.253	.233	.493*	.379
Unstable laws/policies																1.000	.468*	.183	.056	.322	.168
Conflicting laws																	1.000	.537*	-.079	.068	.249
No. of departments																		1.000	-.443	.269	.180
Reporting structure of client org																			1.000	.233	.194
Tasks/roles with no known prcedure																				1.000	.527*
Variety of MI systems																					1.000

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Figure 3: Spearman Correlation Analysis

From the correlation analysis, it could be concluded that the project complexity determinants tend to be positively correlated with less than 30% of the values being negatively correlated. However, the average value of rs2 is equal to 0.16 indicating that the positive correlations are not very high. Finally, less than 8% of the values are above the critical value for $p < 0.05$ and less than 1.5% of them are above the critical value for $p < 0.01$, which means that strong correlations are rare in this case.

Despite the positive correlation being limited among determinants, there are significant correlations between some of them. For example, the highest value of r = 0.661 indicates that 'No. of resources affected' and 'conflicting laws' are significantly positively correlated determinants in evaluation of overall complexity. Similarly, with r = 0.633 'multiplicity of technologies' and 'non-standard specifications' are significantly positively correlated and so are 'impact on environment' and 'urgency of Schedule'. It must, however, be noted that these correlations are not very intuitive and yet are significant at $p<0.01$. Also, another important observation that must be made is that these correlations are significant but not strong because the value of 'r' must be above 0.85 for correlations to be strong. Therefore, in case of fitting this data in a model, it is valid to assume a linear relationship between the determinants.

4.3. Complexity Model: Project Complexity Index

Referring to the framework of complexity evaluation presented in Figure 1, the overall complexity of a project is divided into three main types which are further composed of different components which can be directly measured from the project details.

Therefore, for evaluating the overall complexity of the project, the component complexity indices are first evaluated. These component indices are then added, as per the grouping finalized in proposed framework, to provide values of each type of complexity which can be further added to give a consolidated complexity index for the project. The final refined framework is presented in Table 4-5.

Table 5: Final refined framework of project complexity

Complexity Type	Component Complexity	Complexity Determinant	Short Form	Mean Ranks	Weightage
SCOPE	Functional	No. of elements	FD1	13.05	0.057
		No. of stakeholders	FD2	15.79	0.068
		Diversity of stakeholders	FD3	10.58	0.046
		Uncertainty in goals & methods	FD4	18.08	0.078
		Workspace/Site location	FD5	10.42	0.045
		Urgency of schedule	FD6	8.89	0.039
		Size/Scale of Project	FD7	4.61	0.020
	Technical	Buildability of design	TD1	11.63	0.050
		Degree of overlap design & construction	TD2	10.76	0.047
		Multiplicity of technologies	TD3	10.50	0.045
		Use of non-standard specifications	TD4	11.82	0.051
CONTEXTUAL	Environmental	Impact on environment	ED1	8.08	0.035
		No. of resources affected	ED2	8.92	0.039
	Social	Presence of adverse geopolitical factors	SD1	13.24	0.057
	Institutional	No. and variety of sources of funds	ID1	8.47	0.037
		Likelihood of unstable laws/policies	ID2	11.53	0.050
		Laws in conflict with a project implementation strategy	ID3	10.55	0.046
ORGANIZATIONAL	Organizational	Number of departments in Client organization/project setup	OD1	9.92	0.043
		Long Reporting structure of client organization	OD2	9.26	0.040
		Tasks/roles with no known procedure	OD3	13.82	0.060
		Variety of Management Information systems	OD4	11.08	0.048

4.3.1. *Component Complexity Indices*

Using the weightages from the framework, the component complexity indices are developed and presented in following paragraphs.

Functional Complexity Index

Functional Complexity deals with functional aspects of the scope like project size and scale, stakeholder number and mix, financial sources and financial mix, uncertainty in goals and methods, site location etc. The factors within *functional complexity component* bring out those aspects of project management that deal with functional attributes of a project having their genesis in Scope Management. The first component complexity index is developed which can be represented by the following equation

$$"FCI = 0.057 \times SFD1 + 0.068 \times SFD2 + 0.046 \times SFD3 + 0.078 \times SFD4 + 0.045 \times SFD5 + 0.039 \times SFD6 + 0.020 \times SFD7"$$

where

- FCI represents the Functional Complexity Index
- S_{FD1} to S_{FD7} represent the scores of functional complexity determinants.

The above index has been derived on the basis of assumption that the model is a linear and additive one. This assumption is confirmed by the correlation analysis carried out wherein it is apparent that the determinants are not strongly correlated with each other. Additionally, it has been the view of many researchers that using non-linear models is not recommended when the sample size is not sufficiently large. [42]

Also, from the above equation, it is observed that the complexity index is defined by two main components: the weight coefficient of a determinant and the score of a determinant. The score of a determinant can be obtained on the basis of values of a determinant for an individual project. The methodology for obtaining these scores can be decided by the project organization or the project manager. For example, a rating system may be developed by an organization for determining the scores against complexity determinants to be used in all its projects.

Technical Complexity Index

Technical Complexity deals with technical aspects of scope like a number and mix of technologies used in both machines as well as methods, constructability of design, nature of specifications, contract delivery mechanism etc. The factors within this component of complexity essentially cover operations, that is, equipping and sequencing of activities, characteristics of materials and characteristics of knowledge. All of these three aspects have their genesis again within the scope management

Similar to procedure above, second component complexity index is developed and is represented by following equation

$$TCI=0.050\times S_{TD1}+0.047\times S_{TD2}+0.045\times S_{TD3}+0.051\times S_{TD4}$$

where

- TCI represents the Technical Complexity Index
- S_{TD1} to S_{TD4} represent the scores of technical complexity determinants mentioned in the framework.

Based on the procedure illustrated above, all other component complexity indices are developed and are presented as following equations

Environmental Complexity Index

$$ECI=0.035\times S_{ED1}+0.039\times S_{ED2}$$

Social Complexity Index

$$SCI=0.050\times S_{SD1}$$

Institutional Complexity Index

$$ICI=0.037\times S_{ID1}+0.050\times S_{ID2}+0.046\times S_{ID3}$$

Organizational Complexity Index

$$OCI=0.043\times S_{OD1}+0.040\times S_{OD2}+0.060\times S_{OD3}+0.048\times S_{OD4}$$

The overall complexity index for a project is calculated by adding the component complexity indices which are obtained by applying the method explained in preceding section.

Therefore, overall project complexity is calculated as per following equation

$$\boldsymbol{PCI = FCI + TCI + ECI + SCI + ICI + OCI}$$

Where

PCI represents the Project Complexity Index and FCI, TCI, ECI, SCI, ICI and OCI represent individual component indices.

Also, from the above equation for overall complexity, complexity with respect to Scope can be determined as

Complexity with respect to scope = FCI + TCI.

Similarly, Complexity with respect to Context = ECI+SCI+ICI and Complexity with respect to Organization = OCI

4.4. Evaluating Determinant Scores and Complexity Indices

The mathematical equations representing the model are simple linear equations containing constants and variables. Constants are the weightages obtained on the basis of the Delphi study results while variables are the complexity determinant scores explained earlier.

In order to evaluate the component complexity and the overall complexity, determinant scores need to be determined for a particular project. These determinant scores can be evaluated for each project as per procedures typical and suitable to a particular organization. For example, every organization may have a different benchmark on the number of stakeholders beyond which they may feel project becomes complex to handle. This is true for all the determinants that make up this model. However, in order to demonstrate the application of the model, a procedure for obtaining this score for a project is illustrated. This procedure may be adopted by any organization for their projects in the initial period of application of the model. When sufficient data has been collected on several projects handled, organizations can use scientific methods to find out and benchmark maximum values of component complexities for their organizations.

The procedure is based on the methodology proposed in an earlier study of modelling complexity [17] and consists in framing a questionnaire for project managers to respond for their respective project, for which complexity needs to be determined. The methodology involves posing a set of questions in a number of phases, minimum two. Phase-1 poses a series of questions relating to the project which have been formulated based upon the project complexity determinants that have been identified and finalized through the research. The questionnaire, format conceived by researcher [17] in her research, contains 19 questions pertaining to each determinant in the model. The user of the model must score each determinant between 0 and 10. The question should be scored zero if it has no significance or does not apply to the project. A low number should be scored for lower impact of that determinant on complexity, with the score increasing towards 10 based upon the magnitude of impact the determinant has on that complexity. The questions are also provided with 'cues' to guide the user in filling the scores. The 'cues' provide information of what that determinant encompasses and points the user towards various aspects that particular determinant is supposed to capture.

The project complexity is then calculated using the model equation. This is called the 'baseline' calculation and should be preferably carried out immediately after project brief is ready and one has all the information related to project in hand. The outcome of Phase 1 is the baseline component complexity figures and highlights the areas which need improving in order to reduce the project complexity.

In Phase-2 a new series of questions are posed relating only to the areas which need improving. These are scored in the same way as the original questions in Phase-1 so that the project complexity can be recalculated. However, stage

two questionnaire can be used effectively only if the target maximum level of component complexities are known and established. If target values are not established, it will only provide relative values of complexity for comparison with baseline values, for a particular project. Since the scope of this study is limited to demonstrate the application of model to a particular project at the beginning, the application of phase 2 calculations shall not be covered because due to limited time available for completing this study, it will be difficult to match the progress of the study with a project which is at a preliminary stage of life cycle and then follow as the project moves along.

The whole evaluation process works in the following way:

- Baseline evaluation process determines if the project complexity is at an acceptable level. It is so if all of the component indices score below the target maximum established and the identified complexity can be managed as it is.
- If any of the component complexity indexes is higher than the target maximum, additional information and intervention in terms of strategy is required and therefore phase two of questions must be completed.
- The phase two questions specifically target the areas which have a higher than recommended project complexity value.
- When the stage two questions have been completed, the project complexity calculation and evaluation process is repeated,
- If the project complexity for all of the component complexities is now below the target maximum, the project complexity can be managed.
- If some components are still scoring above the recommended maximum, the phase two questions, calculation and evaluation must be repeated until all of the indices are within the acceptable limits.

5. Testing of Model: Case Studies

In order to test the model and the methodology of applying it described in section 4.4 above, two case studies were analyzed. Since target scores couldn't be made available for the case studies, as an initial exercise, only baseline scores are being determined. Therefore, to have some meaningful comparisons, case studies selected are of similar projects. It may, however, be noted that the model can be applied to any project in any situation. After obtaining the details of both the projects, the project heads of both the projects were asked to fill the baseline sheet for their respective projects. While doing these they were urged to consider the initial conditions at the beginning of the project life cycle. The overview of the case studies and the model application analysis is provided in the following paragraphs

5.1. Case Study 1: International Airport at Chandigarh

Background

The ambitious ₹900-crore project was conceived as a joint venture between Airports Authority of India (AAI) and the governments of Punjab and Haryana. Designed on the green building concept, the terminal in Mohali (Punjab) is spread over 53,000 sq.m and can handle 1,600 passengers, including 450 international travellers, during peak time

The project had several features that could make the planning for the project complex. First of all, the design of the terminal building was based on green concept, which was a first in the country. Consequently, new technologies were also envisaged in the construction of building as well as allied facilities. This was a planning challenge for the project proponents as many of these initiatives were new for them.

Two of the three major stakeholders of the project had a lot of differences among themselves which led to uncertainty in the naming of the project. The project team had to ensure coordination between these two primary and sensitive stakeholders. Thus, from the point of view of stakeholder management, the project had a different type of complexity.

On the basis of the data related to project, the determinant scores provided by the project proponents in the baseline sheets as ratings on a scale of 0 to 10 were entered in the model after dividing the ratings by 10. This was done to normalize the scores to a 1/10th scale and was necessary because the overall complexity index is a score between 0 and 1. In order to maintain the complexity score in this range, it is necessary to reduce the ratings in baseline sheet to a similar scale. Figure 6 presents an overview of the results of the baseline phase.

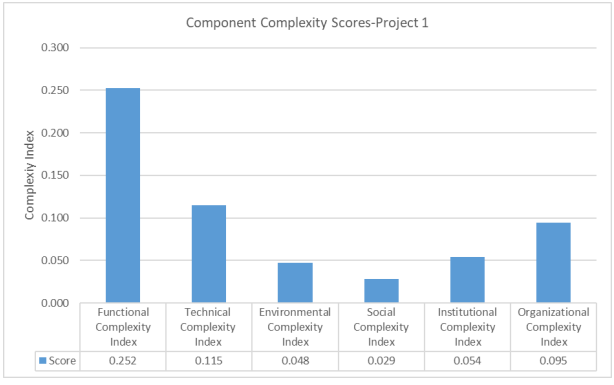

Figure 4: Phase -1 score of Project No 1

The overall project complexity index determined as a sum of component complexities works outs to be 0.593. Corresponding complexity types are as follows:

Complexity with respect scope = 0.368
Complexity with respect to context = 0.131
Complexity with respect to organization = 0.095

The results from the baseline phase show that the functional complexity has the maximum value among all and accounts for almost 43% of the total complexity in the project. This is in line with what one could have intuitively guessed from the details of the project as it was evident that most of the complexity must lie with respect to scope of the project, both in function and technical aspects. The project involved a number of new technologies and processes, had diverse and very sensitive stakeholders, had a lot of uncertainty in terms of final goals of the project due to sparring between two major stakeholders etc. and all these were bound to add to the respective complexities.

Even though the bare or absolute numbers in absence of benchmarks or target values do not provide many insights as to which areas need immediate attention, the indices still provide a relative scale of importance of areas that need more focused attention. Over some time, as already described in preceding paragraphs, this model can become a knowledge-based system so that appropriate benchmarks are available to compare the values.

5.2. Case Study 2: New Airport at Ajmer

The proposed project involves development of domestic airport spread over an area of 283 hectare which is to be constructed after the dismantling of existing airstrip which is not in working condition. The proposed project is located at a distance of 2km from Kishangarh towards the northwest direction.

The estimated cost of the project is ₹161 crores and was to be constructed in 36 months. The development plan includes 16 different work packages.

The project is a green-field airport project and does not involve too many technological innovations and is a general type of airport project for the project proponents who deal with airports projects extensively. Therefore, complexities with respect to scope are expected to be at reasonable levels. However, the project land acquisition has been a major problem due to the displacement of local population. As a result, the project had been going on getting delayed. This would mean that the value of contextual complexity ought to be more for this project and the same should be highlighted by the model.

Following the procedure similar to the one followed for case study 1, on the basis of the data related to project, the determinant scores provided by the project proponents in the baseline sheets as ratings on a scale of 0 to 10 were entered in the model after dividing the ratings by 10. This was done to normalize the scores to a 1/10th scale and was necessary because the overall complexity index is a score between 0 and 1. In order to maintain the complexity score in this range, it is necessary to reduce the ratings in baseline sheet to a similar scale. Figure 7 presents an overview of the results of the baseline phase for this case study.

The overall project complexity index determined as a sum of component complexities is determined to be 0.383 and corresponding complexity types are as follows:

Complexity with respect scope = 0.200
Complexity with respect to context = 0.120
Complexity with respect to organization = 0.063

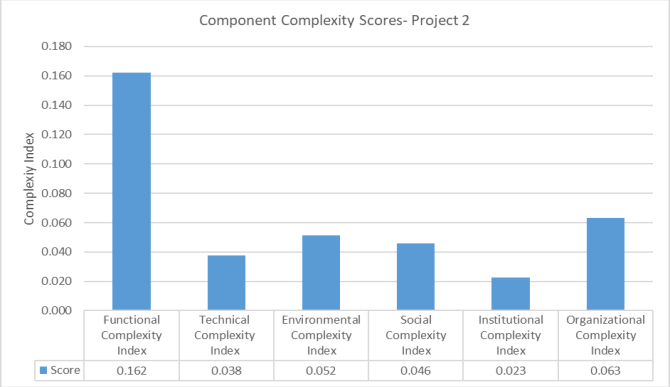

Figure 5: Baseline score of Project 2

These results show that though the functional and technical complexity is lower as compared to project 1, they are still high as compared to other complexity components within this project. The complexity with respect to scope thus, is close to 0.2 which again accounts for around 40% of the total complexity of the project. Similarly, as anticipated, the environmental and social scores of this project are much higher than the project 1 and they account for more than 30% of the total complexity of the project. What appears to be slightly against intuition is that this value of complexity ought to have been the highest in this case as can be gathered from the project details. Instead scope complexity is yet again a major component of total complexity which was not expected given that project did not entail any new technologies or complex procedures. However, the reason for this becomes apparent on studying the baseline data sheet in which determinant scores against No. of elements, no. of stakeholders and urgency of schedule determinants are the highest. This indicates that the functional complexity is increasing on account of some different factors which are not immediately apparent from the general data usually available. Thus, it shows that the results from the model are robust and present a picture of complexity taking into account underlying factors too which are not apparent otherwise.

It is being again reiterated that the implications and the full potential of the model can only be realized when target scores are benchmarked so that phase 2 questions can be used to bring down the complexity values to target limits in case they are exceeding them. However, at the same time, it is clearly seen from the results of above two case

studies that the model is capable of evaluating complexities across projects. It enables one to compare the projects across on complexity scale and will also be able to compare the same project for complexity score before and after interventions for improvements are made.

Therefore, it can be concluded that the model is robust and can be used to provide demonstrable results. The authors declare no conflict of interest.

6. Conclusion

This study tried to focus on identifying key parameters that can be used by industrial practitioners to measure the complexity of projects in the construction sector of India and using these determinants propose a model for evaluating the complexity quantitatively.

A number of factors affecting complexity in a project were identified from the literature. It was proposed that the entire complexity of a project can be attributed mainly to three types. One with respect to scope, second with respect to context and third with respect to Organization. These three types of complexities were further proposed to be composed of different components which formed the basic components of overall complexity too. The number of factors identified from literature were then grouped under each such component and were called the determinants of that component of complexity. Thus, an initial framework of complexity evaluation was proposed which consisted of twenty-three determinants of complexity grouped under seven components which were further organized under three main types of complexities explained above.

To have the framework validated through experts in projects a consensus building exercise was carried out through a Delphi Study. All 23 determinants were framed in the form of a questionnaire and were given to experts for rating each one of them on an importance scale of 1 to 5. The final analysis of results of the Delphi study resulted in a reduction of the number of determinants from 23 to 21. Further, using the results of the Delphi study, the mean ranks of determinants were calculated in SPSS and the corresponding weightage of each determinant in the overall framework of complexity evaluation was determined. Thus, a final framework of evaluation of complexity was proposed.

Using this framework, a model for evaluating the overall complexity of a project using a single index was derived and presented in a form of an equation and was called Project Complexity Index. The project complexity index was determined as a sum of individual component complexities which were in turn derived in the form of equations from the final framework.

This index could be used for any project in India for obtaining a single score which could be used for determining its complexity. The index may also be used for comparing two projects and can assist organizations in setting target maximum component complexities that can be handled and shall also highlight the areas that need interventions to reduce that particular complexity with the purpose of managing this complexity in a better way.

In order to demonstrate the application of this framework in the Indian construction sector, two case studies of similar public infrastructure projects were examined. Using a set of questions, quantifiable values were obtained for each determinant of complexity.

Finally using the component complexity indices equations, component complexities were determined which were further added to determine the overall complexity of the project which clearly indicated that on an overall basis project 1 was more complex to handle than project 2 and thus needed specific interventions to manage this complexity. The model made it possible to evaluate the complexity as well as compare two projects against each component of complexity thereby indicating that the framework was robust.

7. Limitations and Future Research

This study proposed a simple model for evaluating complexity in a construction project in Indian context. The model is a result of the combination between practical construction industry experts' and academic experts' points of view. The model provides a great deal of flexibility by which it can be modified to suit the individual requirements of each organization as the method of determining the scores of determinants can be decided by individual organizations based on their internal procedures and processes.

At the same time the study can further be improved to mitigate the following limitations:

- The model can be used more effectively if target maximum values of overall complexity as well as complexities of various types are established and benchmarked. Methodology for carrying out such a benchmarking was not in the scope of this study and may be taken up further.
- The application of the model has been demonstrated on a limited number of case studies and that too only for ascertaining the baseline values of complexity at the initial stage of project lifecycle (for the reasons already enumerated in this report at relevant places). More number of cases studies may be taken up for study to demonstrate the application of model at various stages of life cycle of project. The above-mentioned limitations can be taken up for further research and study.

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Model for Assessing Mobile Business Intelligence Readiness within South African Telecommunications Industry

Philip Marothi Lemekwane*, Nkqubela Ruxwana

Department of Informatics, Tshwane University of Technology, Pretoria, 0002, South Africa
* Corresponding author: Philip Lemekwane, 0027783210474, philiplemekwane@gmail.com

ABSTRACT: To determine what needs to be done, organisations throughout the world need the capability to find out quickly, what is happening and why it happened. Therefore, having the intelligence to make informed decisions at the right time and place is the key to success in today's dynamic environment. As mobile systems become increasingly available, more accessible, and better performing, data gathering and analysis can be performed off-site and on-site with greater flexibility, in turn extending Business Intelligence (BI) to mobile devices, commonly known as Mobile Business Intelligence (MBI). However, the MBI implementations remain unexplored and unsupported even with the sturdy increase in mobile technology adoption, especially in developing world like South Africa where it is the most viable option. The study aims to establish the MBI readiness factors and developed a model for these organisations to assess their MBI readiness, using South African telecommunications industry as a case. The study employed quantitative research approach, where a closed-ended questionnaires were used as the primary data collection method. Finding suggest a number of key factors significant to MBI readiness in context including Culture, Enterprise Mobility, Organisational Capability, Infrastructure, Security, Skills, Support, etc. The MBI readiness model and its validated elements provide a new way of identifying and verifying critical factors for MBI.

KEYWORDS: Mobile Business Intelligence, Business Intelligence, Mobility, Technology Readiness, Organisational Readiness, Core Readiness

1. Introduction

Rapid changes have been witnessed in organisations' decision making due to the increasingly widespread use of the internet and automation of business activities. Information has become one of the most valuable and important assets for organisations [1]. The need for data integration across organisations has increased due to the desire for global competitiveness and bigger market share.

With advancements in technology and wireless network accessibility, mobile devices such as smartphones and tablets are swiftly gaining popularity due to their wide range of functionality and portability [2]. Employers and employees can access real-time business insights anywhere and at any time through these new generations of mobile devices [3].

Making the right decision at the right time and place is the key to success in today's dynamic environment [4]. As mobile systems become increasingly available, more accessible, and better performing, data gathering and analysis can be performed off-site and on-site with greater flexibility, in turn extending Business Intelligence (BI) to mobile devices, commonly known as Mobile Business Intelligence (MBI) [5].

Mobile workers require immediate access to critical information at any time and from anywhere [6]. In [7], [8], the authors explain that using applications which are optimised for mobile devices, MBI can provide insights for the mobile workforce through its use of information analytics; it provides users with necessary information and content needed, regardless of time and location through mobile devices such as smartphones, tablets, etc. The implementation of MBI initiatives provides organisations with the ability to retrieve vital information at almost any location, drastically changing how information workers collect, analyse and visualize information for decision making purposes [7].

In [9]–[12], the authors explains that although there are organisations adopting mobile technology in South Africa and globally, MBI implementations remain unsupported and unexplored and usually faces significant rate of failure leading to unrealised benefits, huge waste of resources and time. This can be attributed to lack of MBI readiness within these organisations as well as limited frameworks and / or models to guide the MBI implementations.

In [13], [14], the authors asserts that readiness is the most critical factor to ensure that any technological innovation is acknowledged, adopted, and accepted. In order to determine if organisations are ready to invest in MBI initiatives and identify gaps that need to be filled, the assessment of technology readiness is vital. The assessment helps to save organisations much resources and time by identifying gaps that need to be addressed [9].

In [3], [15]–[17], the authors asserts that in terms of BI readiness implementation factors, various researchers have put forward various ideas and frameworks, however, few studies have been consummated on MBI services. The study aims to develop an assessment model for MBI readiness with the focus on telecommunications industry within South African context.

2. Literature review

2.1. Business Intelligence

In [18], [19], the authors describe that busines intelligence encompasses a wide range of applications and technologies that gather, store, analyse, and then provide access to data so that informed decisions can be made utilising the information necessary to aid in decision making. South African organisations that are able to harness the large volume of information will benefit from being able to identify trends earlier, become more competitive, have increased knowledge and understanding of their customers' needs, and achieve organisational goals and objectives. On the other hand, organisations which fails to harness large volume of information might find it difficult to remain competitive and in business.

As organisations matures and grows, there is an overwhelming need to analyse historical business data in order to improve business forecasting and predict future trends [20]. BI systems allow massive varied data collected from various data sources to be transformed into useful information, thus enabling efficient and effective decision making. MBI extends and amplifies BI capabilities by providing platform wherein critical information is accessible immediately at anytime and anywhere [6].

This extension enables South African organisations to be more agile and competitive thus breaking traditional approach of accessing information. South African organisations in the telecommunication industry today are often relying on mobile technologies and Internet for their daily operations. In the wake of coronavirus, most of the South African organisation had to quickly adapt to new ways of working as employees were expected to operate remotely, while other organisations are still battling to deal with challenges that are brought about with remote working. Where BI systems are not in place, these organisations struggles to respond to their customer needs, hence some of the organisations were forced to shut down during Covid-19.

Over the past years, BI has evolved aggressively in order to meet and exceed the changing business needs. The evolution of BI can be categorized into six stages which are critical in the business environment [21]. Figure 1 below outlines the stages of BI evolution:

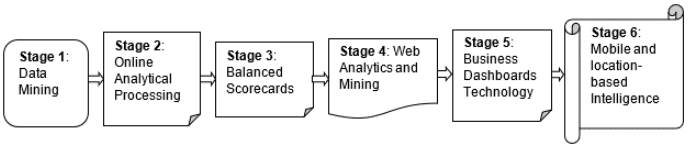

Figure 1: Evolution of BI

MBI is the latest evolution contained in the last stage (i.e. Stage 6) which enables mobile workforce to perform their day to day operations at anytime and anywhere.

2.2. Mobile Business Intelligence

A significant increase in mobility has been attributed to the development of mobile technologies, resulting in changes at the physical, communications infrastructure level as well as geo-locational level. In addition to gaining competitive advantages in the Information and Communications Technology (ICT) industry and ensuring an efficient correlation of the organisational strategy to new trends, MBI solutions or systems also support real-time decision-making within an organisation [22].

Using optimised applications for mobile devices, MBI enables the mobile workforce to gain business insights through information analytics [11]. It enables mobile workers to access real-time data and analytics anywhere and anytime using mobile devices [3]. MBI includes capabilities and features not commonly found on laptops and desktops.

MBI is capable of providing instant event-driven response, proactive alerts to the user, and real-time tracking of data [23]. It empowers employees to gain real-time access to back-end systems at any time regardless of the location. Additionally, MBI helps organisations save costs; for instance, enrolling mobile devices instead of expensive workstations to employees can save organisations lot of cost and time. It eliminates manual processes thus increasing accuracy, validity and reliability of data enabling direct input to the system instead of through paper or manually.

One of the major drawback or limitations of using the smartphones for BI was that their limited screen size prevented delivery of functionality such as interactive reports and full-featured dashboards. In spite of these limitations, smartphone-based BI allowed mobile workers to experience real-time BI [24].

However, mobility though it brings about greater benefits, it can also serve as greater threat to organisations and the mobile workforce if not well managed. For instance, mobile workers might feel tracked and their privacy violated or compromised. The mistrust in mobile technology might be a barrier for organisations that seeks to improve operations and gain competitive advantage through mobile solutions.

2.3. Mobile Business Intelligence Adoption

It is without a doubt that the adoption of MBI presents several advantages to various organisations, similarly it presents various challenges. In [16], the author asserts that MBI adoption often involves significant financial expenditure and organisational changes. In [25], the author emphasizes on key aspects or considerations that requires undivided attention when dealing with mobility. Mobile security features, secure authentication, information display and interaction, context awareness, offline mode exploration, how applications are deployed, information discovery, and rich application functionality are all included in these aspects.

In [26], the author describes that MBI by its nature presents various challenges. These challenges include amongst others; surveillance and spying of mobile workforce beyond normal working hours (Privacy), theft or loss of mobile devices with confidential and classified information (Security), tracing and tracking of mobile devices to determine their location (Safety), and data gathering about topics that are not work related (Ethics).

South African organisations are faced with various risks and challenges relating to the adoption of MBI, these includes lack of sufficient skills and knowledge, lack of support, lack of conducive infrastructure, etc. Furthermore, high cost of mobile devices and data within South Africa requires that organisations make significant investments to enable their employees to access MBI solutions.

Given this conundrum, a readiness model guiding South African organisation looking at implementing MBI solutions is critical. The readiness model assists in ensuring that all critical elements are considered on time thus saving organisational resources as well as ensuring that the anticipated benefits are realised. Although the developed readiness model is focused on the telecommunication industry, other organisations can adapt components relevant to their specific environment.

2.4. Mobile Security and Privacy

There is often a risk of theft, security breaches, and loss of mobile devices. As with laptops and other mobile devices, personal digital assistants (PDAs), and smartphones have posed security concerns. When a mobile device is lost, a vast amount of data may be at risk [27].

Data security and lack of knowledge or skills about mobile systems amongst others, continues to haunt mobile users [15]. Employees within organisations can knowingly or unknowingly be a major security weakness, thus educating and training these employees on security awareness, policies and practices becomes critical to bridge the digital divide and protect organisations against vulnerabilities and security threats.

It is fundamental that security policies and practices are clearly defined and documented, integrated into the overall enterprise ICT security plan, made widely accessible and workshopped to all employees, and strictly enforced.

2.5. Cyber Security

Cyber security refers to the protection of devices, data, systems, devices, and information from malicious attacks or unauthorised access [28]. Malicious cyber activities, such as cyber threats and cyber exploitation, have become increasingly sophisticated, targeted, and serious. There has been an increased volume and variety of attacks as a result of criminally and financially motivated hackers to get confidential as well as personal information [29].

The development of ubiquitous computing has provided the platform and the possibility to utilize technology and mobile devices in an unusual way. There has been continuous demands and developments for seamless interconnectivity of mobile or smart devices (smartphones, tablets, wearable devices, etc.) to deliver various abilities and functionalities to users, however, these brings about various vulnerabilities which are usually considered for larger infrastructures.

The growing adoption of cloud and mobile computing as well as increasing IoT devices rapidly increases cyber security threats and risks levels. Organisations and individuals are increasingly becoming more susceptible to attacks with the rise of IoT extending to interconnected devices such as driver-less cars, smart devices, drones, smart buildings, home appliances, etc. Thus, as security attacks threatens these organisations, proactive detection and response to such threats and the capability to timeously discover and resolve any potential breach by employing effective information security management systems becomes critical [30].

2.6. Mobile Device Management

In [31], the author asserts that security measures such as remote wipe-off all data on a lost device and anti-malware has a very low use rate while the Personal Identification Numbers (PIN) and passwords are the highest used security measures, followed by automatic locks. This was attributed to ignorance in security awareness and practices amongst employees and inappropriate monitoring and control of "bring your own Device" to effectively and successfully mitigate against the risky impacts.

Organisations are faced with various security risks due to increasing use of mobile or smart devices while attackers are presented with the opportunity to explore various cyber-attacks. Cyber criminals can install malicious applications on mobile devices disguised as legitimate applications, malwares may be spread onto mobile devices and compromise information stored therein. Through mobile devices, Distributed Denial of Service attacks can be launched against corporate networks. Thus, management of mobile devices becomes critical for MBI readiness thus mitigating these risks.

3. Methods

3.1. Design of the Study

The study extensively reviewed literature relating to MBI readiness following the problem identification, definition and planning. The information obtained was instrumental in developing and designing the questionnaire measuring items which were subsequently distributed to participants. The data were collected using the close-ended questionnaires. Statistical Package for Social Scientists (SPSS) version 20 was then utilised to code, transcribe and analyse the data. Validation of constructs was performed as well as quantitative analysis. The research process followed is outlined in figure 2 below.

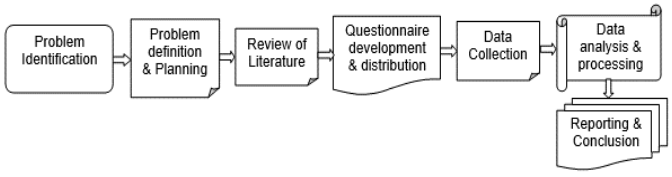

Figure 2: MBI Research Process

3.2. Approach of the Study

For this study, quantitative approach was employed as it offers greater objectivity and accuracy of results. Furthermore, quantitative analysis was used to validate the identified factors in the research model.

Before the main survey was carried out, selected organisations in the telecommunications industry were approached to understand the environment with the focus on MBI, locate potential participants, strategize and to garner support for the collection of data using the developed data collection instruments. Informal interviews were conducted with relevant Executives, Experts, BI Managers, Business Owners, Management, Heads of IT and / or Chief Information Officers amongst others.

The close-ended questionnaires based on five-point ordinal scale were distributed to participants using different platforms and methods such as survey monkey, electronic mail, hand delivery and social media. One hundred and twenty-eight (128) responses were received from participants and were tested. The validity, convergence and confirmatory of constructs were tested using structured equation modelling. Furthermore, regression analysis, correlation between constructs, and relationship patterns between factors were identified.

4. Data Analysis

4.1. Participants Demographics

The participants were believed to be directly or indirectly involved with MBI and BI within the South African telecommunication industry. To validate this, the information gathered included the demographics, knowledge and experience on Computers / Mobile devices, Internet and BI, overall experience, occupation and BI involvement, and their perceptions about BI concepts and effects on readiness. Furthermore, to ensure relevancy and accuracy of collected data, the participants were requested to specify if they are familiar with MBI.

The highest percentage of BI involvement at 18.75% was attributed to management. Thus, BI is used mostly at a strategic level for decision making amongst others by management. This was followed by the analysts involvement at 16.41% and support at 15.63%. This was followed by both the staff and specialists at 12.50%. The BI developers contributed 9.38% followed by BI users at 7.03%. The architects and testers contributed 3.91% respectively.

The participants with over four years of relevant work experience were 88.28% and only 11.72% with up to three years of relevant experience. Furthermore, 90.6% of participants use their mobile device to access enterprise systems or applications for work purposes. The use of laptop devices to access BI systems remains high at 89.1%. The use of smart phones was at 78.9% and tablets at 50%. The use of wearable computers as well as PDAs to access BI systems remains relatively low at 34.4% and 35.2% respectively

BI is utilized for various reasons within the telecommunication industry in South Africa, such as reporting (91.4%), operations and support (89.8%), decision making (88.3%), analytics (87.5%), forecasting (78.9%), data mining (75.8%) and marketing (68%).

4.2. Reliability and validity of constructs

The reliability of the questionnaires was tested using Cronbach's Alpha and were found to be reliable and usable as the overall α-coefficient was 0.960 which is greater than the required minimum value of 0.7. The reliability and validity per construct were also tested and 95% of the constructs were above the required minimum α-coefficient value of 0.7. The constructs that were found to be below the expected α-coefficient were abandoned.

Furthermore, items that investigates participants' knowledge and experience on Computers / Mobile devices, Internet and BI were also tested for reliability and were found to be reliable.

4.3. Kaiser-Meyer-Olkin value and Bartlett's test of Sphericity

In [32], the author explains that the range for Kaiser-Meyer-Olkin (KMO) index is from 0 to 1, and the minimum value for an acceptable or good factor analysis is 0.6, thus the KMO value of 0.744 (KMO > 0.6) was significant enough for conducting factor analysis. Bartlett's test p-value was below the 0.05 threshold and was found to be significant (p = 0.000). The results denotes that the correlation structure was significantly strong enough to perform a factor analysis of the items.

There were twenty-one (21) components which recorded eigenvalues above 1 (25.164, 6.646, 4.887, 4.198, 3.606, 2.974, 2.390, 2.028, 1.972, 1.816, 1.631, 1.622, 1.526, 1.454, 1.394, 1.290, 1.271, 1.212, 1.060, 1.042, 1.019). These components represents a total variance of 78.879 %.

4.4. Data Screening

To detect possible errors, missing data, miscoding, and normality, data screening was conducted. Data screening was also conducted to ensure that the statistical analysis procedures would be precise and that the estimates had a solid basis. A normality check was done to determine how to deal with cases of nonnormality. The data was checked for univariate and multivariate outliers to eliminate biased results. Furthermore, all items were checked for accuracy. The missing data in the questionnaires were checked using Microsoft Excel 2013 and SPSS Version 20.

5. Findings and Conclusion

5.1. Discussions of Mobile Business Intelligence Readiness Model Components

The components of MBI readiness model were categorised in to three main sections, namely; Organisational readiness (i.e., culture, policies, people), Technology readiness (infrastructure, security, skills, training), and Core readiness (Need for change, motivators, inhibitors). Furthermore, the following mediating factors were formed, namely; Organisational Capability, Enterprise mobility, Support, and Change Enablers.

Close-ended questionnaires were used to collect data from participants using five-point ordinal scale. The questionnaires were then coded and transcribed using SPSS and validated through quantitative analysis. Different set of questionnaires relating to MBI were put forward to the participants. The questionnaires focussed on the three main categories stated above as well as the mediating factors.

5.1.1. Organisational Readiness

The study revealed that to enable organisational readiness for MBI, the culture must be conducive. A supportive culture where mobility, new changes and innovations are valued, embraced, and encouraged should be created. Thus, South African organisations within the telecommunication industry should create cultural understanding and awareness to assess its readiness for MBI and to achieve organisational goal and objectives.

These organisations must encourage the culture of knowledge creation and sharing as well as encourage employees to strive for continuous performance improvement. In [33], the author argues that organisations with strong culture cause every member of the organisation or employee to agree and follow the agreed pattern of behaviour that has been proven to be beneficial to the entire organisation.

Furthermore, the study revealed that it is critical for organisations to have updated regulations and policies that enable and support mobility. In [34], the author highlights the importance of having a mobile devices security policy within the organisation. The security policy should define amongst others the types of the mobile devices permitted to access organisational resources, the types of resources to be accessed through mobile devices, the degree or level of access required, access monitoring and management, etc.

In [35], the author asserts that in the absence of policies to support enterprise mobility, organisations run a risk of finding themselves overwhelmed with employee-owned mobile devices and mishmash of various multi-vendor services. The study revealed that just having the policies in place is not enough, the policies must be workshopped and enforced in order to gain maximum benefits. Thus, policies that are not enforced, may render organisations ineffective and its employees frustrated.

Furthermore, it was revealed in this study that People are a critical component of each organisation for MBI readiness. Thus, South African organisations must have the right set of people in order to achieve MBI goals and objectives. In [36], the author asserts that people who

holds positions of Leadership throughout the organisation must model professional behaviour, enforce code of conduct equitably and consistently, embrace and understand the doctrines or tenets of professionalism and furthermore commit to holding everyone equally accountable to support the right working environment.

Furthermore, employees should understand and have clear roles and responsibilities in order to ensure MBI readiness. In [37], the author explains that involving employees and keeping them informed throughout the process of selecting and implementing new technological initiatives it is important thus, ensuring that the implemented technology meet the intended objectives and its fully supported.

5.1.2. Technological Readiness

The revolution of ICT has changed the roots of the nature of business by providing instant access to information which necessitates infrastructural changes and technological developments to adapt to the new wave of business operations [38]. The study revealed that South African organisations within the telecommunications industry must have capable and inclusive infrastructure to support mobile technology initiatives and have mobile platforms that are compatible. In this study, Infrastructure assesses the presence of appropriate hardware (e.g., Servers, connectivity, mobile devices, etc.) and communication infrastructures (i.e., software, systems, applications, etc.) in the organisation to enable or ensure MBI readiness.

The study revealed that mobile devices should be remotely locked and wiped-out in case of theft and other unexpected events. By doing so, the privacy and integrity of information or data, both in transit and in storage will be secured. These devices by nature generally experiences higher exposure to threats than other client devices. Further still, organisations should periodically back-up enterprise application data stored on mobile devices to an ICT controlled backup server.

Various security objectives such as availability, confidentiality, and integrity of data and systems should be supported through mobile devices; thus, these devices should always be secured against a variety of threats and attacks [34]. The study revealed that user authentication, data privacy and security awareness amongst others are essential to enable MBI readiness within South African organisations in the telecommunications industry.

Furthermore, employees should possess the required skills and knowledge for mobile technology. These skills can be acquired through training, experience, observations, associations (e.g., professional bodies, mentorship), self-learning, etc. Skills refers to the abilities and competencies of the employees within the context of South African organisations. One of the key technological inhibitors towards mobile technology is the lack of necessary skills or expertise [39].

South African organisations in the telecommunications industry needs to provide employees with the resources, opportunities, and knowledge to use the mobile technology to enable them to use the technology with ease. The study revealed that where top management does not encourage its staff or employees to develop necessary skills or expertise in their respective field of work, failure is eminent.

Furthermore, the study revealed that training is critical in order to ensure that employees within organisations are equipped and capacitated with the necessary skills and knowledge for MBI readiness. Training refers to a systematic and organised process of learning by which employees develop knowledge, learn attitudes, skills, and concepts aimed at cultivating personal and organisational performance [40].

Organisation must have a clear and mandatory mobile education and training strategy and training programmes wherein employees are required to attend, aligned to the organisational mobile strategy. Furthermore, the study asserts that the mobile technology vendors must provide training sessions for mobile technology in organisations. This will enable South African organisations in the telecommunication industry to have necessary skills to effectively and efficiently implement MBI technologies.

5.1.3. Core Readiness

The management and the entire organisational leadership should not see change as something they should fear but rather as something to embrace. Effective communication is important to enable change. Organisational changes must be effectively communicated from the top management or leadership to all employees throughout the organisation regardless of their level.

It is therefore important that any changes be regularly communicated to all employees using different communication methods and platforms available to the organisation. This inclusive approach will in turn allow all employees to feel as an integral part of the organisation and it will be easier for these employees to embrace change, thus ensuring MBI readiness. This means that change should not only be seen as management responsibility but as the responsibility of each employee throughout the organisation.

Mobile technology provides more freedom of mobility and control over daily operations. Keeping up with the latest technological developments greatly assist organisations for MBI readiness, which in turn enable these organisations to dissect and adopt technologies that are fit for purpose instead of adopting technologies

without considering their environment and expected return on technological investments. Furthermore, things that encourages employees to use mobile technology such as security, comfort, increased control, flexibility, efficiency in life due to technology, being the first using a new technology, etc. should be considered.

Similarly, things that discourages employees to adopt or use mobile technology such as lack of trust, fear of technology, discomfort, insecurities, etc. should be considered. Believing that mobile technology makes it easier for organisations to spy on people or its employees is likely to negatively affect organisational wide readiness for MBI.

The study revealed that while other employees believe that human touch is very important when dealing with technology, others believe that whenever something gets automated, they need to check carefully that the machine or computer is not making mistakes. Furthermore, other participants believe that one can never be sure that information which is transmitted over the internet or through a machine reaches its intended recipient or the right place.

Thus, it is critical for South African organisations within the telecommunications industry to determine possible inhibitors and mistrusts when assessing its readiness. Failure to identify and evaluate these elements or inhibitors will negatively affect organisational readiness for MBI implementations.

5.1.4. Mediating Factors

The study revealed that it is important for organisations to have the capability to recruit and retain the required skills necessary to attain its goals and objectives. The success of the organisations characterised by frequent turbulences of fast changes depends on its capability and aptitude to acclimatise to the new needs of the market and environment. These organisations must have competent and adept employees to implement and manage mobile technologies and have mechanisms in place to nurture and maintain high levels of employee morale and motivation.

Furthermore, organisations must have the flexibility and ability to create competitive advantage, align business strategies to directly support organisational goals, provide new products or services, and improve relationships with customers. These organisations must provide faster and easier access to useful, accurate and reliable internal and external information. The study revealed that mobility within organisations improves business efficiency, business processes, new business plans and business models, financial resources, structure, processes skill levels, and expand capabilities.

Top management support as well as support from all levels of management is critical for new technological developments and implementations, MBI readiness, and the achievement of organisational goals and objectives. Furthermore, lack of funding may result in failure or inability to implement and support MBI readiness. It is therefore critical for organisations to have a clear budget and funding strategy to ensure MBI readiness.

The study revealed that top management should consider mobile technology as an important factor for organisational success. For organisations to ensure readiness for mobile technology, there should be budget allocated specifically for mobility. Insufficient or lack of budget for mobility will results in the organisation failing to achieve or implement required solutions.

5.2. Discussions of Findings

The study revealed that MBI adoption within South African Organisations in the telecommunication industry is still at its embryo stage. This is despite the fact that; (1) mobile devices (e.g. tablets, smartphones, etc.) provides a wide range of portability and functionality, (2) there are many ideas and frameworks on the subject of BI readiness implementation factors. Although mobile devices have become extremely popular in recent years, this does not always mean that they are being used for business purposes.

Furthermore, although there are many success stories on BI implementations, the same cannot be said about MBI. This is attributed to the fact that mobility brings about different risks and challenges such as (1) Security and privacy of proprietary information, (2) Lack of standardised mobile offerings, (3) Slow adoption of globally available mobility solutions, (4) non-adherence to policies and standards, (5) Fragmented mobile platforms and diversity issues, (6) Limited processing, graphics, display, etc.

Within the South African organisations, MBI adoption is expected to increase significantly in the coming years. This increase will be attributed to several factors, including the unprecedented shift in culture, the emergence of MBI models, and the devastation caused by rare diseases such as the Covid-19, forcing the majority of businesses locally and across the globe to operate remotely. As human contact gets reduced due to the pandemic, organisations will heavily rely on MBI to improve its business operations and service delivery.

Note should be taken that the readiness factors considered within South African organisations will not necessarily be the same as those in other countries due to different culture, policies, technological and organisational factors amongst others. Furthermore, within the South African context, readiness factors

relevant to other industries such as Education, Mining, SME, etc. will not necessarily be applicable or relevant to those in the telecommunications industry. Thus, it is important to appreciate MBI components or factors within the context and content of various industries and organisations.

Fear of technology, mistrust and insecurities towards technology, complexities and data irregularities, lack of inclusive infrastructure readiness, lack of comprehensive policy that governs mobile devices usage, high costs, and limited top management support remains some of the barriers for MBI. These barriers can also be regarded as disks that needs to me mitigated. On the other hand, some of the key enablers for MBI readiness were found to be freedom of mobility, fit-for-purpose technological developments as well as strong security measures and technology comfort.

The identified factors or components of MBI readiness model were validated using quantitative analysis as outlined on Table 1 below.

Table 1: MBI Readiness validated components

Components / Factors	Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	Number of Items	Significance value (P value)
Culture	0.876	0.876	3	P = 0.000 < 0.05
Policies	0.835	0.834	5	P = 0.001 < 0.05
People	0.807	0.811	2	P = 0.003 < 0.05
Infrastructure	0.866	0.867	2	P = 0.001 < 0.05
Security	0.773	0.803	6	P = 0.000 < 0.05
Skills / Capability	0.852	0.852	2	P = 0.001 < 0.05
Training	0.940	0.940	4	P = 0.000 < 0.05
Need for Change	0.842	0.847	6	P = 0.000 < 0.05
Motivators	0.775	0.798	8	P = 0.033 < 0.05
Inhibitors	0.763	0.767	9	P = 0.013 < 0.05
Organisational Capability	0.830	0.831	3	P = 0.021 < 0.05
Enterprise Mobility	0.851	0.860	4	P = 0.002 < 0.05
Support	0.915	0.916	4	P = 0.001 < 0.05
Change Enablers	0.788	0.789	2	P = 0.000 < 0.05
MBI Readiness	0.707	0.722	2	P = 0.008 < 0.05

The study resulted in the development of a comprehensive model for assessing MBI readiness within South African organisations in the telecommunications industry as shown in Figure 3 below. The model will amongst others enable these organisations to make informed decisions before investing in mobile technologies by assessing their readiness for MBI.

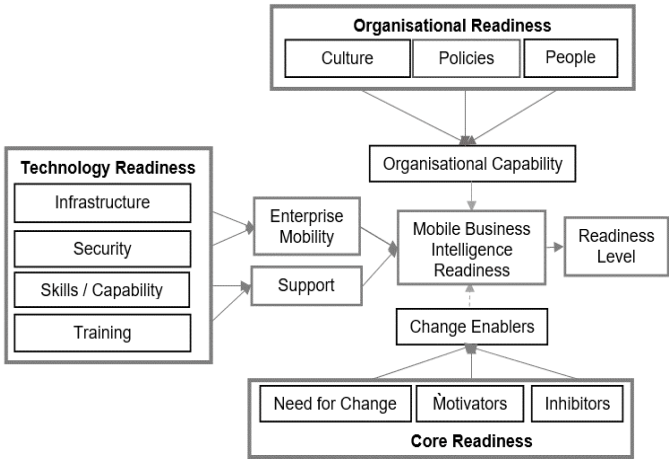

Figure 3: Model for assessing MBI Readiness

5.3. Limitations of the study and future research

The study was conducted within the context of South Africa, so the data was collected specifically from participants in South Africa, and therefore it does not entirely represent global trends. Although the focus of the study was on the telecommunications industry, some readiness factors and components might be similar across other industries, however generalisation of the results should be interpreted with caution. A comparative study across different industries could be conducted.

The study used cross-sectional survey as data were collected at a specific point in time. As the use of the internet continues to grow, technology changes constantly, natural or manmade disasters happen, rare diseases emerge (such as Covid-19), and cultural changes occur, the results of this study may be limited in forecasting future trends, and over time many of the readiness factors established may no longer be relevant. Hence, future research can focus on longitudinal studies.

5.4. Conclusion

An assessment model was developed for assessing MBI readiness in South African Telecommunications industry. The objectives of the study were achieved in developing the said model. These were to determine the state of MBI adoption within South African organisations, to establish readiness factors for BI adoption and their significance in MBI readiness assessment, determine what South African organisations consider to be enablers and barriers to MBI adoption, and establish empirical MBI readiness factors within South African organizations as well as validate the conceptualised MBI readiness model.

Although the model was developed with the focus on telecommunications industry within South African context, it can be tailored or customised to other industries. Researchers could thus use, extend or replicate the model to develop other MBI readiness models in a variety of contexts. The study made a substantial contribution to the literature relating to MBI which can serve as reference to other researchers.

Furthermore, the study provides organisations with practical advice and guidance for assessing their readiness, allowing them to develop an in-depth understanding of pivotal readiness factors, which will greatly assists them in realising anticipated benefits and making informed decisions while saving cost, time, and resources. The information provided by these critical readiness factors and their impact on practice will enable organisations to formulate better strategies and approaches for MBI readiness, resulting in a high success rate on MBI investments.

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Mr Philip Marothi Lemekwane has done his bachelor's degree from Tshwane University of Technology in 2011. He has done his master's degree from Tshwane University of Technology institution in 2014. He is currently studying towards his PhD degree in Computing from Tshwane University of Technology.

He is a dynamic ICT professional and academic, with extensive industry experience and research interest in the areas of Business Intelligence, ICT Governance, Business Systems, Data Analytics, IT Risk Management, etc.

Professor Nkqubela Ruxwana has done his bachelor's degree from Tshwane University of Technology in 2006. He has done his master's degree from Tshwane University of Technology in 2007. He has completed his PhD degree in Information Technology from the Nelson Mandela Metropolitan University in 2011. He completed his MBL from University of South Africa in 2012. He has done his SLD from University of Witwatersrand in 2014.

He is a dynamic ICT professional and academic, with extensive industry experience and research interest in the areas of cyber security, IT governance, project management, business analysis, enterprise architecture, strategic leadership, change management, business intelligence, knowledge management, ICT for development, ICT in education, and health informatics. He is a passionate academic and mentor, currently supervising and lecturing postgraduate in various Information systems domains.

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Barriers of the Green Supply Chain Management Implementation: A Benchmark of Studies of Analytic Hierarchy Process and Interpretive Structural Modeling

Hamza Fahmy *, Mohamed Mazouzi, Ayoub Alami Masmoudi, Tamasna El Mehdi

Mechanical department, Laboratoire de Mécanique, d'Ingénierie et d'Innovation (LM2I)-ENSEM, Casablanca, Morocco
Abdellah Ibrahim Street (Ex. Road d'El Jadida) .
*Corresponding author: Hamza FAHMY , fahmyhamza@gmail.com

ABSTRACT: Because firms are considering the influence of their operations on the environment, the green supply chain has become a crucial indication of corporate performance. The issues here necessitate both competent management and a fresh, innovative strategy for cost reduction, productivity enhancement, and natural resource protection. We shall try to understand the Barriers of Green Supply Chain Management concept in this report. A total of 47 obstacles were discovered after a thorough review of the literature. Priority ranking stability is investigated via a sensitivity analysis. Using existing models have mostly focused on identifying these constraints.

KEYWORDS: Green supply chain management, Barriers of green supply chain, Green Logistic, Analytic Hierarchy Process (AHP); Interpretive structural modeling (ISM)

1. Introduction

In recent years, ecological hardship and devastation have drawn attention to the negative repercussions of human activities. Green supply chain practices are gaining traction in today's manufacturing environment. Natural resource depletion, rising consumer demands for quality and quantity, tight regulations, and cost reduction are all issues we face. On the other side, environmental protection by the government and the general population is a significant problem and hardship. As a result, the GSCM, or "Green Supply Chain Management," addresses the environmental conundrum, which illustrates the absorption of environmental issues into traditional SCM, or "Supply Chain Management," on many levels. GSCM is essential for decreasing a manufacturing facility's total negative environmental impact. Green values can be included into everyday supply chain operations [1]. Nonetheless, the benefits of the GSCM in the sector, as well as the adoption of the Green ideology, will pose a slew of issues for businesses. The difficulties, referred to as problems encountered throughout GSCM's employment, are classified into five categories: subcontracting, technology, information, financial, engaging, and supporting.

The following is how this paper is made: A literature overview of GSCM obstacles is presented in Section 2. part 3: a list of all the barriers that we were able to get from the studies Section 4 discusses the study's solution method, which represents the two solutions that we will focus on: the ISM and the AHP. Finally, section 5 summarizes the study's findings and makes recommendations for further research [2].

2. Literature review and background.

Despite the benefits and relevance of the GSCM for our company and future, businesses may face challenges in implementing the Green idea. Obstacles experienced during GSCM's time on the job.

Many scholars conducted a literature review, according to which [3–5] . The hurdles to GSCM are divided into five categories:

1. Inadequate technology and facilities.
2. A lack of awareness and assistance.
3. Administration and activity policies that are not supportive.
4. Economic problems.
5. Outsourcing.

Table 1: Some existing works on green supply chain barriers analysis [2]

Authors	Nature of contribution
[6]	Lessons from the public and private sectors on the drivers and impediments to environmental supply chain management techniques.
[7]	From an Indian viewpoint, the barriers to implementing green supply chain management employing interpretative structural modeling methodologies in the car sector.
[8]	Modeling the Information Sharing Barriers with an ISM framework.
[9]	The drivers and roadblocks to implementing green supply chain management in Mozambique's industrial industry.
[10]	A Complete Interpretive Systemic Modeling Approach to Flexible Green Supply Chain Management Opportunities and Barriers
[11]	Multi-objective sustainable and green closed loop Network architecture of a fuzzy supply chain.
[12]	Definition and Challenges of Green Supply Chain Management, as well as Literature Analysis During Implementation
[1]	An instance of an emerging economy's assessment of impediments to green supply chain management application
[13]	An exploratory investigation of Chinese SMEs in terms of integrating sustainable, operationally successful supply chain techniques.

3. The list of the barriers in GSCM

Based on literature surveys and research conducted [14], 47 obstacles were discovered and categorised based on their context and similarities throughout this study. Table 2 lists the sources of source barriers.:

Table 2: List of barriers [14]

Outsourcing	1. A concern for environmental suppliers' preservation.
	2. Difficulty in calculating and recording suppliers' environmental practices.
	3. There is no environmental interaction between the supplier and the environment.
	4. Goods and rules may collide in the future.
	5. The government's lack of support for environmentally friendly initiatives.
	6. There is no suitable training or reward structure in place for vendors.
Inadequate technology and facilities.	7. Don't be frightened to fail.
	8. A lack of successful environmental policies.
	9. Humans are not supported.
	10. Difficulty in putting one's optimistic outlook on the world into action.
	11. In terms of professional experience, there is a dearth of it.
	12. Difficulty in reusing/recycling used things.
	13. Use feature complexity to reduce resource/energy consumption.
	14. There isn't enough flexibility in current practice to switch to a new method.
	15. A scarcity of new items, technologies, and procedures.
A lack of awareness and assistance.	16. A lack of awareness about the implementation of reverse logistics.
	17. Lack of belief in the benefits of climate change.
	18. Perception of a'responsibility-free zone.'
	19. Finding opportunities for the environment is difficult.
	20. A lack of eco-literacy among supply chain members.
	Inadequate environmental awareness is number twenty-one.
	22. Practitioners' lack of visibility in the green system.
	23. Difficulty in determining third-party remembrance of used products.
	24. There are no explicit environmental goals.
	25. Collecting information on future climate changes is difficult.
	26. Reluctance to convert to new systems due to fear or apprehension.
Economic problems.	27. A strong investment with a low investment-to-return ratio.
	Expenses for the collection of used things (number 28).
	29. The cost of environmentally friendly packaging.
	30. Inability to obtain bank loans to facilitate processes or purchase green items.
	31. The inventory of hazardous materials poses a risk.
	Finance's contradictions number 32.
	33. The requirement for additional human characteristics

	The high expense of hazardous waste disposal.
	35. The cost of migrating to a new system.
Administration and activity policies that are not supportive.	36. A lack of industry-specific training courses, consulting firms, and organizations to prepare, monitor, and mentor advancement.
	37. GSCM pressure and a lack of consumer awareness.
	38. A lack of corporate social responsibility.
	39. There is little interest in climate-related initiatives or meetings.
	40. Business rules that discourage product/process stewardship.
	41. Poor supplier engagement/reluctance to share information.
	42. Inadequate coordination of interdepartmental communication.
	43. A lack of enthusiasm on the part of upper management in implementing green supply chain management.
	44. A lack of understanding of the company's environmental impact.
	45. Inadequate management space.
	46. In the corporate world, there is a lot of competition and a lot of misunderstanding.
	47. A lack of support and guidance from regulatory authorities.

4. Solution methods

4.1. Interpretive structural modeling:

ISM (Interpretive Structural Modeling) is a tool for assessing the relationship between specific elements that define a problem or issue. It was first created in the 1970s. [15], [16]. ISM is interpretive since the choice of group for analysis determines if and how the variables are linked.[17] These ISM modeling phases are depicted in Figure 1.

Table 3: Top 12 barriers of green textile supply chain [13]

1 Absence of a Supplier Incentive Program (RS)
2 There is a scarcity of eco-literacy and training (ELT)
3 The Green Method and the Complexity of System Design (GPD)
4 Noncompliance with regulatory requirements (SEL)
5 A lack of commitment to the top management (TMC)
6 A scarcity of green providers (GS)
7 Regulatory agencies provide insufficient direction and assistance (SRA)
8 Significant installation and maintenance costs (IMC)
9 There are no economic benefits (EB)
10 Customer support and motivation are lacking (CSE)
11 Between supply chain participants, there is a lack of trust and environmental coordination (TEP)
12 There aren't enough climate protections in place (EEM)

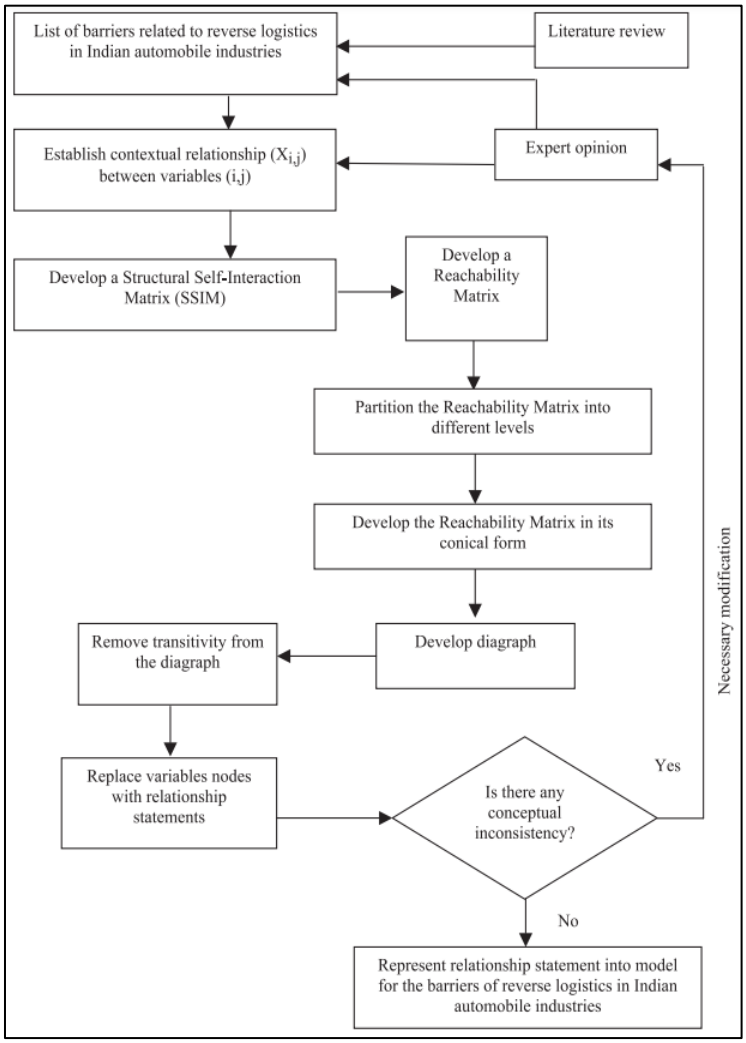

Figure 1: ISM methodology flow chart [17]

- Stage 1: Variables that impact the system: barriers (Table 2)
- Stage 2: With the most experienced supply chain managers and corporate executives, a group investigation is conducted to identify the most prominent barriers and establish a short list for the ISM study based on the hurdles highlighted in phase 1:

Example of case study of textile in South-east Asia [13]:

- Stage 3 : The formation of the structural self-interaction matrix is the first stage of the ISM (SSIM). Between either of the two obstacles I and j) and the related relationship path, contextual relationships were tested. Four symbols were

utilized to represent the orientation of the relationship between two barriers (I and j) .:

- V: Barrier I has an impact on Barrier J.
- A: Barrier J has an impact on Barrier I .
- X: I and j are barriers that impact each other.
- O: The I and j barriers have nothing to do with each other.

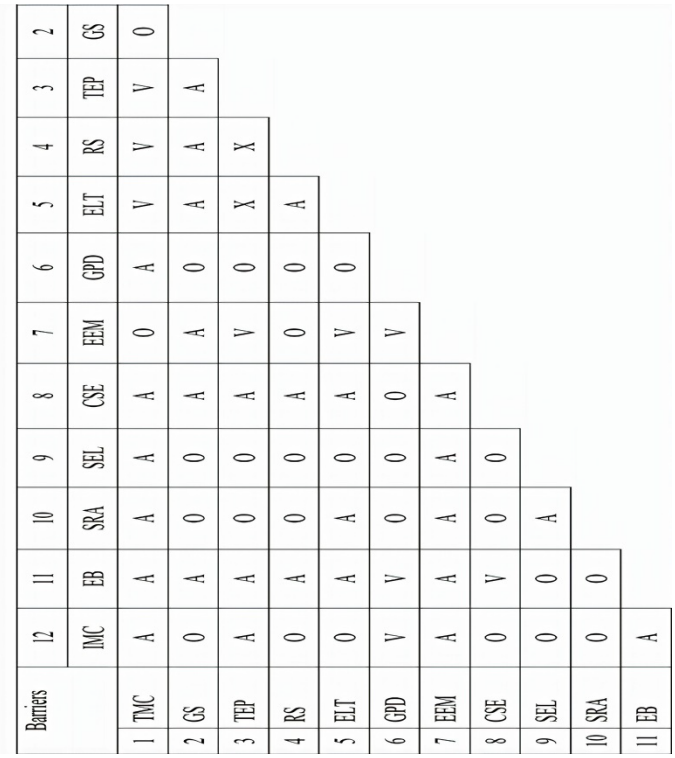

Figure 2: Green textile supply chain barriers' structural self-interaction matrix [17]

- Stage 4: The SSIM has developed an accessibility matrix that has been tested for transitivity. ISM makes a key assertion about the transitivity of contextual interactions. Variable A must be associated with variable C if variable B is connected with variable C. SSIM was transformed to a binary matrix called the Initial Reachability Matrix by replacing V, A, X, and O with 1 or 0 and implementing the following principles. o If the SSIM entry I j) is V, the entries I j) and (j, I become 1 and 0, respectively.

o If the SSIM entry (I J) is A, the entries (I J) and (J, I) become 0 and 1, respectively.

o If the SSIM entry (I J) is X, then both (I J) and (J I) become 1.

o If the SSIM entry (I J) is O, then both (I J) and (J, I become 0.

Table 4: Reachability matrix [13]

	TM	GS	TEP	RS	ELT	GPD	EEM	CSE	SEL	SRA	EB	IMP
TM	1	1	1	1	1	0	1	0	0	0	0	0
GS	0	1	0	0	0	0	0	0	0	0	0	0
TE	0	1	1	1	1	0	1	0	0	0	0	0
RS	0	1	1	1	1	0	1	0	0	0	0	0
EL	0	1	0	0	0	0	1	0	0	0	0	0
GPD	1	1	1	1	1	1	1	0	0	0	1	1
EEM	0	1	0	0	0	0	1	0	0	0	0	1
CS	1	1	1	1	1	0	1	1	0	0	1	0
SE	1	1	1	1	1	0	1	0	1	0	0	0
SR	1	1	1	1	1	0	1	0	1	1	0	0
EB	1	1	1	1	1	0	1	0	0	0	1	0
IM	1	1	1	1	1	0	1	0	0	0	1	1

- Stage 5 : The reachability matrix from Phase 4 was separated into many layers. The final reachability matrix's reachability and history collection [15] For each factor, they are obtained. The intersection of the sets was then used to extract all variables. The top-level factor in the ISM hierarchy becomes the factor for which the accessibility and intersection sets are the same. [17]:

Table 5: Level partitions [13]

	Barrier	Reachability set	Antecedent set	Intersection set	Level
1	TCM	1,2,3,4,5,7	1,6,8,9,10,11,12	1	IV
2	GS	2	1,2,3,4,5,6,7,8,9,10,11,12	2	I
3	TEP	2,3,4,5,7	1,3,4,5,6,8,9,10,11,12	3,4,5	III
4	RS	2,3,4,5,7	1,3,4,5,6,8,9,10,11,12	3,4,5	III
5	ELT	2.3.4.5.7	1.3.4.5.6.8.9.10.11.12	3.4.5	III
6	GPD	1.2.3.4.5.6.7.11.12	6	6	VII

7	EEM	2.7	1.3.4.5.6 .7.8.9.10 .11.12	7	II
8	CSE	1.2.3.4.5.7 .8.11	8	8	VI
9	SEL	1.2.3.4.5.7 .9	9.10	9	V
10	SRA	1.2.3.4.5.7 .9.10	10	10	VI
11	EB	1.2.3.4.5.7 .11	6.8.11.12	11	V
12	IMC	1.2.3.4.5.7 .11.12	6.12	12	VI

- Step 6: Table 5's level is utilized to generate a new digraph that contains transitivity ties that have been gained: A final digraph was constructed once the indirect connections were removed. The top level of the digraph was placed at the top. the second level at the second position. and so on until the bottom level was placed at the lowest position of the digraph.

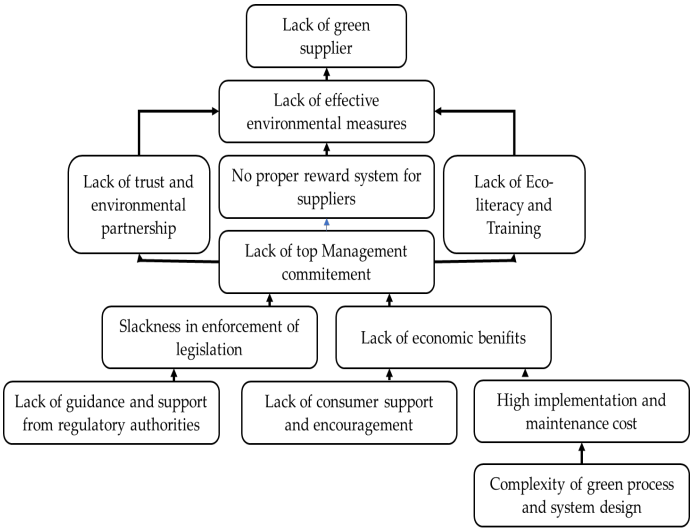

Figure 3: ISM model of barriers of green supply chain management in textile industry [13].

- Stage 7: The generated diagraph is transformed into an interpretative structural model by replacing variable nodes with sentences [17].

The driver's power-dependence matrix reveals the relative importance of each aspect as well as their interdependence. Factors of Autonomy / Dependence / Driving / Linkage

4.2. Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP). which rigorously delineates the complexity of the issue setting. is based on a set of assumptions. It is built on a well-defined mathematical structure of consistent matrices and the capacity to construct true or approximate right-hand weights. the eigenvector [18]. It's a multi-criteria decision-making (MCDM) methodology that's been successfully used to environmental challenges in recent years. This method is commonly used in the corporate world to make decisions [19].

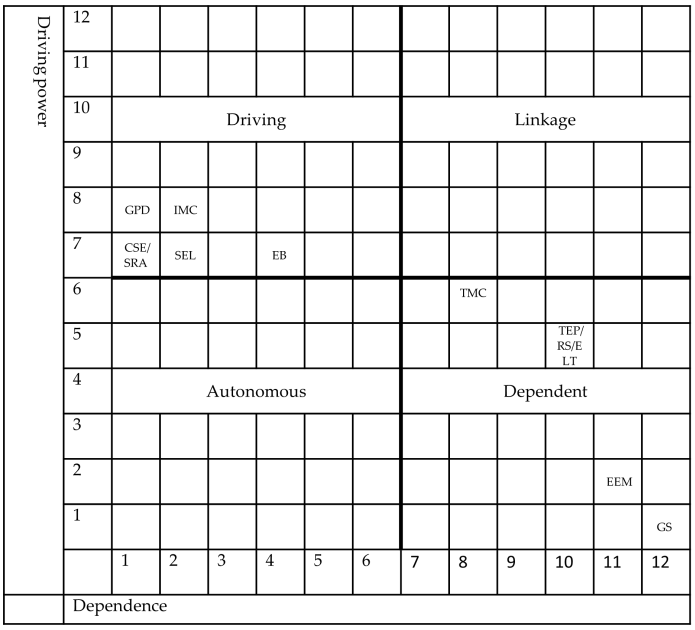

Figure 4: Driving power and dependence diagram

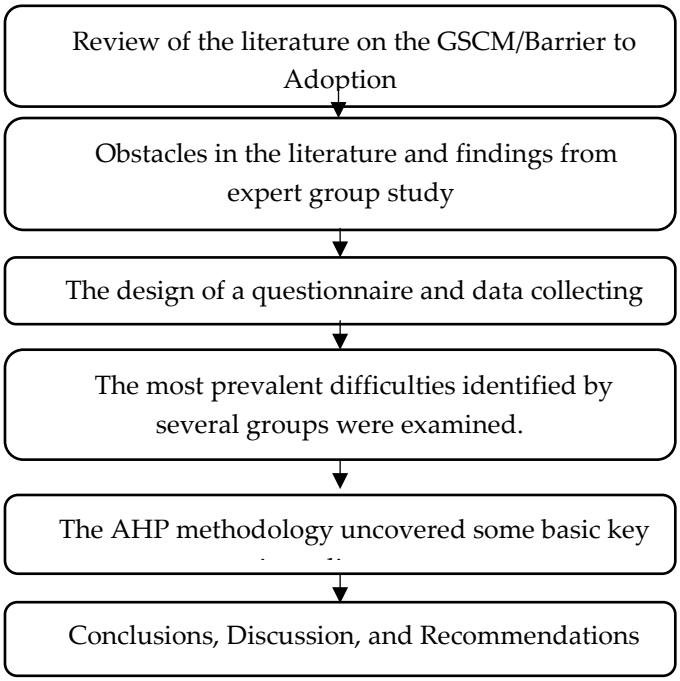

Figure 5: Flowchart of research

Three criteria have been used to AHP to assure the grading of obstacles to GSCM deployment. and the findings have been reported.

4.2.1. Identifying roadblocks and constructing a hierarchical prioritizing model. as specified in Chapter III

The common impediments are identified and escalated to a priority level of concern after the first stage.

In this level Figure 6. the four-hierarchy choice process is broken down into phases:

- Level-I: The goal/general purpose.
- Level-II: This is the level reflected in the barrier group.
- Level III: This level of the system presents unique obstacles.
- Level-IV: Priorities for critical barriers are defined at this level.

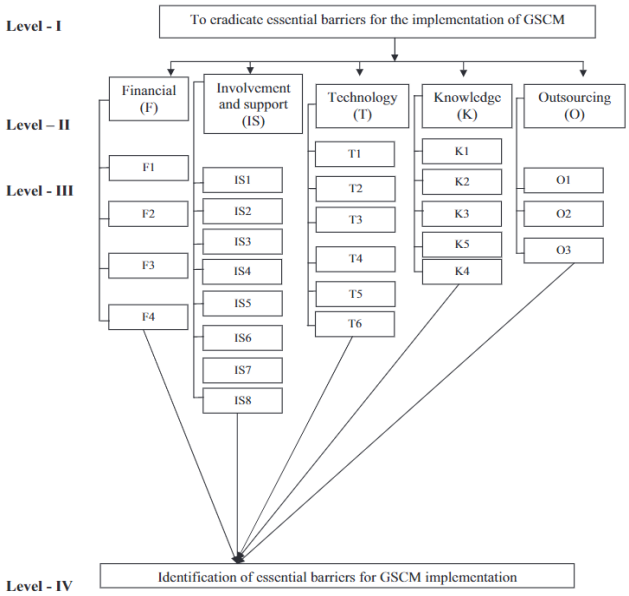

Figure 6: AHP methodology for identifying critical GSCM implementation roadblocks.

4.2.2. *Establish normalized weights for each barrier category and each individual barrier*

We'll need a numerical scale to do comparisons that demonstrates how much more significant or better one piece is than another in terms of the criteria or characteristic being compared against.

Table 6: Selection ratio among two components

Weights of choice	Definition	Explanation
1	Equally preferred	There are two procedures that lead to the same objective.
3	Moderately	Practice and judgment favor one behavior over another by a little margin.
5	Strongly	Experience and choice significantly or fundamentally favor one action over another.
7	Very strongly	A certain activity is greatly desired over another. and its superiority is demonstrated in practice.
9	Extremely	The greatest level of affirmation is the proof that favors one procedure over another.
2.4.6.8	Intermediate values	A balance between theabove-mentioned preferences is represented by this symbol.
Reciprocals	Reciprocals for inverse comparison	

4.2.3. *Pair-Wise Comparison Matrix Consistency Check* [20]

The consistency ratio may be computed using the procedures below:

- Calculate the eigenvector or relative weights for each n-dimensional matrix.
- Compute the consistency index for each matrix of order n by the formula: CI = (λmax−n) / (n−1)
- The consistency ratio is then calculated using the formula: CR=CI/RI (random Index)

Arrange the elements in a matrix and get comments from individuals who are arguing the relative relevance of the various factors in relation to the ultimate objective of home happiness [21]. Table 6 depicts the decision-making scale to be used. This scale has been proven to be effective in a variety of applications as well as theoretical comparisons with a variety of other scales.

Table 7: Pair-by-pair comparison matrix for the barrier group [14]

	O	T	K	F	IS
O	1	0,78	2,73	0,66	2,48
T	1,281	1	2,89	3,7	2,89
K	0,3663	0,346	1	1,66	1,98
F	1,5152	0,2703	0,6024	1	2,6
IS	0,4032	0,346	0,5051	0,3846	1
SUM	4,5676	2,7423	7,7275	7,4046	10,95

Table 8: Standardize matrix of barrier category

	O	T	K	F	IS	Weight
O	0,219	0,284	0,353	0,089	0,226	0,2345
T	0,280	0,365	0,374	0,500	0,264	0,3565

K	0,080	0,126	0,129	0,224	0,181	0,1482
F	0,332	0,099	0,078	0,135	0,237	0,1761
IS	0,088	0,126	0,065	0,052	0,091	0,0846

The weight is simply derived by dividing each value from Table 7 by the sum, yielding the standardised matrix,

To test if the measured value is right, multiply the value of the column of criterion value by the weight,

Table 9: Matrix of pair-wise comparisons multiplied by weight [14]

	0,2345	0,3565	0,1482	0,1761	0,0846
	O	T	K	F	IS
O	1*0,23	0,78*0,35	2,73*0,14	0,66*0,17	2,48*0,08
T	1,2*0,23	1*0,35	2,89*0,14	3,70*0,17	2,89*0,08
K	0,36*0,23	0,34*0,35	1*0,14	1,66*0,17	1,98*0,08
F	1,51*0,23	0,27*0,35	0,60*0,14	1*0,17	2,6*0,08
IS	0,40*0,23	0,34*0,35	0,50*0,14	0,38*0,17	1*0,08

Table 10 :Weighted sum value ration with Critirea value [14]

Weighted sum value	Critirea weight	Ratio
1,243	0,2345	5,3022
1,981	0,3565	5,5570
0,817	0,1482	5,5167
0,937	0,1761	5,3194
0,445	0,0846	5,2602

So λ max = 5,39114602

CI = (λmax−n) / (n−1) = 0,0977865 ➔ 0<CI<1

CR = CI/RI = 0,094732

The random index is abbreviated as RI, the random index table for up to 10 parameters was shown by the randomly produced pairwise matrix consistency index [14]:

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,49

We may assume that the matrix is sufficiently consistent since CR 0,1 and then utilize the result

Table 11 : AHP weights for barrier category [14],

Class Of Barrier	Sorted weight importance
T	0,3566
O	0,2345
F	0,1762
K	0,1482
IS	0,0846

5. Conclusion

To focus on environmental challenges, manufacturing firms have lately begun to implement the green idea in their supply chain management. However, owing to the identification of impediments, the process of applying green concepts in their supply chain management was found to be extremely challenging. The goal of this study is to identify and prioritize the hurdles to implementing Green supply chain management (GSCM) using both assess the ISM and AHP methods . From a thorough literature review and discussions with industry experts, 47 frequent hurdles were identified, and both studies were carried out using a questionnaire-based survey and work study group . this work utilizing a model used by well-known researchers in the field into foreign countries, An ISM-based model was constructed to investigate the interactions between the factors, The driver's power-dependence matrix reveals the relative importance of each aspect as well as their interdependence, The ISM-based model provides a clear picture of the relationship between the variables, [22], The recommended solution, however, The AHP method was used to assign these barriers a rank (priorities) based on industrial experts judgments, which were then converted into a Pair-wise comparison matrix for barrier category, by dividing this matrix on the sum of each colomne we get a standardization matrix for barrier category, and finally a weight wich is the medium of the sum of each line, which gave us the barriers priorities ,This method is more accurate and give a clear idea on the impact of the main barriers and then we can focus on the solution , this method is used for almost all the issues that face the industrial world,

Our perspective for the the future is the application of AHP process on the moroccan industries with various activities in order to understand what block ou moroccan companies to apply the green supply chain management in their activities .

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Hamza Fahmy has done his bachelor's degree from Sidi Lahcen Lyoussi school at Sefrou City in 2010, he has done his Engineering degree from National school of electricity and mechanics ENSEM at Casablanca in 2015,

He is a PhD student Hassan II University of Casablana,

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An Analysis of SiC Power Electronics Implementation in Green Energy Based Extremely Fast Charging

Naireeta Deb [1,*], Rajendra Singh [2]

[1] Holcombe Department of Electrical and Computer Engineering, Clemson University, Clemson, SC 29631, USA
[2] Department of Automotive Engineering, Clemson University, Clemson, SC 29631, USA
* Corresponding author: Naireeta Deb, ndeb@clemson.edu

ABSTRACT: Existing extremely fast charging (XFC) of electrical vehicles (EVs) is based on silicon power electronics and internal conversion of AC power into DC power. In this paper it has been shown that silicon carbide power electronics and the use of DC power source in the design of XFC of EVs has many distinct advantages over current XFC of EVs. Silicon carbide power electronics provide reduction of charging time, higher power conversion efficiency, size reduction of heat sink and improved battery's state of health. The use of larger size silicon carbide wafers will further reduce the cost of power electronics based on silicon carbide. Use of green energy sources (solar and wind) and lithium-ion batteries for electrical power storage can provide end to end DC power network. Such networks combined with silicon carbide based XFC of EVs can play a revolutionary role in saving green electrical and provide reduced of charging of EVs. This paper reports almost 50% reduction in power losses by using Silicon Carbide DC technology. End to end DC power networks combined with SiC based XFC of EVs can play a revolutionary role in solving climate emergency.

KEYWORDS: Silicon carbide, extremely fast charging, DC power, Single wafer manufacturing

1. Introduction

One of the most difficult problems faced by humanity is to solve climate emergency [1]. 24 % of the carbon emission globally is due to transportation as per 2018 data [2]. Among these, road vehicles contribute to 75% of transportation carbon emission [2]. Passenger vehicles contribute to 45.1% of this 75% and the rest come from heavy duty vehicles or freight vehicles [2]. According to 2019 data, 444 million metric tons of carbon dioxide was emitted by medium and heavy-duty trucks contributing to 18% of total global road freight CO_2 emission [3]. Thus providing green electric power with highest efficiency of power utilization has the potential of providing solution to greenhouse gas emission due to surface transportation [4], [5]. For almost all over the world sustainable electric power can be provided by photovoltaics (PV) and battery based network at extremely-low cost, except where solar intensity is less than about 3-4 kWh/m^2 per day [6]. In such places wind turbines can be major source of electrical power generation and PV can play the role of supplemental source of electrical power [6]. For automobiles, extremely fast chargers (XFCs) in the power range of 120-350kW are available in the market [2]. Medium/heavy duty trucks can use CharIN MCS charging standard under 1000V/1000A (1MW) today and have potential to use 1500V/3000A (4.5MW) in the future [5]. With advancements in technology and volume manufacturing of lithium ion batteries, the driving range of new battery electric vehicles (BEVs) has been steadily increasing and BEVs with over 700 miles range are in development stage [7]. However, one of the major roadblocks in the implementation of large scale electrification of surface transportation is the lack of low cost extremely fast charging (XFC) infrastructure. In a recent article [2] different aspects of current charging infrastructure has been reviewed by the authors and thus they concluded that the power electronics topologies are the cornerstone for charging stations. Creating XFCs more efficiently is the key to making the charging stations low cost and widespread [2]. In this paper improvement in XFC based on DC power and Silicon carbide power electronics has been analyzed. The previously reported literature in this area concentrates in the implementation of Silicon Carbide in EV hence enhancing the EV efficiency, but the implementation of SiC in charging technology remains rarely touched. The novelty of this paper is in the implementation of a new fully DC infrastructure powered by Silicon Carbide power electronics. In a recent review article [2] numerous publications dealing with various aspects of DC-SiC charging infrastructure has been examined by authors,

which shows the limitation of previous research in this area. No concrete research is found in the heat loss, charging time reduction or a comparative study between Si or SiC power electronics in EV charging infrastructure. Most of the previous research focuses on the topology selection or particular methodology for heat loss reduction using SiC. A complete system level overview remains untouched in literature. Thus, the objective of this paper is on evaluating a system for XFC, based on end-to-end DC power and Silicon carbide power electronics. Thus providing green electric power with highest efficiency of power utilization has the potential of providing solution to greenhouse gas emission due to surface transportation [4][5]. For almost all over the world sustainable electric power can be provided by photovoltaics (PV) and battery based network at extremely-low cost [8-11], except where solar intensity is less than about 3-4 kWh/m2 per day [6]. In such places wind turbines can be major source of electrical power generation and PV can play the role of supplemental source of electrical power [6].

The paper is organized as follows; section 2 discusses the importance of a fully DC power system for charging infrastructure. In section 3, the importance of SiC based power electronics is described. Model developed in this paper is described in section 4. Validation of the model is described in section 5. Charging time calculations are described in section 6. The heatsink size for SiC and the reduction from its Si counterpart is described in section 7. Potential cost reduction pathway for SiC power electronics manufacturing is discussed in section 8. In section 9 paper has been concluded.

2. Importance of DC Power Charging Infrastructure for XFC

Thomas Edison conceptualized the fundamentals of locally generated DC power thus saving the transmission losses. But since the inception of power transmission, globally the electricity infrastructure is dominated by AC power. The situation is different today. More than 30% of power and capital can be saved by implementing DC instead of current AC based network [12]. Solar photovoltaics generates power in DC form, so does wind energy in erratic AC form that is converted to DC before AC transmission. Batteries and fuel cells store DC power. Due to lower cost of photovoltaics and batteries, high voltage DC (HVDC) transmission is playing a key role in the use of green electric power at the scale of 10.5 GW [13].

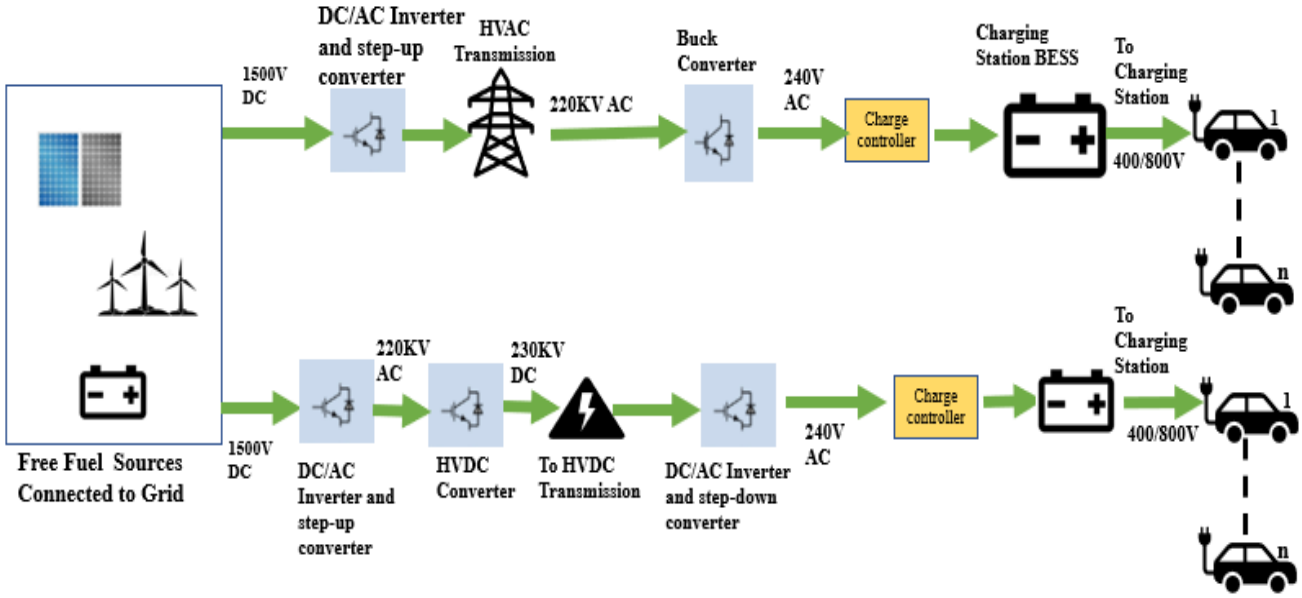

Figure 1: Clean electric power and capital being ruined in current charging infrastructure.

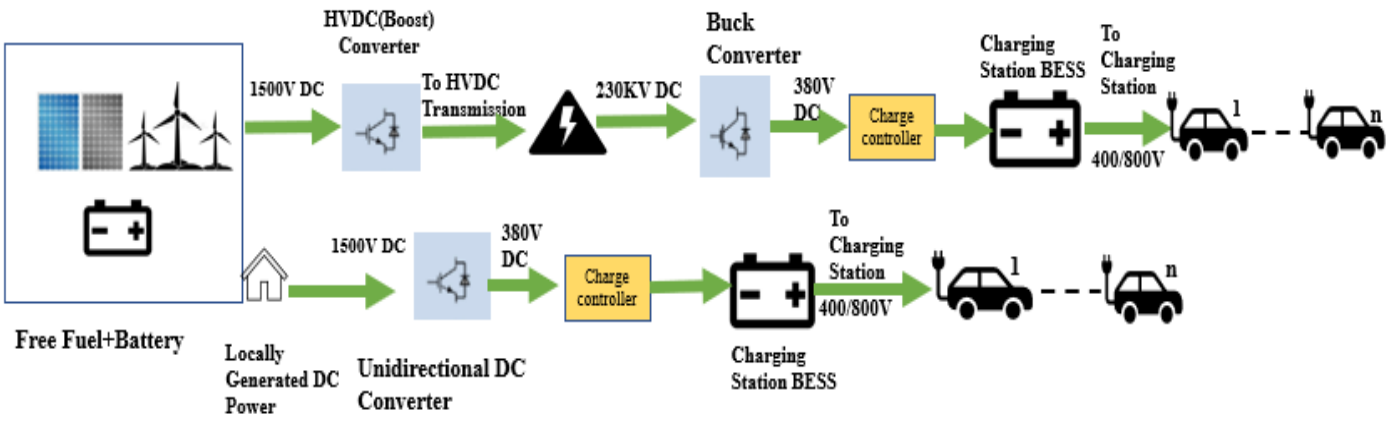

Figure 2: DC power based charging infrastructure without the necessity of transmission

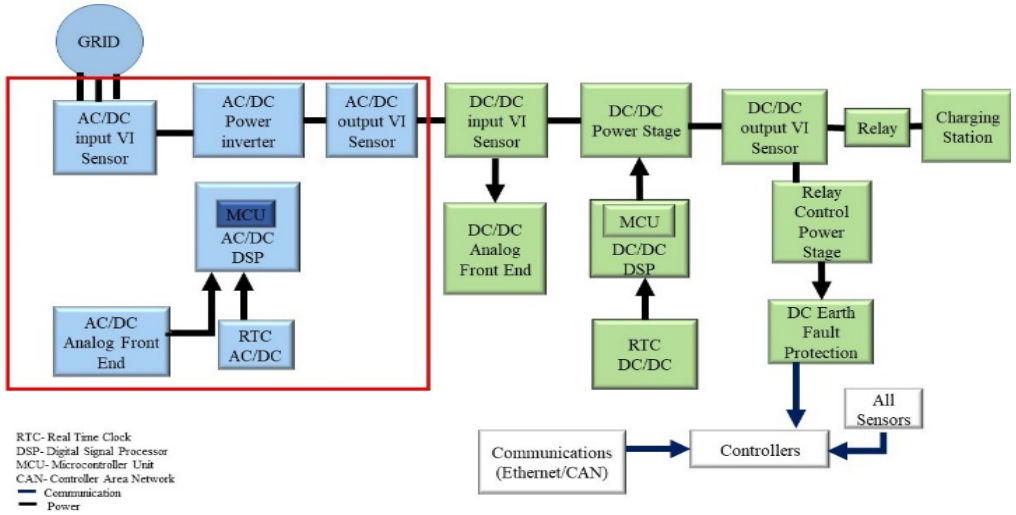

Figure 3: Capital cost savings by lessening equipment and thermal dissipation by electing DC grid [14]

As shown in Figure 1, for charging electrical vehicles, the green electrical power generated by solar and or wind and stored in batteries is wasted in several DC to AC and AC to DC conversion steps in current high voltage AC (HVAC) transmission. Even for existing HVDC transmission illustrated in Figure 1, the DC power is first converted to AC power and then converted back to DC power. These unnecessary power conversion steps can be avoided in present day power generation and storage sources. As depicted in Figure 2, the green DC power is fed to both HVDC network and locally generated LVDC network and feeding the power to charging stations. As compared to Figure 2, the losses in Figure 1 are higher as inverter losses are higher and DC/DC conversion losses are lower to be discussed in the model derived in the next sections.

As depicted in Figure 3, the components shown in blue color, convert AC power into DC power, within current DC fast chargers. Thus wastage of a significant amount of green electrical power and capital is taking place in current charging stations. As opposed to this, if the components used as marked in the blue boxes in the AC system are eliminated, a large amount of electric power and capital can be saved if the entire charging infrastructure is based on DC power.

3. Silicon Carbide Based Power Electronics for Charging Infrastructure

In the last several decades, silicon power devices have dominated the world of power electronics. A large amount of energy is dissipated during conversion steps of AC/DC/AC due to the low electro thermal conductivity of silicon devices. High breakdown voltage, high operating electric field, high operating temperature, high switching frequency and low losses are several compelling advantages of silicon carbide power devices. It is suitable to use SiC devices in high voltage applications with the output capacitance being low. Thus, the magnetizing parts like transformers, chokes and inductors etc. are also reduced in size or completely eliminated. Packaging density becomes higher as the cooling requirement reduces. The use of SiC power electronics will reduce the dissipated energy, and the device life expectancy will increase due to less thermal exposure. As compared to silicon power electronics cost will be saved in two ways. SiC based power electronics will reduce the losses incurred in EV charging and also reduce the footprint of XFCs. As the cooling need decreases and power density increases, it will also significantly reduce the charging time [15]. By increasing packaging density the voltage capacity of EV can be doubled [16], hence similar technology can also be implemented in charging infrastructure. It also drastically reduces the size of the on board charger as reported in reference [17]. The fundamental limits of silicon power electronics can be overcome by the utilization of silicon carbide ICs in place of silicon ICs. Silicon carbide modules are providing higher power density of motor drive of electric vehicles [18]. Thus by enhancing the performance and cost reduction of power train of EVs and XFC, silicon carbide power electronics has the promise of accelerating growth of electrification of transportation.

4. Model

In this section the analytical model for power loss calculation has been developed. The calculated values of power loss of Si and SiC devices are compared with the best experimental data available in the literature.

4.1. Methodical Loss Calculation at Device Level

To calculate the power losses, Si and SiC devices with similar voltage level has been. The Si device is Digi chip N channel MOSFET 2SK2044 [19]. The SiC devices are Infineon F4-11MR12W2M1_B76 [20] and UnitedSiC UF3C170400K3S [21]. Two different SiC MOSFETs are used to show the potential of upcoming technology and will be referred to as SiC 1 and SiC 2 respectively. Infineon F4-11MR12W2M1_B76 is currently being used in high voltage PV and charging applications [14], whereas UnitedSiC is currently being used for Power Factor Correction (PFC) devices and have a potential for charging station applications as well. The parameters from datasheets are given in the Table 1.

Table 1: Parameters Used for Calculation

Symbol	Attribute	Si Digichip N channel MOSFET 2SK2044 [19]	SiC Infineon F4-11MR12W2M1_B76[20]	SiC UnitedSiC UF3C170400K3S[21]
I_{DON}	On Time Current	4A	100A	14A
R_{DSON}	On Time Resistance	2.4Ω	14/18mΩ	410mΩ
t_r	Rise Time	15nS	20nS	13nS
t_f	Fall Time	40nS	28nS	27nS
V_{DD}	Working Voltage	600V	1200V	1700V
D	Duty Cycle	50%	50%	50%
f_{sw}	Switching Frequency	1MHz	1MHz	100KHz
t_{off}	Off Time	160nS	67nS	34nS

MOSFET Power loss equations are taken from reference [22] and the values are calculated based on Vendor's data sheet and application notes

Power loss during conduction or conduction loss is

$$P_{COND} = I_{D(ON)}^2 * R_{DS(ON)} * D \quad (1)$$

Where,
P_{COND}= Conduction loss
$I_{D(ON)}$= On state current
$R_{DS(ON)}$ =On state Resistance
D= Duty Cycle

The switching losses are the sum of two separate losses viz ON time loss and OFF time losses given below.
Energy loss during ON time,

$$E_{ON} = I_{D(ON)} V_{DD} \frac{t_{ri}+t_f}{2} \quad (2)$$

Where,
E_{ON}=Energy Loss during ON time
$I_{D(ON)}$= On state current
V_{DD}= Drain Voltage
t_{ri}=Rise time
t_f=Fall time
Therefore, the ON time power loss is given by:

$$P_{ON} = E_{ON} * f_{sw} \quad (3)$$

Where,
P_{ON}=ON time power loss
E_{ON}= ON time energy loss
f_{sw}= Switching Frequency
Energy loss during OFF time,

$$E_{OFF} = \frac{I_{D(ON)} V_{DD} t_{off}}{2} \quad (4)$$

Where,
E_{OFF}= Energy Loss during OFF time
$I_{D(ON)}$= On state current
V_{DD}= Drain Voltage
t_{off}=off time
Therefore, the OFF-time power loss is given by,

$$P_{OFF} = E_{OFF} * f_{sw} \quad (5)$$

Where,
P_{OFF}=OFF time power loss
E_{OFF}= Energy Loss during OFF time
f_{sw}= Switching Frequency

Therefore total power loss,

$$P_{loss} = P_{COND} + P_{ON} + P_{OFF} \quad (6)$$

Using these equations in the values of Table 1 and using the methods for loss calculation from [23], 11.5% device level losses for Si-MOSFET and 5.81% for SiC-MOSFET 1 and 5.67% for SiC MOSFET 2 is obtained. Silicon power electronics is a matured technology, and silicon carbide power electronics is evolving technology. Thus in future even lower losses in SiC transistors can be expected.

4.2. Analytical Loss Calculation of Inverter:

The overall performance of the AC power system is defined by various losses. Different modulation techniques are used in three level inverters to modulate the switches. Based on our review article [2], Neutral Point Clamped 3-Level Inverter (NPC-TLI) is the most efficient topology for renewable applications [2]. However here a notional system based on an analytical model has been created. As explained previously, the loss calculation in real world is dependent on factors solely varying system to system. This specific system which is a clear representation of a DC-SiC based charging system is calculated and calibrated according to the equations mentioned below.

The selection of modulation technique is important to achieve marginal losses in the output current and voltage waveform and decreased harmonic distortion. Several modulation techniques rule the power electronics research arena, however two predominant ones in industry are sine pulse width modulation or SPWM and Space vector pulse width modulation or SVPWM. To solve the positive half cycle of the output voltage in SPWM technique, the voltage drop across Si-MOSFET over a conduction period can be expressed [22] as follows.

$$P_{Cond(MOSFET)} = 1/2\pi \cdot 1/T_s \int_0^{\pi} V_D \; i_D t_{MOSFET} \; (dwt) \quad (7)$$

Where,
$P_{COND(MOSFET)}$=Conduction Loss
V_D= Voltage drop over condution period
t_{MOSFET} = ON time for the MOSFET,
i_D=Current over conduction period
T_s =switching time of the device given by $1/f_s$ [23].

The MOSFET switching losses during ON and OFF time can be given by,

$$P_{sw} = \frac{f_{sw}}{2\pi} \int_0^{\pi} (V_{DSON} I_{DSON} + V_{DSOFF} I_{DSOFF}) dt \quad (8)$$

Where,
P_{sw}= MOSFET switching loss during T(ON+OFF)
f_{sw}= Switching Frequency
V_{DSON}=MOSFET ON time voltage
I_{DSON}=MOSFET ON time current
V_{DSOFF}=MOSFET OFF time voltage
I_{DSOFF}=MOSFET OFF time current

The diode loss for this topology is:

$$P_{C(DIODE)} = V_F I_0 + \frac{R_F I_0^2}{1-D} \quad (9)$$

Where,
$P_{C(DIODE)}$= Diode Conduction Loss
V_F= Diode Forward Voltage
I_0==Ideal diode Current
R_F=Diode Forward Resistance

A three phase NPC inverter contains three legs known as phase a, phase b, phase c. From reference [2], if the topology each leg is studied, it can be observed that contains 4 MOSFETs and two clamping diodes. The same amount of losses are considered in each of the semiconductor devices situated in the same half of the inverter. Similarly in each leg it can be assumed that the MOSFETs to have same amount of losses and the diodes to have same amount of losses.
Thus, the conduction loss of Si NPC-TLI inverter in SPWM modulation is obtained as follow:

$$P_{COND} = 3[2P_{C(MOSFET)UP} + 2P_{C(MOSFET)DOWN} + P_{C(DIODE)UP} + P_{C(DIODE)DOWN}] \quad (10)$$

For switching loss the equation can be given by,

$$P_{SW} = 3[2P_{(MOSFET)UP} + 2P_{(MOSFET)DOWN}] \quad (11)$$

Where,
$P_{(MOSFET)UP}$=Power Loss in Upper MOSFETs of leg
$P_{(MOSFET)DOWN}$=Power Loss in Lower MOSFETs of leg

The power loss in the charging capacitor can be given by,

$$P_C = R_{ESRC} \left(\frac{\Delta I_{DC}}{\sqrt{3}}\right)^2 \quad (12)$$

Where,
P_C= Power loss in capacitor
R_{ESRC}= Equivalent series resistance for the capacitor.
I_{DC}= Capacitor Current

The values from Table 1 and equations 1-6 can be substituted in equation 7-9.
The total loss is given by,

$$P_{TOTAL} = P_{COND} + P_{SW} + 2P_C \quad (13)$$

A 10.64% inverter loss was calculated, putting the values of Table 1 in equations 7-13 and the method mentioned in [23].

4.3. Analytical Loss Calculation of a Rectifier:

To supply DC power to the EV chargers, a three-phase full wave diode bridge rectifier can be employed. Three phase PWM rectifiers are preferred for grid connected applications. But for applications like this, a diode rectifier will be a cheaper and robust option where the source is supplying a fixed amount of load. The average output voltage is given by [22].

$$V_L = \frac{6}{2\pi} \int_{\pi/3}^{\pi/2} V_{mL} \sin(\omega t + 30) \, d\omega t \quad (14)$$

Where,
V_L= Load voltage
V_{mL}= Maximum load voltage

The average load voltage was calculated to be 95.4% of source voltage for SiC 1 and 96.1% for SiC 2, thus giving a 4.6% and 3.9% loss respectively in similar way as inverter [23].

4.4. Analytical Loss Calculation of DC-DC Converter:

For the case of Figure 2, a unidirectional DC-DC converter is used for converting the PV/Wind generated erratic power to amplified smooth DC power. Different approaches of converting that DC- to charging station can be taken the simplest one being, installing a unidirectional DC to DC converter that feeds power directly to the charging station as shown in Figure 2. Unidirectional converters are simple in design thus reducing system cost and power losses. Unlike dual active bridge converter as shown in Figure 1 for the AC counterpart, it does not need a transformer, making it lighter in design as well. For a national and international scenario such as this one it is scalable and perfect. The piecemeal loss calculation [22] is given below:
The Power loss in the inductor [23] is given by,

$$P_L = \frac{1}{T_S} \int_0^{T_S} R_{ESRL} (i_L^2(t)) \, dt \quad (15)$$

Where, R_{ESRL}=Equivalent series resistance for the inductor.
I_L= Load current
T_s =switching time of the device given by $1/f_s$

The Power loss in the capacitor is given by

$$P_C = R_{ESRC} \left(\frac{\Delta I_L}{2\sqrt{3}}\right)^2 \quad (16)$$

Where, R_{ESRC}=Equivalent series resistance for the inductor.
The loss occurred in diode

$$P_D = I_o V_D (1 - D) \quad (17)$$

Conduction loss in MOSFET is given by equation (1) and switching loss is given by,

$$P_{SW} = I_{DON}^2 \cdot R_{DSON} \cdot D + I_o V_D (1 - D) + R_{ESRL} I_0^2 + R_{ESRC} \frac{\Delta I_0^2}{12} \quad (18)$$

(Variables are of the same interpretation as previous equations.)

Duty cycle is directly proportional to power dissipation and 50% was decided to be optimum for this application. Reference [24] sheds more insight on this issue. For Silicon device the loss at 50% duty cycle was found to be 160W in terms of total losses. For SiC it was 10W per device. It is consistent with the loss data reported in section 7. Taking into consideration the duty cycle of 50%, input of 1200V for SiC 1 and 1700V for SiC 2 and load resistance of 17 mΩ and 410 mΩ respectively, the losses calculate to be 8.3% and 7.81% respectively. Here a fixed duty cycle has been chosen for comparison, as shown in Table 1. Power loss with varying duty cycle for SiC and Si power electronics is shown in Figure 4.

5. Model Validation:

Charging time data calculated by the model developed in this paper are compared with the experimental data reported in the literature for Si [24] and for SiC [25] based XFCs. As shown in Table 2, excellent agreement is observed between our calculated values and the experimental values.

6. Charging Time Calculations of SiC Power Electronics Based XFC:

Today XFC is recommended only a limited number of times to protect battery health. On the other hand fast charging is required for long-distance travel automobiles and is the only solution to electrify transportation of long-distance heavy-duty vehicles. In this section the charging time reduction, improved battery health and power system loss reduction with the implementation of SiC power electronics will be discussed. Higher efficiency of the power electronics provides lesser stress on battery and powertrain [25].

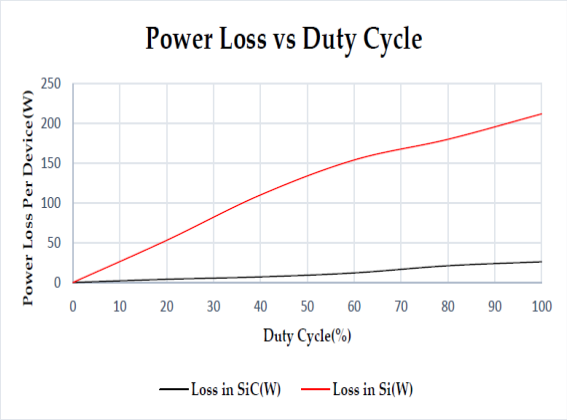

Figure 4: Power loss per device vs duty cycle for Si and SiC devices.

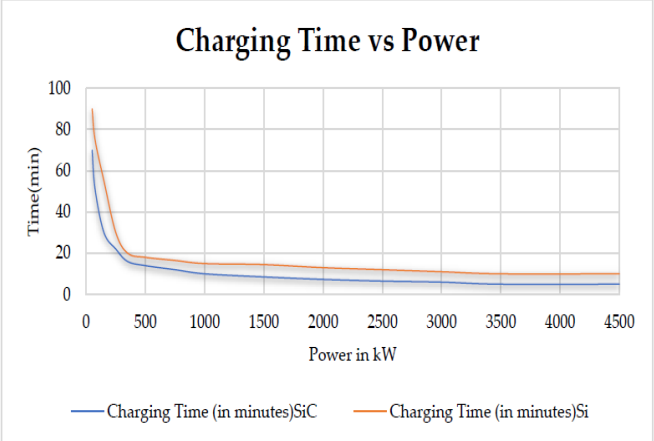

Figure 5: Reduction of charging time with increasing charging power (kW) for Si and SiC Power Electronics based XFC.

Table 2: Charging Time Reduction Comparison with Literature

Vehicle	Pack Voltage (V) & Approximate Energy kWh	Range (mi)	Max Charging Power kW	Si XFC from Ref[24] (mins)	Our Si XFC model(mins)	SiC XFC from ref [25] (mins)	Our SiC XFC Model
Tesla Model 3 long range	400 & 78.3	350	250	28	23		20
Porche Taycan Turbo S	800 & 93.4	200	270	22.5	18		18.7
Xpeng EV	800 & 250	125	480	-		5	4.5
ABB terra HP	400 & 150	200	350	20 min	17.5		15

To reduce charging time, battery pack voltage is increased to obtain maximum charging power and comes with additional complexity of a larger BMS. To accommodate the higher voltage, the number of cells connected in series must be increased. As an example, twice the number of cells must be connected in series for an 800V SiC based XFC as compared to the 400V Si based XFC. Additional circuitry like current sensors, controllers and temperature sensors etc. remain practically unchanged. The charging time also depends on the ambient temperature and circuit's heat dissipation capacity [26]. Figure 5 shows the results of charging time as a function of power with Si and SiC based power electronics as the variable. An ambient temperature of 25°C was assumed. As observed from Figure 5, a steep decline in time is noticed up to 1MW, thereafter the heat loss increases and charging time get affected by the losses, and hence the time reduces less drastically than observed at the lower wattage.

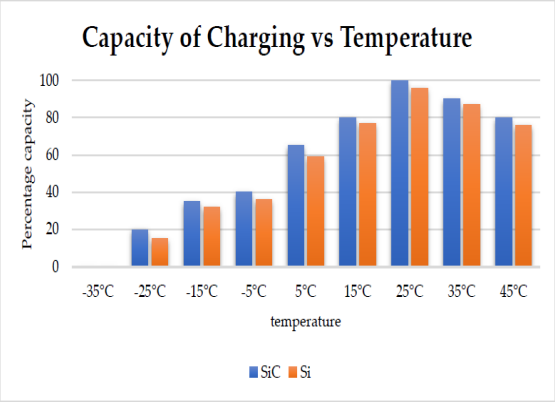

Figure 6: Capacity of charging as a function of temperature for Si and SiC based XFCs.

Figure 6 shows the capacity of charging at different ambient temperature for Si and SiC based XFCs. A standard high power battery pack of 1.2 MW was considered. As observed, the capacity of charging is very low at lower temperatures and is maximum at 25°C. At all temperatures, the capacity of charging is higher for SiC XFC.

Connecting a greater number of cells to operate at a higher power level comes with the drawback of deteriorated state of health (SOH) of batteries. The improvement of battery health while using SiC based fast charging is achieved by lesser heat exposure and better temperature control. The losses in Li-ion battery can be classified into two major types viz cycle life loss and calendar life loss. Overcharging the battery contributes the loss of cycle life. As an example if a 1.2 MWh battery is supposed to have 2000 cycles as per datasheet and if the charge is controlled to 1.1 MWh, then it is possible for the battery to last 2500+ cycles [27]. Calendar life loss is defined by the loss of health in battery after storing energy for typically 6-10 months [27]. A semi empirical formula for total loss [28] is given below.

$$Q^{\,total\ loss}\left(\delta t\right) = B_1 e^{\,B2Irate}\, I_{rate}\delta t + 0.5 f e^{-Ea/RTb}\, t^{-1/2}\, \delta t \quad (19)$$

Here B_1 and B_2 are the polynomials of the temperatures of the battery Tb. I_{rate} is the rate of current for charging the battery and R is temperature coefficient. Therefore the model is highly temperature dependent. When the total loss is calculated over a period using different scenarios of DC power based XFC, the increase in battery health is observed. An energy dense battery of 1.2MWh is used in calculations in this paper. Table 3 shows the state of health (SoH) data for both Si and SiC based XFC.

Ambient temperature has a direct impact on the performance and reliability of lithium-ion batteries (LIBs). Battery capacity and cycle life are affected by operating temperature. Ideal operating temperature for Li-ion batteries is 15-35°C [26]. In general the useful life of LIBs can range between 3,000 to 5,000 cycles [29]. However, with optimal charging, the useful life can be up to 7,000 cycles [29]. Operating at higher temperatures will reduce cycle life due to cell degradation [30]. Continuous operation at higher than 35°C (95°F) will typically reduce battery cycle life by 50% [31].

Table 3: SOH with Age in Time Varying DC XFC Usage for Si and SiC Power Electronics Enabled Battery Energy Storage System

State of Health (SoH) (%) with Time Varying DCFC Use						Battery Age (Months)
Never		0-3/Month		>3/Month		
Si	SiC	Si	SiC	Si	SiC	
1	1	0.95	1	0.92	0.956	3
0.95	0.97	0.89	0.94	0.85	0.91	6
0.92	0.95	0.85	0.915	0.82	0.89	12
0.88	0.91	0.82	0.89	0.79	0.865	24
0.85	0.88	0.79	0.87	0.765	0.85	36
0.83	0.86	0.76	0.855	0.73	0.845	48

Figure 7 shows the energy efficiency as a function of power level both for Si and SiC based XFC. It is clearly evident from Figure 7 that at a higher power level, the fluctuations in energy efficiency are far lower in case of SiC than the corresponding values for Si. The efficiency almost decreases 20% at higher power levels for Si but remains in the range of 5% for SiC counterpart. This will not only reduce the loss in generated power but in addition will help battery health, powertrain health and the associated control equipment to operate at a stable operating condition.

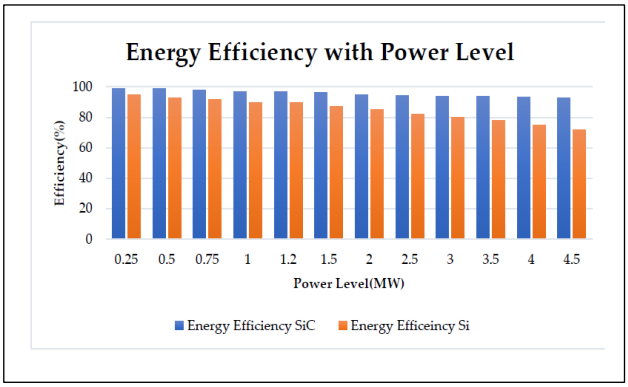

Figure 7: Energy efficiency in Megawatt level charging

7. Heat Sink Size Reduction

As shown in Figure 1, currently AC electricity infrastructure is used to provide charging of EVs which is based on silicon power electronics. To calculate the size of heat sink, first the system losses are calculated. The analytical model described in section 4 is used to calculate the losses of two SiC modules. The subsequent losses and the comparison with silicon counterparts [32] is given in Table 4.

Table 4: Charging Time Reduction Comparison Using SiC Counterparts

Conversion Level	% Loss reported in Silicon Devices [28]	%Loss derived for SiC1	%Loss derived by SiC2
Inverter	15	10.64	10.64
Rectifier	6.1	4.6	3.91
Chopper	9.2	8.3	7.81

After calculating the percentage losses of inverter, the heat sink has to be designed based on the available system parameters. But the more universal approach is to calculate the heat sink per module as explained below.

There is one heat sink solely responsible for inverter bank and another one responsible for the rectifier bank. For SiC XFC based on DC power as input, only one heat sink is necessary for DC-DC converter bank. For this paper three devices were used. Upcoming SiC technology of reference [21] was considered although the switching frequency was lower, but the potential for improvement was observed as a charging time reduction was calculated. To show the advantages of SiC system, a quantitative power loss analysis is performed based on the parameters of Table. 1. In the calculations, the switching loss of diode is neglected, because it is much smaller compared to the switching loss of IGBT or MOSFET. The sinusoidal pulse width modulation (SPWM) is employed in the control of inverter. Although different devices are used in the two systems, the calculation methods are identical. This method is applicable for any system size. The AC-DC and the DC-AC conversion stage can be designed in two ways. A solo inverter with high power rating equipment or an inverter bank with multiple inverters is connected. The later approach has been used for high power applications for reasons such as scalability of the system, ease of construction and carrying load, safety concerns and load sharing, and in case of fault in one inverter the rest of the bank can carry on the load.

Table 5: Heat Losses at Different Stages

	Inverter Losses for Si-MOSFET
Conduction loss (per device)	MOSFET 70 W
	Diode 10 W
Switching loss (per device)	80 W
Total loss (6 MOSFETs+6Diodes)	960 W
Efficiency	89.36%
Total Losses	960W
Output Power	9.02kW
	Rectifier Losses
Diode Conduction Loss	10W
Total Loss	60W
Efficiency of Bridge Rectifier	95.4%
Output Power	8.96kW

Therefore, in this section the heatsink design for each of the segments of inverter and rectifier banks will be calculated and compared to similar DC-SiC bank. A scaled down version is used here for practical dimension purposes as available in industrial datasheets. The system mentioned in this paper is massive, and no vendor has yet provided a datasheet for such design of a heat sink. Undoubtedly, if the system is stressed and made larger for XFC charging of high-power vehicles, the banks can be added together to operate smoothly. So a heatsink capable of removing 1,020W of heat must be selected. Reference [32] uses an identical system for 1800W heat loss. Selected heatsink was based on similar criteria.

Table 6: Heat Sink Calculation for Inverters

Table 6: Inverter Heat sink	Inverter heat sink
Power Loss (Per Device)	160W
Efficiency	89.36%
Package size (Calculated from datasheet)	170mm^2
Heat Sink Size	Width(WD)= 300 mm, Depth (D)= 100 mm, Height (H)= 40 mm
Heat Sink Weight	3.6Kg
Thermal Resistance $R_{heatsink}$	0.021°C/W

A smaller heatsink is required for rectifier as follows:

Table 7: Rectifier Heat Sink Parameters

	Rectifier heat sink with SiC 1	Rectifier heat sink with SiC 2
Power Loss (Per Device)	10W	12.1W
Efficiency	95.4%	94.5%
Heat Sink Size	WD=50mm,D=20mm, H=15 mm	WD=55mm,D=22mm, H=15 mm
Heat Sink Weight	0.6Kg	0.73Kg
Thermal Resistance $R_{heatsink}$	0.021°C/W	0.0196°C/W

For DC-DC converter one SiC MOSFET and one diode is used in the system constituting 8.3% of losses. So for a similar sized bank the losses will be half of the total rectifier and inverter bank. Hence the heatsink size will be half as well. But SiC has better power handling capability and the number of devices used in the circuit is lesser. The voltage level shown in Figure1 and 2 are 1500VDC- 220KV for inverter and 1500V to 380V for unidirectional rectifier / DC-DC converter. In both cases the number of devices is same. Using these numbers, SiC-MOSFET DC-DC converter heatsink is 28.6 % that of the inverter plus rectifier bank. But there are additional negligible losses. So a 30% round up number was estimated. An exact precise number in this scenario did not seem reasonable as every system will have different components. Using the new upcoming technology of SiC 2, slight increase in heat was observed due to higher $R_{DS\,(ON)}$, yet it was 44% of the size of the inverter plus rectifier bank in a Si counterpart.

After reducing the dissipated heat at component level, heat pump can be used to further reduce the size of the heat sink. In case of Tesla model Y [33], a heat pump is used to collect the dissipated heat from battery energy storage (BESS) and converter bank to heat or cool the car. For heating below -10 0C this method is highly effective [34]. The system efficiency is improved by a liquid cooled condenser where the BESS and converters reject heat and it's moved around in passenger cabin, battery, and the drive unit and sometimes outside ambient temperature to improve system efficiency [35]. The sizing of heat pump was a critical aspect [36] to determine the overall cooling system size reduction. Almost 7-30% heat is recycled using this technology depending on the outside ambient temperature [33].

A similar technology for XFC heat reduction is proposed in this paper. The residue heat from the converters may be compressed and used to heat or cool the adjacent control rooms or used for other purposes. Calculating the correct size of heat pump is imperative to ensure the heating technology is not dissipating too much heat while propagating through the pump. Several factors like the kilojoules needed for the space, the direct sunlight exposure of the recipients, the energy rating of the heat pump etc. are important factors to be considered while calculating the heat pump size [36]. By accurately calibrating the dimensions, Tesla was able to make their heat pump 300% more efficient than their resistive heating system [37]. Since the system size for a charging station is larger than that of a vehicle, the dissipated heat during propagation should be higher. The recalibrated heat sink values for different level of converters using both SiC and heat pump are given in Table 8.

Table 8: Heat Sink Dimensions Calibrated for Each Converter Bank after Installing Heat Pump and Implementing SiC Technology

Converter Bank	Heat Sink Size
Rectifier Bank	WD=20 mm, D= 10 mm, H= 5 mm
Inverter Bank	WD= 70mm, D= 50mm, H=10mm
DC-DC Converter Bank	WD= 30mm, D= 20mm, H=10mm

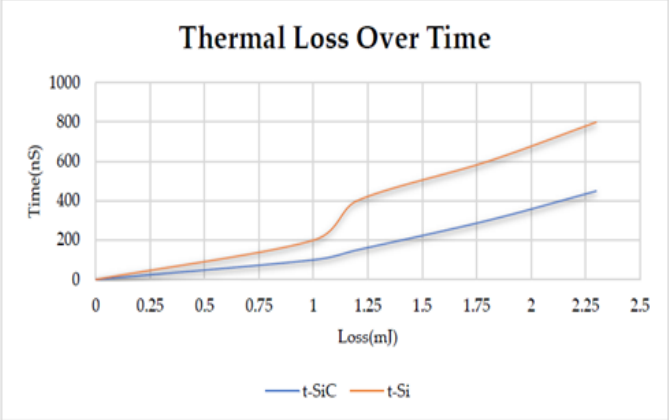

Figure 8: Thermal loss with time representing the volume reduction of heat sink by replacing Si with SiC

Assuming constant current, the thermal loss over operating time was calculated with the given $R_{DS(ON)}$ and

the standard circuit heating formula H= I²Rt. These results are shown in Figure 8 both for Si and SiC based XFC.

8. Manufacturing Cost Reduction of Silicon Carbide Power Electronics

The cost of SiC based power electronics can be significantly reduced in very near future, it is pretty evident [38]. Attributable to the high growth of EVs, Silicon carbide modules are providing higher power density of motor drive of electric vehicles [39]. No supply-chain issues in the manufacturing of its related power electronics are predicted due to the abundance of elements of SiC. Higher performance, higher reliability, higher yield, and lower cost of ownership of SiC based power electronics will be provided if policies in favor of electrification of transportation, volume manufacturing, single wafer processing [40] and large diameter wafer manufacturing are implemented [41]. Silicon carbide fabs are migrating from 150 mm wafers to 200 mm wafers [42]. With progress in technology, the feature size of transistors and defect density will also be reduced. Akin to Si, the cost of SiC power electronics with the use of 300 mm SiC wafers will further reduce. Reminiscent of the growth of Si based nanoelectronics and power electronics, the growth of SiC based power electronics is expected to evolve in a similar fashion. Recently, the author of Reference [43] has analyzed the current and projected cost of silicon carbide die.

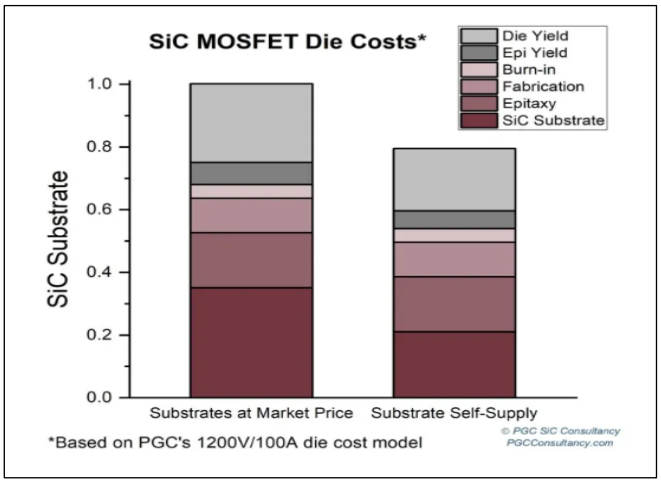

Figure 9: Cost breakdown of a SiC MOSFET die. Data on the left side shows that SiC die manufacturer purchased SiC wafer from the market. On the other the hand, data on the right side shows in-house manufacturing of SiC wafer as well as die [43].

As shown in Figure 9 [43], companies having in-house manufacturing of SiC wafers have the advantage of lower cost of SiC die. Based on industrial trends, the author of reference [43] has also projected the substrate cost, defect density, die size and die cost reduction from current values to year 2030. Due to current geo-political event, we expect that the electrification of transportation will accelerate and the graphs shown in Figure 10, may even reduce faster than projected in reference [43]. converters and high voltage DC to medium voltage DC converters that can provide 100 % DC power for EV charging infrastructure [44]. Other markets such as power networks, high frequency, and ultra-high-power electronics for harsh environments etc. will also progress with the success of SiC power electronics. The lower cost of SiC based XFCs will contribute to the growth in other markets as well.

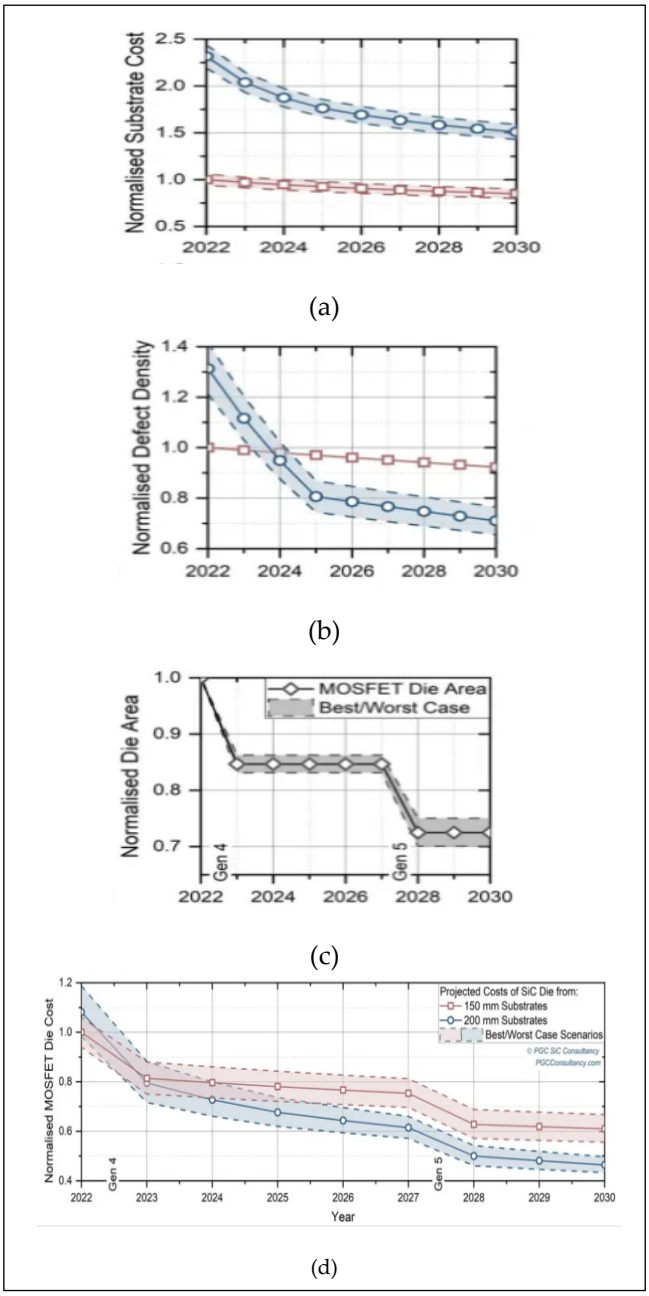

Figure 10: Current and projected trends to year 2030 in the reduction of (a) cost of SiC wafer, (b) defect density, (c) die size and (d) die cost [43].

9. Conclusions:

In this paper the design and analysis of XFC based on silicon carbide power electronics has been provided. As compared to Silicon power electronics based XFC, reduction of charging time, higher power conversion efficiency, reduced size of heat sink, and improved battery state of health are obtained in case of SiC power electronics XFCs. For heavy duty trucks SiC based XFC may be the only practical solution. The use of larger

diameter silicon carbide wafers will further reduce the cost of SiC based power electronics. Using free fuel energy sources namely solar and wind and the use of lithium ion batteries for electrical power storage, it is possible to implement end-to-end DC system for power generation, power storage, power transmission and power distribution. Combining such DC power network and SiC based DC power XFC will provide revolutionary solution for electrification of transportation.

The use of silicon carbide-based power electronics will also be enabler of medium voltage DC to high voltage DC

Nomenclature

AC- Alternating Current

BMS- Battery Management System

BESS- Battery Energy Storage System

CHAdeMO- Charge de move

CharIn- Charging for Megawatt systems

CPS- Cyber Physical System

DAB- Dual Active Bridge

DC- Direct Current

ECU- Electronic Control Unit

EOT- Electrification of Transportation

ESU- Energy Storage Unit

EV: Electric Vehicle

EVCS- Electric Vehicle Charging Station

HVAC- High Voltage Alternating Current

HVDC- High Voltage Direct Current

ICEV- Internal combustion Engine Vehicle

IGBT- Insulated Gate Bipolar Transistor

kW- Kilowatt

LIB- Lithium-Ion Battery

MCS-Megawatt Charging System

MOSFET- Metal oxide semiconductor field effect transistor

MVAC- Medium Voltage Alternating current

MW- Megawatt

NPC-TLI- Neutral Point Clamped 3-Level Inverter

PFC-Power Factor Correction

PV- Photovoltaic

PWM- Pulse Width Modulation

RES- Renewable Energy System

SiC- Silicon Carbide

SoC- state of charge

SoH- State of Health

THD- Total harmonic distortion

XFC: Extremely fast charging station

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Ms. Naireeta Deb is an Electrical Engineer with a Bachelors and Masters degree in Power Electronics,from NIT,Agaratala,India. She has several years of industry experience in the area of machine design and power utility. She is currently pursuing her Ph.D. with a focus in power electronics design for extremely fast charging at Clemson University, USA, and simultenously working as a Project Engineer for Superchargers in Tesla. Her interests are in electric vehicles, charging stations, HVDC, renewable generation, FACTS and electrical machines.

Dr. Rajendra Singh is the D. Houser Banks professor in the Holcombe Department of Electrical and Computer Engineering and Automotive Engineering at Clemson University (CU). He is also the Executive Director of Electrification of Transportation minority program. He left India in 1973 and during the energy crisis of 1973 decided to do Ph.D. dissertation in the area of Silicon Solar Cells. In the last 48 years, he has contributed and witnessed the growth of photovoltaic and semiconductor industries. With proven success in operations, project/program leadership, R&D, product/process commercialization, and start-ups, Dr. Singh is a leading technologist with the focused goal of mitigation of climate related challenges by providing green electric power for various sectors including transportation, desalination and manufacturing. He is fellow of IEEE, SPIE, ASM and AAAS. Dr. Singh has received a number of international awards. In 2014, he was honored by US President Barack Obama as a White House "Champion of Change for Solar Deployment" for his leadership in advancing solar energy with photovoltaics technology. In 2019, he received Hind Rattan Award presented by Bibek Debroy, chairman of the Economic Advisory Council to Prime Minister Narendra Modi.

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An Algebraic Specification/Schema for JSON

Konstantinos Barlas[*,1], **Petros Stefaneas**[2]

[1]Department of Informatics and Computer Engineering, University of West Attica, Athens, 12243, Greece

[2]School of Applied Mathematical and Physical Sciences, National Technical University of Athens, Athens, 15780, Greece

[*]Corresponding author: Konstantinos Barlas, University of West Attica, Ag. Spyridonos Str., Egaleo & kosbarlas@uniwa.gr

ABSTRACT: **J**ava**S**cript **O**bject **N**otation (JSON) is an open standard data format that is used widely across the internet as means of exchanging structured data due to its low overhead. While originally created in the early 2000s, it has only gained standard status in 2013 and then again in 2017 with a new version that focused more on security and interoperability. In this paper the authors present a different specification of the JSON standard that relies on algebraic formal methods and provides certain benefits over a regular natural language specification. This specification can also function as a schema that can attest a JSON data document's compliance to its blueprint.

The absorption of Formal Specification methods by the industry happens at a very slow pace, mostly because there is little incentive to tread into a fairly unknown territory. Notwithstanding this reluctance, the authors encourage the usage of Formal Specification techniques to the specifications of open standards; Formal specifications are more succinct, less ambivalent, consistent to the standard, reusable as they support module inheritance and can be executable.

The process of designing new Standards can benefit from Formal Specifications as the resulting specification i) is more tangible; ii) allows a thorough and clear understanding of the standard and also iii) allows property checking and property verification.

KEYWORDS Formal Specifications, Algebraic Specifications, Formal Methods, JSON, open standards

1. Introduction

Standards released by a standard setting organization are usually accompanied by a publicly-available delineating *specification document* that consists of the requirements that any implementation of the standard has to hold [1]. However, because such a document is written in a natural language there can be some shortcomings:

1. **Verbosity**: Just like any technical document, a specification document written in any natural language often yields quite *lengthy* documents. For instance, the specification of Digital Imaging and Communications in Medicine (DICOM), an open standard that describes the operations that can take place in medical imaging (e.g. handling, storing, printing, and transmitting information) consists of 18 different documents ([2]) and a total of 4900 pages.

2. **Vagueness**: Using natural languages to express terms that depend on being expressed with precision and unambiguity can be an arduous task that usually results in documents that are difficult to comprehend [3]. Words with different meanings or phrases that hypothesize some common background can make this issue even worse. Clarity is important when trying to formalize a statement.

3. **Requirements intermixture**: Due to the non modal nature of natural languages, we often see the merging of a standard's disparate requisites [3]. This renders the tracking of the consequences that a change incurs rather cumbersome, since it is better to examine each requirement individually rather than process a fusion of different yet connected requirements.

4. **Requirements confusion**: Different kinds of a standard's properties can appear mixed up; functional and non functional requirements, system goals and design information are at times used as if they are the same thing [3] .

Those shortcomings can create issues throughout the standard's development and specification stages, issues that are frequently ascertained at the latest stages and are therefore, costly to correct [3]. These drawbacks can be present to any standard's specification document (open or not) but this paper focuses on open standards since their specifications are publicly available.

In this paper we:

1. Reason about how a Formal Specification of an open standard can deal with the issues of specifications written in natural languages that are discussed in this section.

2. Create a Formal Specification of the JSON open standard by converting JSON entities into their equivalent

formal versions.

3. Address the points raised earlier and argue about how this specification methodology is better than the natural language one. In order to do that, a test case will be presented in which we use the formal specification of JSON as a schema, in order to verify additional properties.

This paper is an extended version of [4], a short conference paper that introduced an algebraic schema for JSON and presented the basics of treating JSON objects in an algebraic way. This paper provides the details for almost all operators needed to handle a JSON object as an algebraic item as well as how they operate together and, in an attempt to respond in detail to comments from the conference review, it also expands more on how a formal specification of an open standard can be beneficial to the standard as it can be better than a specification written in natural language. Both this paper as well as its predecessor continue in a similar path as [5], in which the authors have formalized XML structures and used the result to create a formal version of RSS v2.0 open web standard.

2. Background material

2.1. Open Standards

While the definition of a Standard can be quite straightforward (an established norm/requirement for a repeatable technical task), it's the term "open" that makes the definition tricky as that word can have a different meaning depending on the point of view; dictionaries, national IT agencies, World Trade Organization (WTO), etc. all provide different points of view for the term "open". An intersection of all those different definitions deals with their motivation, development and usage. The motivation to create and promote an Open Standard usually has to do with promoting interoperability. When it comes to its development, an Open Standard:

1. Most of the times emerges by a process that can be effortless for anyone to attend.
2. Is open to public input [6, 7].
3. Is not regulated by any particular collective or vendor.

2.1.1. Advantages of Open Standards

Developing and adhering to an open standard does not produce any financial gain, at least not in the short term but in the long run, the interoperability, the sustainable development and the smooth communication channels that come along, all give value to this investment. Additional benefits from following Open Standards are summarized below [8, 9]:

- Open Standards ensure that a vendor cannot gain full control over a format. Since an open standard's specification is available to the public, another party can always implement a solution that adheres to its requirements if the previous solution stopped working for whatever reason.
- Open Standards provide smooth interoperability between different systems that may even use different technologies. Communication between such systems can be difficult if there is not an "agreement" to use a pre-approved channel that each system can identify and work with. For example, a company that requires that all its desks use office software applications compatible with the Open Document format (an Open Standard) gives each employee the freedom of choosing to use **any** such office software, ensuring full compatibility with the rest of the company.
- Open Standards can act as a buffer against applications that stop being developed. If such an application was using a proprietary data format then an end user would have a difficult time trying to save the data in a way that some other application could use. However, if that application was using an open standard document format, it would not be difficult for another application to make use of that data. The issue of program data becoming unusable can be even worse for any big organizations like government agencies (e.g. police [10]) or national Electronic Health Records ([11]).

2.1.2. Problems of Open Standards

On the other hand, Open Standards have some noteworthy drawbacks. Firstly, creating an Open Standard (with all its steps; designing, reviewing, rating, implementing) can be quite costly in resources. For instance, the amount of time required for an Open Standard to go through that process varies, from a few months to many years, depending on the standard-setting organization.

Also, interoperability can be achieved even with non open standards. There is an abundance of proprietary standards that come with a Reasonable and non-discriminatory licensing (RAND) that do not hinder in any way interoperability (e.g. GSM, CD, DVD, MPEG, Wi-Fi, etc.) [8], [9].

2.2. About Algebraic Specifications of Open Standards

Formal (especially algebraic) specifications can complement (or even substitute) the original natural language specification of the standard as they can deal with the problems discussed in Section 1:

1. Formal specifications are most often than not small in size, mainly due to their modular nature and their basis on mathematics.
2. Their mathematical foundation also allows them to be as precise as mathematics can allow, resulting in unambiguous results.
3. Many specifications can be executable, enabling developers to test an implementation of a standard against its specification.

While this process can be applied to any kind of standard, Open Standards are better candidates for a formal specification since their original specification, the one written in a natural language, is available for anyone to read and attempt to improve by formalizing (versus trying to reverse engineer a proprietary standard). Considering that this process is not done by the standard-setting organization, any attempts to formalize a standard are only as good as the understanding of the standard by the reader. Depending on how intricate and entangled the original specification is, such a task can be of considerable difficulty.

This process may also uncover flaws in the standard; since the formalization process forces someone to ask the right questions, there have been cases in which ambiguities in original natural language specifications have been detected, for example the specification of "time-to-live" element of **R**eally **S**imple **S**yndication (RSS) in [5]. Naturally, the time and resources needed for a formal specification are increased (or differently allocated according to Sommerville [3]), unless the formal specification is developed along the standard.

Formal Methods may at first alienate many readers, especially those not sufficiently versed, however getting acquainted is not such a difficult task [12, 13] and the benefits may make it worthwhile. Perhaps until Formal Methods become more popular, a middle ground would be to have both natural language and formal specifications for standards.

2.3. CafeOBJ

The formal specification of JSON that is presented in Section 3 is written using CafeOBJ, which according to its webpage ([14]) is an "advanced formal specification language which inherits many advanced features (e.g. flexible mix-fix syntax, powerful and clear typing system with ordered sorts, parametric modules and views for instantiating the parameters, and module expressions, etc) from 'OBJ' (or more exactly 'OBJ3') algebraic specification language".

The OBJ (and OBJ3) family has been used in many applications ([15]) such as the debugging of algebraic specifications, rapid prototyping, the executable definition of programming languages, the specification of software systems (such as GKS graphics kernel system, Ada configuration manager, Macintosh QuickDraw, etc), specification of hardware, specification of user interface designs and theorem proving. The main axiomatic systems that it uses are order-sorted algebras [16, 17] (used to specify abstract data types) and hidden algebras [16, 18] (used to specify abstract state machines, enabling object-driven specifications).

Algorithm 1 shows a CafeOBJ module for factorials. A specification in CafeOBJ consists of modules; places where sorts, operators and equations are declared [19]. The keyword *mod!* initiates a module and is followed by curly brackets that define the start and end of the module's code block. The next line, *pr(INT)* imports the built-in integer module, allowing sort, operator and equation inheritance. To declare an operator, keyword *op* is used. Operators are like functions and they need explicit domains and codomains. In Algorithm 1, operator *factorial* assigns an integer (domain) to another integer (codomain). A variable in CafeOBJ is declared with the keyword *var* followed by its name and domain. Here, variable *N* belongs to *INT*, the sort of Integers that was imported into the module with the *pr* command. To write the equations describing the factorial we will need a recursive case as well as a base case, as shown in the last two lines of the module, starting with *ceq*. Once the module declaration is over, command *select* selects the created module so that we can use its definitions to calculate the factorial of a number. The command *red* command will try to reduce $fact5$ to its value using the module's equations and left-to-right rewriting rules. Lastly, inline comments in CafeOBJ use the −− prefix.

Algorithm 1: Factorial's definition in a CafeOBJ module

```
mod! FACTORIAL
{
    -- Factorial declaration
    pr (INT)
    op factorial : Int -> Int
    var N : Int
    ceq factorial(N) = N * factorial(N - 1) if N > 0 .
    ceq factorial(N) = 1 if not (N > 0) .
}

select FACTORIAL .
red (factorial(5)) .
```

2.4. About JSON

Java**S**cript **O**bject **N**otation (**JSON**) is an open standard data format and file interchange format that does not bind itself to any specific language and declares entities as lists of properties in the *attribute: value* format [20]. JSON started as a non-strict subset of JavaScript [20], as defined in the European Computer Manufacturers Association Script (ECMAScript) Programming Language Standard, Third Edition [21], but ever since, it can be (and has been) used in many programming languages. JSON was originally designed to be minimal, portable, textual, a subset of JavaScript [21] but not too far away from the broad spectrum of C-family of languages ([22]).

JSON became a standard originally in 2013, under the name ECMA-404 [23]. The second version of the ECMA-404 standard came along in 2017 [24]. Request for Comments (RFC) published JSON as a standard in 2017 [21] and this is the current JSON standard version that is compliant with ECMA-404 [24].

JSON can express structured data in six ways; the four non-structured primitive types (booleans, strings, numbers and the unique "null" type) and two structured types (arrays and objects) [21]. Arrays and objects can be nested into larger, complex JSON structures, [22].

2.5. Uses

JSON has become a very popular data format, with a broad range of applications. It is being used as a configuration language, storing application settings in its low-overhead format, although surprisingly, it lacks support for comments, discouraging people from meddling directly with

such files. JSON is intended as a lightweight alternative to the widespread XML format that has bigger space requirements as XML uses more overhead to store its data.

JSON can be used with most of the languages of the C-family (such as C, C++, C#, Java, JavaScript, Perl) but is also supported by many more, such as Python, Filemaker, .Net, Matlab, Lisp, Haskell, Fortran, OCaml, Prolog, Rust, Scala, etc. [22].

2.6. Similar works

Formal versions of JSON schemas have been created in the past, e.g. [25] in which JSON is used as a JSON schema. There also is [26], in which the authors display an Extended Backus–Baur Form (EBNF) grammar of JSON. While JSON and XML are different, formalizing XML is quite similar in nature with the ideas presented in this paper; the authors in [27] have created a formal framework for XML schema languages. What distinguishes this paper from the rest is that a valid schema for JSON is created using an algebraic specification language.

3. JSON entities as algebraic objects

The proposed schema for JSON data (Section 3.3) treats JSON objects as lists (Section 3.1) and is written in CafeOBJ (Section 2.3). In order to create an algebraic specification of a JSON file in CafeOBJ, the JSON file has to be converted into a format that CafeOBJ can read and process. A simple command line converter has been created that parses a JSON file and outputs it into a format that we will call JSON-OBJ. The rules for such a translation can be seen in Section 3.2. The resulting JSON-OBJ file can now be loaded into CafeOBJ and can be reasoned with, as seen in Section 3.4.

While the reason for choosing CafeOBJ as the language for this formal schema is the authors' familiarity with it, we would argue that a formal specification of JSON would work equally well with any Formal Method tool; especially those that put more weight on data structures like Z, VDM, Estelle or any language of the OBJ family (e.g. Eqlog, FOOPS, Kumo, Maude, OBJ2, OBJ3). Selecting a proper Formal Method tool can be quite a daunting task as lots of different tools exist, all specializing in different features, yet often having some overlap with other tools.

3.1. Lists

JSON describes, in its essence, a list of structured data. A list is a collection of elements where an element can be a list itself. A list module provides operators that can i) append an element into a list, ii) search if an element is contained in one, iii) remove an element from a list and iv) concatenate two lists. These operations are specified in a recursive manner.

For example, Algorithm 2 shows the equations necessary for removing an element from a list. The operator "\" takes an element and list and removes that element from the list, if the list contains that that. The first two equations provide the base cases and the next two the recursive cases. The recursive cases state that given an element $Elem_1$ that's merged with a list Lst; if we want to remove an element $Elem_2$ from that list, then if $Elem_1$ is the same as $Elem_2$ then the operation returns Lst, otherwise the removal operation is now applied to Lst.

Algorithm 2: Removing an element from a list

```
op _\_ : List Elt → List
vars Elem1, Elem2 : Elt
var Lst : List
eq (nil  Elem1) = nil .
ceq (Elem1 \ Elem2) = nil if (Elem1 = Elem2) .
ceq ((Elem1 | Lst) \ Elem2) = Lst if (Elem1 = Elem2) .
ceq ((Elem1 | Lst) \ Elem2) = Elem1 | (Lst \ Elem2)
  if not(Elem1 = Elem2) .
```

Algorithm 3 shows the declaration and equations for querying a list for the existence of an element. The operator "*//in*" returns true if a given element is inside a given list. The base cases describe how we check an element against another element or against an empty list. The recursive case states that an element $Elem_1$ exists in a list that consists of an element $Elem_2$ and a sublist Lst, only if $Elem_2$ is $Elem_1$ or $Elem_1$ exists in Lst.

Algorithm 3: Querying a list for the existence of an element

```
op _//in_ : Elt List → Bool
ceq (Elem1 //in Elem2) = true if (Elem1 = Elem2) .
eq (Elem1 //in nil) = false .
ceq (Elem1 //in (Elem2 | Lst)) = true if (Elem1 =
  Elem2) or (Elem1 //in Lst) .
```

3.2. JSON data in CafeOBJ format

The most basic JSON element comes in the form of {"key": "value"} and that would get converted into <"key" [txt("value")] >. Symbols "<" and ">" contain the element's name inside quotes and its following value inside brackets. Values can be in a number of different types (string, number, boolean, object, array, *null*), so the value of an element is held within the right operator for its type; string values are contained inside the *txt* operator, *log* for boolean values, *int* for integers, etc. A more complex JSON element is the *object*, which is a comma separated collection of *key:value* elements held inside curly brackets. Its equivalent form in CafeOBJ notation is a series of parenthesized elements, concatenated with the @ operator.

The last JSON element type is the *array*, an ordered, comma separated collection of *key:value* elements that is contained within brackets. Since the sequence of the array elements needs to be preserved, the < "key" [txt("value")] > format is extended so that the n^{th} element of such an array would be declared as ({ n } <"key" [txt("value")] >).

A value in JSON can be another JSON element, as this format supports nested elements. Some sample JSON data can be seen in Algorithm 4 and its conversion to the JSON-OBJ format can be seen in Algorithm 5. Algorithm 5 also shows how each JSON data type gets converted into its appropriate JSON-OBJ format (string - *Name*, boolean - *isAlive*, number - *age*, object - *address*, array - *phoneNumbers* and null - *spouse*).

Algorithm 4: Sample JSON data

```
{
    "Name": "John Smith",
    "isAlive": true,
    "age": 27,
    "address": {
        "streetAddress": "21 2nd Street",
        "city": "New York",
        "state": "NY",
        "postalCode": "10021"
    },
    "phoneNumbers": [
        { "number": "212 555-1234",
        "type": "home" },
        { "number": "646 555-4567",
        "type": "office"}
    ],
    "spouse": null
}
```

Algorithm 5: Sample JSON data in CafeOBJ format

```
(< "Name" [ txt( "John Smith" ) ] >) @
(< "isAlive" [ log( true ) ] >) @
(< "age" [ int( 27 ) ] >) @
(< "address" [
    (< "streetAddress" [ txt( "21 2nd Street" ) ] >) @
    (< "city" [ txt( "New York" ) ] >) @
    (< "postalCode" [ txt( "10021-3100" ) ] >) @
    (< "state" [ txt( "NY" ) ] >) ] >) @
(< "phoneNumbers" [
    ( 1
        (< "number" [ txt( "212 555-1234" ) ] >) @
        (< "type" [ txt( "home" ) ] >) ) @
    ( 2
        (< "number" [ txt( "646 555-4567" ) ] >) @
        (< "type" [ txt( "office" ) ] >)
    )
] >) @
(< "spouse" [ NULL ] >)
```

3.3. Algebraic Schema for JSON

The operators in the algebraic schema for JSON can be employed to parse and validate a JSON-OBJ (as described in Section 3.2) file against its requirements. The operators used in the schema can be seen in Table 1 and are used to extract the data stored (and the way it is organized) in any JSON file. The output can then be used in order to check the file against its specification.

In this paper we will describe operators *jNodeExists* and *getParent*.

Table 1: Operator names and their descriptions.

getKey	Given an element, it returns its key name
getValue	Given an element, it returns its value
returnJnode	Given a list of elements and an element's key, it returns the whole element. If the element is within an array, returns the parent as well
jNodeExists	Given an element's key name and a list of elements, it searches for the key in the element list and returns a boolean value
hasNextElement	Given a list of elements and an element's key, it returns a boolean value based on whether the key has a *next* element
getParent	Given an element's key name and a list of elements, searches for the key name inside the list and returns its parent, if there is one
getArrayNo	Given an array and an element's key, it returns its array index value

3.3.1. jNodeExists

Algorithm 6 displays the declaration for the *jNodeExists* operator along with its equations; The operator takes a key name (*KeyName*) and a list of elements (*ElementList*) and returns a true/false value. In the equations that define the operator, Key_1 and $Key2$ are variables that describe a key name. *Cont* is a variable that describes content of any sort. $Elem_1$ and $Elem_2$ are variables that describe elements and N is a natural number variable that describes the N^{th} element of an array.

The base-case of the operator's recursive definition is given in the first two equations: if the list of elements is just a single element then either its key name matches the one given to the operator and the operator returns *true*, or there is no match and the operator returns *false*. Two base-case equations are needed considering that *keyname* can also try to match a single element of an array.

Algorithm 6: jNodeExists operator

```
op jNodeExists : KeyName ElementList -> Bool
eq jNodeExists(Key1, < Key2 [ Cont ] >) = if (Key1
  == Key2) then true else false fi.
eq jNodeExists(Key1, N < Key2 [ Cont ] >) = if (Key1
  == Key2) then true else false fi .
eq jNodeExists(Key1, Elem1 @ Elem2) = if
  (jNodeExists(Key1, Elem1)) then true else
  jNodeExists(Key1, Elem2) fi .
eq jNodeExists(Key1, < Key2 [ Cont ] > @ Elem1 ) =
  if (Key1 == Key2) then true else jNodeExists(Key1,
  Elem) fi .
eq jNodeExists(Key1, N < Key2 [ Cont ] > @ Elem1 )
  if (Key1 == Key2) then true else jNodeExists(Key1,
  Elem) fi .
```

The recursive actions for the operator are given in the next three equations:

- Given a key name Key_1 and an element list that is made out of two elements, the operator will call itself on the first element and if there is no match, it will do the same to the second element.

- Given a key name Key_1 and an element with key name Key_2 that is concatenated with a list of elements, it will compare Key_1 against Key_2 and if they are different it will continue recursively with the list of elements until the expression collapses to one of base case equations. Again, two recursive equations are required due to the two different ways an element can present itself; as part of an array or in any other way.

3.3.2. *getParent*

Algorithm 7 displays the declaration for the *getParent* operator along with its equations; The operator takes a key name *K* and a list of elements (*ElementList*) and then seeks element *K* inside *ElementList*, returning the key name of *K*'s "parent", or a *null* value if that element is not found or has not parent. Since this operator relies on *jNodeExists* (Section 3.3.1), this shows the way multiple operators can work together.

In the equations that define the operator, Key_1, Key_2 and Key_3 are variables that describe key names. *Cont* is a variable that describes content of any sort. $Elem_1$ and $Elem_2$ are variables that describe elements.

The first two equations describe the base case: If asked to retrieve the parent of an element named Key_1 from a single element *Elem*1, the operator returns null (the special *nil* operator). If asked to retrieve the parent of an element named Key_1 from an element called Key_2 that contains a single nested element (*Elem*), then it will invoke *jNodeExists*, to search for element Key_1 inside *Elem*, returning K_2 if found, or *nil* otherwise.

The next three equations describe what may happen if we are searching for the parent of element with key name Key_1 in the following scenarios:

- The element list is a concatenation of a simple element and any other element: *getParent* operator ignores the simple element as it cannot have a parent and gets applied to the other element.

- The element list is a concatenation of a simple element and one with nested elements: *getParent* operator ignores again the simple element and gets applied to the element with the nested elements.

- The element list is a concatenation of two elements that both have sub-elements: if the first element contains Key_1 then *getParent* returns its key Name otherwise it is applied to the second element.

Algorithm 7: getParent operator

```
op getParent : KeyName ElementList -> KeyName
eq getParent(Key1, < Key2 [ Cont ] >) = nilKey .
eq getParent(Key1, < Key2 [ Elem1 ] >) = if
 (jNodeExists(Key1, Elem1)) then Key2 else nilKey fi .
eq getParent(Key1, < Key2 [ Cont ] > @ Elem1) =
 getParent(Key1, Elem1).
eq getParent(Key1, < Key2 [ Cont ] > @ < Key2 [
 Elem2 ] >) = getParent(Key1, < Key2 [ Elem2 ] >) .
eq getParent(Key1, < Key2 [ Elem1 ] > @ < Key2 [
 Elem2 ] >) = if (jNodeExists(Key1, Elem1)) then Key2
 else getParent(Key1, < Key2 [ Elem2 ] >) fi .
```

3.4. Test case

This section examines a hypothetical scenario in which a company's management software keeps its contacts in JSON format and those contacts need to adhere to the following traits:

1. Entries for *Name*, *address* and *isAlive* are necessary.
2. *Address* must have entries for *streetAddress*, *city* and *postalCode*.
3. Property *isAlive* must be true.
4. Age of contact should be between 18 and 60 years old.

To validate the JSON stored contacts against those requirements, the contacts data file gets converted into the JSON-OBJ format of Algorithm 5 and then it gets tested against the requirements of the company. For this test case, the contacts in Algorithm 4 will be used.

In order to validate the contacts against those requirements, we will need to create an operator that formalizes those requirements and then tries to validate a given JSON-OBJ file against them. This operator, called *properschema* returns true only if all requirements are held. Algorithm 8 contains the operator's signature and equation; given an *ElementList E*, it checks it against all 4 of the requirements. Operator *properschema*:

1. Verifies that the three entries of the first requirement exist. To achieve that, operator *jNodeExists* is called for each entry key name and responds with a boolean.
2. Verifies, using *jNodeExists* operator, whether the three address properties (street address, city and postal code) exist and for each one of them, using *getParent*, checks whether they are child nodes of *address* element.
3. Gets the value of *isAlive* node, using operators *returnJnode*) and *getValue* in succession.
4. Gets the value of *age* node, using operators *returnJnode*) and *getNumber* in succession. The result is checked against the range of allowed values.

In order to verify that the sample JSON-OBJ file (denoted as *samplejson*) holds all desired properties, *properschema* operator has to parse the file. To do that, the *reduce* command

is used; it uses the related operators' equations to try to rewrite the term, eventually returning a boolean value. Output Sequence 1 shows the result of the execution. CafeOBJ returns *true* which means that the JSON data satisfy the four wanted requisites. In case the output was *false*, we can identify through CafeOBJ's output which of the requirements failed to evaluate to true and then act accordingly.

Operator *properschema* acts as a schema /specification in this scenario since it lays out the requirements that any contact should hold and it is also capable of validating any contact against these requirements.

Algorithm 8: *properschema* operator

```
op properschema : ElementList -> Bool .
var ElemList : ElementList .
eq properschema(ElemList) =
    if
    -- 1st requirement:
    jNodeExists("Name", ElemList)
    and jNodeExists("address", ElemList)
    and jNodeExists("isAlive", ElemList)
    -- 2nd requirement:
    and (
        jNodeExists("streetAddress", ElemList)
            and getParent("streetAddress", ElemList)
             == "address"
        and jNodeExists("city", ElemList) and
            getParent("city", ElemList) == "address"
        and jNodeExists("postalCode", ElemList) and

            getParent("postalCode", ElemList) ==
             "address" )
    )
    -- 3rd requirement:
    and getValue(returnJnode("isAlive",ElemList))
     == true
    -- 4th requirement:
    and (
        getNumber(returnJnode("age",ElemList)) >=
         18
        and getNumber(returnJnode("age",ElemList))
         <= 60
    )
    then true
    else false
    fi .
```

Output Sequence 1: CafeOBJ's reduce command and output

```
-- defining module SCHEMA done.
open SCHEMA .
-- opening module SCHEMA done.
red properschema(samplejson) .
-- reduce in (true):Bool
(0.0000 sec for parse, 0.0640 sec for 502 rewrites +
 10912 matches)
```

4. Conclusions and future work

This paper presented an algebraic specification / schema for the JSON Open Standard written in the CafeOBJ language. The proposed formal specification provides a framework for treating JSON objects in an algebraic way that allows formal requirement specification and JSON document validation against a schema.

Formal specifications are in general small in size and our test case is no exception; at only 26 lines of code, it is quite small in size, even with comments present. The requirements in the test case's formal specification are laid out in a clear and non-ambiguous way, provided one can familiarize themselves with the operators and the syntax of the specification. That aside, we believe that such a specification can be quite easy for someone to understand. The way the requirements are presented makes it easier to separate the requirements from one another allowing to track the changes one of them may bring to the whole specification thus reducing any issues of requirement intermixture or confusion. Finally, since this specification is in algebraic format, it is also executable allowing us to verify sample data against the specification.

Despite those advantages, there have not been many attempts in formalizing standards. One reason for this discrepancy could be the plethora of different formal methods that can make early steps such as choosing a tool quite difficult, and also the questionable applicability of a specific formal method to the standard.

The authors hope to continue work on using formal methods to create specifications of more open standards, especially web data standards (e.g. YAML or TOML) in order to achieve benefits over natural language specifications.

Conflict of Interest The authors declare no conflict of interest.

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Dr. KONSTANTINOS BARLAS has received his bachelor's and integrated master's degree in Applied Mathematical and Physical Sciences from National Technical University of Athens, Greece in 2006. He has completed his PhD degree on Algebraic Methods at the School of Electrical and Computer Engineering of the National Technical University of Athens, Greece in 2018.

His current research includes Algebraic Specifications, Formal Methods, Open Standards, Formal Verification, Formal Semantics and Formal Logic.

Prof. PETROS STEFANEAS coordinates the Logic and Formal Methods Group (λ-ForM) of the Algorithmic Applications and Logic Laboratory at the Department of Mathematics of the National Technical University of Athens, Greece. Dr. Stefaneas has done extensive work on the applications of formal verification and specification techniques to engineering problems.

His current research includes formal methodologies for information privacy, legal documents and open data policies. Other research interests include abstract model theory, algebraic specifications, computational creativity and semantics and ethics of computer science.

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VSC-HVDC Robust LMI Optimization Approaches to Improve Small-Signal and Transient Stability of Highly Interconnected AC grids

Yankai Xing[1], **Elkhatib Kamal**[1], **Bogdan Marinescu**[*,1] **Florent Xavier**[2]

[1]Ecole Centrale de Nantes, LS2N-CNRS, 1 rue de la Noë, Nantes, France

[2]R&D Division, RTE, Paris La Défense, France

[*]Corresponding author: Bogdan Marinescu, 1 rue de la Noë, Nantes, France, Bogdan.Marinescu@ec-nantes.fr

ABSTRACT: In this paper, for the situation of HVDC inserted in meshed AC power grid, a model-matching robust H_∞ static output error feedback controller (RSOFC) and model-matching dynamic decoupled output feedback controller (DDOFC) are proposed to improve the damping of inter-area oscillation modes and maintain robustness to face the effects of different operating points and unstable zeros. Sufficient conditions for robust stability are derived in the sense of Lyapunov asymptotic stability and presented in the form of linear matrix inequalities to obtain H_∞ RSOFC and DDOFC gains based on the reference model. The efficiency and robustness of the proposed controllers are tested and compared to Linear-Quadratic-Gaussian (LQG) control, mixed sensitivity H_∞, standard (IEEE) Power Oscillation Damping (POD) controllers on a realistic benchmark of 19 generators connected by a meshed AC grid. The main contributions of this paper are: (i) Compensate the negative effect of unstable zeros (non-minimum phase behavior) on the performances of the closed-loop; (ii) the robustness is improved in order to provide good responses in case of network variations (load evolution, line, and generator trips, etc.) and HVDC line parameters changes; (iii) improve the damping compared with standard controller structures (LQG, mixed sensitivity H_∞ and standard POD controller).

KEYWORDS: LMI, H_∞, robustness, output feedback controller, HVDC, damping controller, inter-area modes.

1. Introduction

The traditional electricity transmission system based on three-phase AC grids, in general, works well and with good levels of reliability. However, there are challenges arising mainly from environmental impact and the increase in the renewable generation, (according to [1] the next decade will be devoted to the large-scale exploitation of offshore wind energy, which means the need to transport electrical energy over long distances to establish a connection with the main power grid). This will likely increase the level of variability and unpredictability in the operation of power grids, leading to an increased need for power reserves for balancing energy consumption and will require more flexible power flow control. The solution that overcomes these problems is the use of high voltage direct current (HVDC) transmission systems, which are more feasible and also more competitive than traditional transmission systems (HVAC), especially with the development of power electronics components. One of the most important advantages of this technology against the HVAC technology is that the former is suitable for long distances with minimal losses. The second advantage is the right-of-way; it is often easier to get permission for underground DC cables due to the reduced environmental impact [2]. The HVDC system is a power electronics technology used in electrical power systems primarily because of ability to transmit large amounts of energy over long distances [3]. In the case of HVAC systems the power transfer is limited because of the difference between the voltage angles of the terminals which increases with distance [4]. To solve this problem the network operator can use reactive power means of reactive power compensation along the line, such as such as FACTS (Flexible Alternating Current Transmission System) devices. However, these devices are very expensive and cannot always be installed in the most appropriate place. Once the development of high power switching devices and their devices and their availability at low prices, Line-commutated converters (LCCs) which used thyristors as the basic as a basic component in HVDC were replaced by voltage source converters (VSCs) [3]. Since VSC-HVDC has been gradually incorporated into the grid, they can be utilized to suppress low-frequency oscillations. The modes usually considered in the past were the most spread inter-area ones which are at low frequencies (in Europe about 0.2 Hz). For HVDC inserted in a meshed AC network, such as the recent interconnection reinforcements in Europe, inter-area modes corresponding to a limited number of generators in the area near the HVDC may be involved. They

are at a higher frequency, around 1 Hz. However, in this frequency range, inter-area modes are close to other modes of a different nature (see [5, 6]) which are disturbed by the HVDC power oscillation damping (POD) controller. The use of classical Institute of Electrical and Electronics Engineers (IEEE) POD controller structures and tuning methods (see e.g. [7]) are focused on only one mode, and tends to inefficient damping and destabilize other modes.

It is well known that unstable zeros can degrade the performance of the control system. However, there is rare research on the origin of unstable zeros in HVDC links inserted into meshed AC networks. Therefore, it is important in research and practice to analyze network parameters with HVDC links to highlight their influence on unstable zeros. In addition, modeling errors and system uncertainties in plant models are inevitable in many applications. To ensure accuracy, design techniques must take these errors and uncertainties into account to be practical. Therefore, a (*robust*) control approach must be used to deal with the uncertainties arising from operating point changes in the power system, as well as the modeling errors caused by modeling and model reduction of realistic power systems.

Hence, the contributions of this paper, based on the aforementioned works are to develop robust POD controllers which improve the damping of aforementioned high frequency inter-area modes without deteriorating the damping of the others and to eliminate the impact of unstable zeros. To develop advanced control one usually needs a state-space representation of the system [8], [9]. In [10], it is studied in detail the stability at small perturbations with power stabilizers (PSSs) in order to satisfy some recent objectives and constraints imposed by the evolution of large-scale interconnected power systems. H_∞ or H_2 approaches in the field of robust control are studied in a huge number of publications since the mid-1980s. In the context of robust control of linear systems, modern multivariate synthesis methods integrate a model of the process with a family of systems. They use a deviation model, which is defined either by different types of norms in the frequency or time domain, or by uncertainty domains on the parameters, or by sectors of the complex plane. For some types of error modeling, a synthesis technique is associated. A presentation of these different techniques will be proposed, with particular attention to those based on the use of H_∞ and H_2. The H_∞ optimal control is used to control a system subject to modeling errors and parametric uncertainties [11]. In [12], an H_∞ controller is compared to a controller obtained by a LQG/LTR (Loop Transfer Recovery) method, allowing to recover some robustness properties of the LQ (in the sense of modulus margin and not parametric robustness). The H_2 methodology was applied in [13], to find state feedback controller offering a satisfactory the required performance. The paper [14] proposes an iterative methodology in order to obtain a static output controller by a mixed H_2/H_∞ synthesis. Many works deal with the analysis of stability and the stabilization to design robust dynamic output-feedback controllers [15], [16] based on Linear matrix inequalities (LMI). LMI are used to solve several problems of automation, (optimization problems in control theory, system identification,...) which are generally difficult to solve analytically. The interest of methods based on LMIs comes from the fact that they can be solved using convex programming [17]-[19]. With this approach, one is no longer limited to problems with an analytical solution. By solving these inequalities, one obtains a domain of feasible solutions, i.e. solutions satisfying these LMIs, larger than the one generated by the search for analytical solutions. Using the fact that an inequality has more solutions than an equation it is possible to use the additional degrees of freedom to include other objectives than those than those initially chosen. The notions of LMIs are found in several works since many years. Thus Lyapunov conditioned the stability of a system by LMI [20]. In the work presented here, two model-matching based methods are proposed to solve above mentioned problems. The contributions and novelty of this paper are: i) *Firstly*, the reference model in this work is proposed as having the desired characteristics, which means to horizontally shift the poles to left in the complex plane until getting the desired damping (over 10 %). Moreover, unstable zeros of the control model are shifted to left plane which is closed to the vertical axis to decrease the control difficulty. ii) *Secondly*, sufficient conditions are derived based on LMIs for robust stabilization, in the sense of Lyapunov method to obtain robust H_∞ static output error feedback controller (RSOFC) and dynamic decoupled output feedback controller (DDOFC) gains based on the reference model. iii) *Thirdly*, different controls from the literature (Linear-quadratic-Gaussian (LQG), mixed sensitivity H_∞ and standard (IEEE) Power Oscillation Damping (POD) controllers) are implemented for the realistic benchmark of 19 generators connected by a meshed AC grid to compare with the proposed H_∞ RSOFC and DDOFC. The rest of the paper is organized as follows. Section 2 presents the problem statement and control model of the realistic benchmark of 19 generators connected by a meshed AC grid. The stability and the design of the proposed strategies are studied in Section 3. Section 4 introduces the proposed RSOFC and DDOFC. In Section 5, a simulation study to evaluate the performances of the proposed strategies is presented. In the Section 6 we present the conclusions and future works.

2. Problem Formulation, Main Difficulties and Modeling

2.1. Test system

A test system with aforementioned particularities is proposed. It contains an HVDC line inserted into an AC network consisting of 19 generators. All generators are controlled by AVR (Automatic Voltage Regulator) and PSS (Power System Stabilizer). The order of full nonlinear system is 724, which is linearized to obtain the full linear model of the same order. The less damped and highest residue modes found in Table 1 (see details in [21]).

2.2. Control model

In this paper the studied control model is developed in our previous work [21], [22]. By definition, a linear system is a system governed by ordinary linear differential (or even algebraic) equations with non-constant coefficients. They describe the temporal evolution of the constituent variables

Table 1: The linearized model

No.	Mode	Damping ξ (%)	Freq. (Hz)	Mode shape (participation mag (%))		Residue	
					–	ABS MAG	Phase
1	-1.62+j8.19	19.5	1.30	GE_914 (100)	GE_913 (32.4)	0.0157	35.0
2	**-0.24+j5.53**	**4.5**	**0.88**	**GE_911 (100)**	**GE_917 (68.8)**	**0.0181**	**83.4**
3	-0.53+j5.29	10.1	0.84	GE_917 (100)	GE_918 (55.1)	0.0129	-56.2
4	-0.40+j4.79	8.3	0.76	GE_918 (44.3)	GE_912 (100)	0.0038	-33.3
5	-0.33+j3.29	10.1	0.52	GE_915 (100)	GE_918 (17.7)	0.0121	104.5
6	-18.83+j7.21	93.3	1.14	GE_921, GE_922 (100)	GE_923, GE_924 (74.1)	0.0034	14.5
7	-1.54+j6.55	22.9	1.04	GE_914 (100)	GE_911 (68.3)	0.0125	151.5
8	-19.32+j6.47	94.8	1.03	GE_921 (100)	GE_922 (37.6)	0.0117	118.9
9	-20.33+j4.86	97.2	0.77	GE_921, GE_922 (84.5)	GE_927 (100)	0.0026	-168.1
10	-18.72+j3.35	98.4	0.53	GE_913 (33.4)	GE_912 (100)	0.0072	136.1

(state variables) of the physical system. This broad definition explains the complexity, the diversity of linear systems as well as the variety of methods that apply to them. A state representation of a linear system is given by:

$$\begin{array}{l} x \;\; Ax \;\; Bu \\ y \;\; Cx \end{array} \tag{1}$$

where $x \in \Re^{n\times 1}$ is the state vector of the system, $y \in \Re^{g\times 1}$ is the measured output vector and $u \in \Re^{m\times 1}$ is the input vector, $C \in \Re^{g\times n}$, $A \in \Re^{n\times n}$ and $B \in \Re^{n\times m}$, are matrices of linear functions.

In our case, $y \;\; \Delta\theta$ and u is Q , where Q is the reactive power, $\Delta\theta \;\; \theta_1 - \theta_2$ is the difference of angles of the terminal voltages [23].

2.3. Classic POD

The detailed classic POD in this paper is proposed based on [7], [21], [22]. It is defined by the transfer function given by (2). The classical adjustment of the parameters of this system is given in the [24]. For the desired damping of 10% set for mode 2 in Table 1, The classic POD tuning parameters K, T_1, T_2, T_w and n are defined in [22].

$$H_{POD}s \;\; K\left(\frac{T_w s}{1 \;\; T_w s}\right)\left(\frac{1 \;\; T_1 s}{1 \;\; T_2 s}\right)^n \tag{2}$$

2.4. Main objectives and difficulties

1. Particular frequency range of inter-area modes: As mentioned in Introduction, in highly meshed AC grid, the inter-area modes are at higher frequency. In this range of frequency, other types of modes exist: local modes and electric coupling modes or general electric modes linked to other electric phenomena. In the theory of systems, the models used for the design of control laws are often models of reduced size. However, the increase in electrical interconnections has caused the increase in the size of models representing these electrical systems. This makes their use for the design of controllers almost impossible. Moreover, the extension of the European synchronous area to the east of Europe has not only made the volume of numerical calculations in the field of "electrical" systems, but also changed the frequencies of the inter-area modes. These modes are associated with oscillations involving a number of machines distant from the electrical system and will be defined in in detail in [5]. More precisely, these modes shift to lower frequencies (by about a decade), which makes the gap between the frequency of the inter-area modes and the local modes (which concern only one generator) which remain in high frequency ranges. This deviation considerably modifies the global transient behavior of the electrical system and makes it difficult to synthesize controllers for a mixed specification, i.e., for both inter-area and local modes. In the previous works, the regulator design approaches use a simplified model consisting of a machine connected through a line of reactance X to the rest of the electrical system modeled by an infinite bus. Although this simplified model, also called "single machine on infinite bus", is very small compared to the full model of the electrical system, it cannot reproduce the dynamic phenomena concerning the voltage regulation specifications in the case of the very large systems mentioned above. Indeed, this model has only one inter-area mode which frequency depends on the parameter X, i.e., the length of the line connecting the machine to the infinite bus. It cannot therefore reproduce both local and inter-area local modes and inter- area modes of much lower frequency. Therefore, controllers designed with this model are not very efficient to meet the above-mentioned requirements. In [25], the balanced realization of an electrical system (representation of a complete electrical system by a reduced system containing only the most controllable and observable oscillatory modes) has been used for the construction of a control model allowing an optimal choice of the PSS locations to prevent blackouts in electrical systems. Although the chosen locations of the controls and measures improve the stability of the electrical system in the general case, these models are not optimal from the point of view of the most controllable and observable modes are not the undamped modes of the system. To answer this problem, we have proposed in this paper to use the control model built from the complete model representing the electrical system. This model allows, by preserving an important set of variables and oscillatory modes of the complete model, to reproduce a given oscillatory

behavior of the complete system which has both local and global components, i.e., that involves both local and global modes. Therefore, the controllers designed with this model will have an effective action once implemented in the complete system.

2. *Unstable zeros:* The existence of unstable zeros in the HVDC embedded system depends on the topology of the grids [26]. The effectiveness of POD can be decreased because of these unstable zeros [27].

3. *Uncertainty of system:* The modeling of a physical system is a crucial phase in the synthesis of the controller. Due to uncertainties, the mathematical model may not reflect the physical reality of the system. Nevertheless, if we manage to characterize these uncertainties, it is possible to complete the nominal model with an additional uncertain part. The sources of uncertainties are numerous but they are generally classified in two categories

   - *Non-structural uncertainties* also called non-parametric. They represent external dynamics, for example: measurement noise, external disturbances, etc. disturbances, etc. In general, their dynamics are unknown and we have no information on the way they act on the system. On the other hand, we know that they are bounded in norms.
   - *Structural uncertainties* also called modeling or parametric uncertainties. They are generally due to approximation errors and/or simplifications necessary to obtain an exploitable control model reflecting the real dynamics of the physical system.

   In this paper, we design the controller for control model (1) (cf. Fig. 1) subject to the non-structural uncertainties.

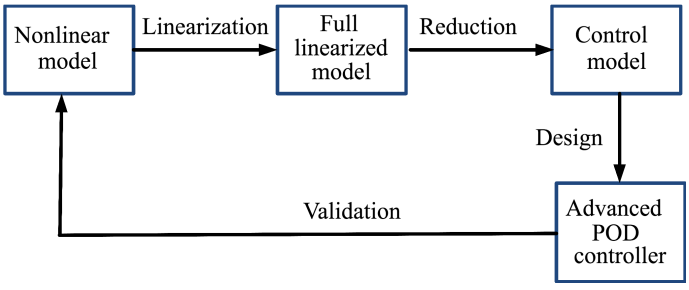

Figure 1: Design process.

It should be noted that all these requirements cannot be fully satisfied neither with the classic POD recalled in Section 2.3, nor with the standard H_2 and H_∞ robust controllers. To overcome this, a new design methodology summed-up in Fig. 1 was proposed.

3. Preliminaries

In this section, we first recall the theory of stability in the sense of a quadratic (LQ) and Gaussian quadratic (LQG) linear equation and mixed sensitivity H_∞. For the LQ, we focus on the problem of free-horizon control. In this context, the Lyapunov theorem is an interesting alternative to demonstrate the results of the LQG regulation and H_∞ based on [21], [24]. We also present the robustness properties and the asymptotic behaviors of the LQG control. Finally, we are interested in the Root Square Locus which is a graphical tool to guide the choice of weights on modal considerations in the complex plane.

3.1. LQG controller

For the system (1), the feedback control that stabilizes the system and minimizes the criterion LQG [8], [27]:

$$J_{LQG} \quad E\left\{\lim_{T\to\infty}\frac{1}{T}\int_0^T x^T Q x \;\; u^T R u dt\right\} \tag{3}$$

with the weighting matrices W and V, Q and R and the controller gains K_r and L are given by:

$$K_r \quad R^{-1}B^T X \tag{4}$$

$$L \quad YC^T V^{-1}, \tag{5}$$

and X and Y positive (symmetric) solution of the two Riccati equation:

$$\begin{array}{l} XA \;\; A^T X - XBX^{-1}B^T X \;\; Q \;\; 0 \\ YA^T \;\; AY - YC^T R^{-1} CY \;\; W \;\; 0. \end{array} \tag{6}$$

Fig. 2 shows the proposed LQG POD. The classic POD wash-out filter is added in LQG POD controller to avoid steady-state error. $Q \;\; I, R \;\; 10^{-4}; W \;\; I, V \;\; 10^{-2}$ in this case. The transfer matrix of regulator is:

$$Q_{pod} \;\; -K_r x \;\; -K_r sI - A \;\; LC^{-1}\begin{bmatrix} B & L \end{bmatrix}\begin{bmatrix} u \\ \Delta\theta_w \end{bmatrix} \tag{7}$$

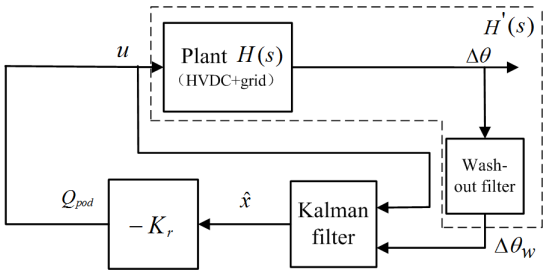

Figure 2: The proposed LQG control implementation.

3.2. Mixed sensitivity H_∞ based on LMI

The interest of this approach lies in the clarity of its formalism and the physical interpretation of the synthesis criterion since it is defined by a transfer function or even a block diagram showing weights placed on the physical inputs and output signals of the system and this independently of the norm that one wishes to minimize (H_2 or H_∞). This formulation is conducive to the introduction of frequency weights on some signals (e.g., the control) to satisfy frequency specifications (e.g., the roll-off at high frequencies) for which the optimal LQG-type approach is poor (note however that the frequency LQG approach proposed a solution since the beginning of the 70's to take into account frequency

specifications. Particular standard forms (notably the mixed sensitivity presented in Fig. 3) have been studied and are directly adapted to the formulation of frequency robustness specifications on sensitivity functions. We show here how to formalize the mixed "SKS" synthesis problem for our application. For that we use frequency weights: W_1 for S and W_2 for KS. The H_∞ problem consists of minimizing:

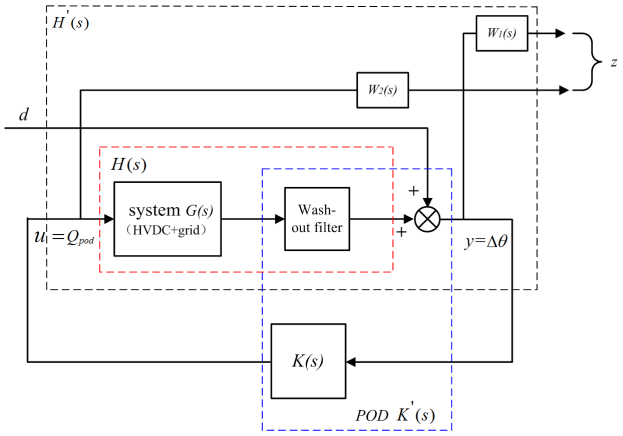

Figure 3: The proposed mixed sensitivity H_∞ based on LMI implementation.

$$\left\| \begin{bmatrix} W_1 sS\ s \\ W_2 sKS\ s \end{bmatrix} \right\|_\infty < \gamma, \tag{8}$$

where γ denotes a positive real number. We consider the disturbance d as the only disturbance in the system (Fig. 3). $W_1 s$ and $W_2 s$ are the stability and performance specifications respectively and take the following forms [27]:

$$W_1 s \ \frac{s \sqrt[k]{M_s} \ \omega_b}{s \ \omega_b \sqrt[k]{\varepsilon}}^k, W_2 s \ \frac{s \ \omega_{bc} \sqrt[k]{M_n}}{\sqrt[k]{\varepsilon_1} s \ \omega_{bc}}^k \tag{9}$$

where the bandwidth are ω_b 0.628 rad/sec, ω_{bc} 12.56 rad/sec. M_s, M_n are defined for the peak sensitivity and ε 0.1, ε_1 0.1 for the steady state error. k is the order of the weighting function. The target damping is set to $\xi_{desired}$ 10% for all the modes, as was the case for the design of classic POD. Thus, β 168° (β is the angle of conics in left complex plane directly correlated with damping ratio ξ $\cos\frac{\beta}{2}$).

The different matrices are combined into a single system, called the *augmented system*. It is defined by the following state equations:

$$\begin{cases} x_p \ A_p x_p \ B_{p1} d \ B_{p2} u \\ z \ C_1 x_p \ D_{p11} d \\ y \ C_2 x_p \ D_{p21} d \end{cases} \tag{10}$$

be a stable representation of the augmented plant $H's$ of Fig. 3.

The state space parameters of controller Ks are A_k, B_k, C_k and D_k which can be found via solving LMIs (11), (12), (13).

$$\begin{bmatrix} Q & I \\ I & S \end{bmatrix} < 0 \tag{11}$$

$$\begin{bmatrix} \Pi_{11} & \Pi_{21}^T \\ \Pi_{21} & \Pi_{22} \end{bmatrix} < 0 \tag{12}$$

$$\eta \otimes \Psi \ \eta^T \otimes \Psi^T < 0 \tag{13}$$

Where

$$\eta \begin{bmatrix} \sin\frac{\beta}{2} & \cos\frac{\beta}{2} \\ -\cos\frac{\beta}{2} & \sin\frac{\beta}{2} \end{bmatrix}, \tag{14}$$

$\otimes$ is the Kronecker product, Q and S are obtained by solving the following Π_{11}, Π_{21}, Π_{22} and Ψ.

$$\Pi_{11} \begin{bmatrix} A_p Q \ QA_p^T \ B_{p2}C \ C^T B_{p2}^T & B_{p1} \ B_{p2}DD_{p21} \\ B_{p1} \ B_{p2}DD_{p21}{}^T & -\gamma I \end{bmatrix} \tag{15}$$

$$\Pi_{21} \begin{bmatrix} A \ A_p \ B_{p2}DC_{p2}{}^T & S B_{p1} \ BD_{p21} \\ C_{p1}Q \ D_{p12}C & D_{p11} \ D_{p12}DD_{p21} \end{bmatrix} \tag{16}$$

$$\Pi_{22} \begin{bmatrix} A_p^T S \ SA_p \ BC_{p2} \ C_{p2}^T B^T & C_{p1} \ D_{p12}DC_{p2}{}^T \\ C_{p1} \ D_{p12}DC_{p2} & -\gamma I \end{bmatrix} \tag{17}$$

$$\Psi \begin{bmatrix} A_p Q \ B_{p2}C & A_p \ B_{p2}DC_{p2} \\ A & SA_p \ BC_{p2} \end{bmatrix} \tag{18}$$

A state-space representation of the controller Ks is

$$D_k \ D; \tag{19}$$

$$C_k \ C - D_k C_2 Q M^{T-1}; \tag{20}$$

$$B_k \ N^{-1}B - S B_{p2} D_k; \tag{21}$$

$$\begin{aligned} A_k \ N^{-1}A - SA \ B_{p2} D_k C_{p2} Q M^{T-1} \\ - B_k C_{p2} Q M^{T-1} - N^{-1} S B_{p2} C_k. \end{aligned} \tag{22}$$

by solving LMIs (19) to (22), Q, S and A, B, C, D are calculated, and M and N are given by

$$MN^T \ I - RS. \tag{23}$$

4. Proposed H_∞ RSOFC based on model-matching

4.1. Selection of reference model

The nominal (or reference) model is a realization in the state space and selected in order to give desired damping (over 10%) (cf. Fig. 4) and stable zeros (see details in [21]). It is possible to write the state model in the following form.

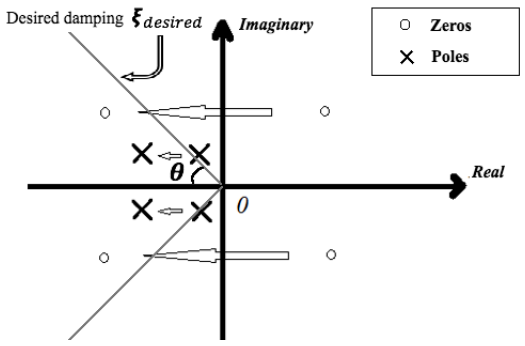

Figure 4: The selection of reference model

$$\begin{matrix} x_r \ A_r x_r \ B_r u_r \\ y_r \ C_r x_r \end{matrix} \tag{24}$$

The reference model and open-loop comparison validation is shown in Fig. 5. The proposed H_∞ RSOFC based on model-matching is given in Fig. 6.

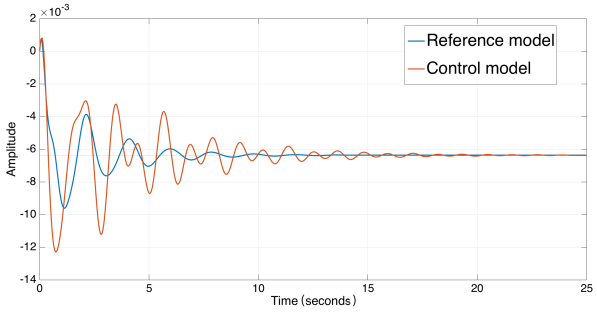

Figure 5: The reference model step response.

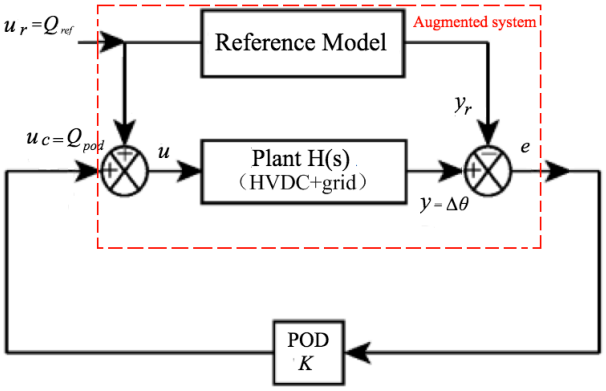

Figure 6: The proposed H_∞ RSOFC.

Based on (1) and (24), the augmented system is defined by the following state equations (cf. Fig. 6).

$$\begin{array}{l} X \;\; AX \;\; Bu_c \;\; B_r u_r \\ e \;\; C_e X \end{array} \tag{25}$$

where the controlled output is given by $e \;\; y - y_r$ and $X \;\; \left[x \quad x_r \quad e\right]^T$.

$$\begin{array}{l} A \left[\begin{array}{cc|c} A & 0 & 0 \\ 0 & A_r & 0 \\ \hline CA & -C_r A_r & 0 \end{array}\right], B \left[\begin{array}{c} B \\ 0 \\ CB \end{array}\right] \\ B_r \left[\begin{array}{c} B \\ B_r \\ CB - C_r B_r \end{array}\right], C_e \left[\begin{array}{ccc} 0 & 0 & I \end{array}\right] \end{array} \tag{26}$$

In this paper, the proposed H_∞ RSOFC is defined by

$$u_c \;\; Ke, \tag{27}$$

where K are the controller gains.

From (25), (26) and (27), the closed-loop system is given by ,

$$\begin{array}{l} X \;\; AX \;\; B_r u_r \\ e \;\; C_e X \end{array} \tag{28}$$

where $A \;\; A \;\; B\left[0 \quad 0 \quad K\right]$.

4.2. Proposed H_∞ RSOFC stability and robustness analysis

The conditions of global asymptotic stability to determine the controller gains so that the system (28) is robust is studied in this subsection. This leads to the conditions expressed in Theorem 1.

Theorem 1: The robust control system in the form (28) under the control law (27) is asymptotically stable if and only if $X \;\; X^T > 0$ and Y and below LMIs are verified

$$\min \gamma \tag{29}$$

subject to

$$\begin{array}{l} \left[\begin{array}{ccc} AX \;\; XA^T \;\; BY \;\; Y^T B^T & B_r & C_e * X^T \\ B_r{}^T & -\gamma I & 0 \\ C_e * X & 0 & -\gamma I \end{array}\right] < 0 \\ X > 0 \end{array} \tag{30}$$

Then, based on (30), the controller gains (27) are obtained.

$$K \;\; XY^{-1} \tag{31}$$

Proof. The proof of Theorem 1 is established by using the disturbance u_r to the output e Transfer Function (TF).

$$T_{u_r e} s \;\; C_e sI - A \;\; BK^{-1} B_r \tag{32}$$

By minimizing the H_∞ norm of (32) ($\|T_{u_r e}\|_\infty \leq \gamma$), the rejection of external disturbances is obtained. Based on bounded real lemma ([17, 28]), the robust control system in the form of a (28) is stable, if and only if the matrix $P \;\; P^T > 0$ is symmetric positive definite and the following LMIs are verified

$$\left[\begin{array}{ccc} A^T P \;\; PA & PB_r & C_e^T \\ B_r{}^T P & -\gamma I & 0 \\ C_e & 0 & -\gamma I \end{array}\right] < 0. \tag{33}$$

From, (28) and (33),

$$\left[\begin{array}{ccc} \phi & PB_r & C_e^T \\ B_r{}^T P & -\gamma I & 0 \\ C_e & 0 & -\gamma I \end{array}\right] < 0, \tag{34}$$

where $\phi \;\; A \;\; B\left[0 \quad 0 \quad K\right]^T P \;\; PA \;\; B\left[0 \quad 0 \quad K\right]$. Define

$$T \left[\begin{array}{ccc} P^{-1} & 0 & 0 \\ 0 & I & 0 \\ 0 & 0 & I \end{array}\right] \tag{35}$$

where I is the identity matrix. Multiplying left and right sides of the (34) by T and T^T, respectively, with $X \;\; KY$, $X \;\; P^{-1}$, the stability conditions (29) and (30) in Theorem 1 are obtained.

5. Proposed H_∞ DDOFC based on model-matching

To avoid to run the reference model in real-time in order to produce the e signal in the controller, a an output-feedback is proposed. The structure of the resulting model-matching robust H_∞ DDOFC is given in Fig. 7.

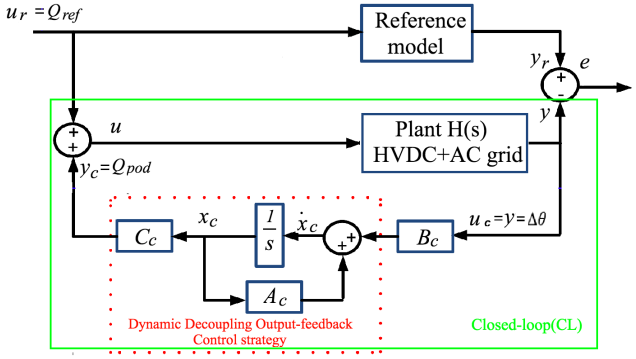

Figure 7: The robust H_∞ DDOFC strategy.

The proposed H_∞ DDOFC dynamic equations are given by the following form

$$\begin{matrix} x_c & A_c x_c & B_c u_c \\ y_c & C_c x_c \end{matrix} \tag{36}$$

From Fig. 7, it follows,

$$\begin{matrix} u & u_r - u_c & u_r - y_c & u_r - C_c x_c \\ u_c & y & Cx \end{matrix} \tag{37}$$

From (1), (24) and (36), the virtual system state-space equation is

$$\begin{matrix} X & AX & Bu_r \\ Y & CX \end{matrix} , \tag{38}$$

where $Xt \begin{bmatrix} x \\ x_r \\ x_c \end{bmatrix}^T$, and

$$A \begin{bmatrix} A & 0 & -BC_c \\ 0 & A_r & 0 \\ B_c C & 0 & A_c \end{bmatrix}, B \begin{bmatrix} B \\ B_r \\ 0 \end{bmatrix}, C \begin{bmatrix} -C \\ C_r \\ 0 \end{bmatrix}^T .$$

5.1. Proposed H_∞ DDOFC stability and robustness analysis

Theorem 2: The virtual system (VS) in the form (38) subject to the proposed H_∞ DDOFC dynamic law (36) is asymptotically stable if and only if the matrcies $Q, Z \in \Re^{nn_r \times nn_r}$ are symmetric positive definite , $\widehat{A}, \widehat{B}, \widehat{C} \in \Re^{nn_r \times nn_r}$, are non singular and scalar γ, and below LMIs are verified,

$$\min \gamma \tag{39}$$

$$\begin{bmatrix} \phi_1 & \phi_1^T & \widehat{A}^T \begin{bmatrix} A & 0 \\ 0 & A_r \end{bmatrix} & \begin{bmatrix} B \\ B_r \end{bmatrix} & Q \begin{bmatrix} -C^T \\ C_r^T \end{bmatrix} \\ * & & \phi_2 \ \phi_2^T & Z \begin{bmatrix} 0 \\ B_r \end{bmatrix} \widehat{B} & \begin{bmatrix} -C^T \\ C_r^T \end{bmatrix} \\ * & & * & -\gamma I & 0 \\ * & & * & 0 & -\gamma I \end{bmatrix} \leq 0 \tag{40}$$

$$\begin{bmatrix} Q & I \\ I & Z \end{bmatrix} \geq 0 , \tag{41}$$

where

$$\phi_1 \begin{bmatrix} A & 0 \\ 0 & A_r \end{bmatrix} Q \begin{bmatrix} -B\widehat{C} \\ 0 \end{bmatrix}, \phi_2 \ Z \begin{bmatrix} A & 0 \\ 0 & A_r \end{bmatrix} \begin{bmatrix} B\widehat{B}C \\ 0 \end{bmatrix}^T ,$$

Therefore, by solving LMIs (40)-(41), the H_∞ DDOFC parameters can be written as follows:

$$A_c \ N^{-1} A M^{-T}, B_c \ N^{-1}\widehat{B}, C_c \ \widehat{C} M^{-T}, \tag{42}$$

where

$$A \ \widehat{A} - Z \begin{bmatrix} A & 0 \\ 0 & A_r \end{bmatrix} Q - N \begin{bmatrix} B_c C \\ 0 \end{bmatrix}^T Q - Z \begin{bmatrix} BC_c \\ 0 \end{bmatrix} M^T \tag{43}$$

and

$$NM \ I - ZQ. \tag{44}$$

Proof. By minimizing the H_∞ norm of (32) ($\|T_{u_r e}\|_\infty \leq \gamma$), the rejection of external disturbances is obtained. Based on bounded real lemma ([17], [28]), the robust control system in the form of a (36) is stable, if and only if the matrix $W \in \Re^{2nn_r \times 2nn_r}$ is symmetric positive definite and LMIs are satisfied,

$$\begin{bmatrix} A^T W \ WA & WB & C^T \\ B^T W & -\gamma I & 0 \\ C & 0 & -\gamma I \end{bmatrix} \leq 0 \tag{45}$$

$$W \geq 0 . \tag{46}$$

Based on Schur complement method [29]- [32] using W and W^{-1} , we have;

$$W \begin{bmatrix} Z & N \\ N^T & \star \end{bmatrix}, W^{-1} \begin{bmatrix} Q & M \\ M^T & \star \end{bmatrix} \tag{47}$$

where $\star$ is unknown matrix. Let

$$_1 \begin{bmatrix} Q & I \\ M^T & 0 \end{bmatrix}, _2 \begin{bmatrix} I & Z \\ 0 & N^T \end{bmatrix} \tag{48}$$

From $WW^{-1} \ I$, it can be inferred

$$_2 \ W \ _1 \tag{49}$$

In this case,

$$_2^T WA \ _2^T A \ _1 \tag{50}$$

So that,

$$\begin{matrix} {}_2^T A \ _1 \begin{bmatrix} I & 0 \\ Z & N \end{bmatrix} \begin{bmatrix} A & 0 & -BC_c \\ C & A_r & 0 \\ B_c C & 0 & A_c \end{bmatrix} \begin{bmatrix} Q & I \\ M^T & 0 \end{bmatrix} \\ \begin{bmatrix} \begin{bmatrix} A & 0 \\ 0 & A_r \end{bmatrix} Q \begin{bmatrix} -BB_c \\ 0 \end{bmatrix} M^T & \begin{bmatrix} A & 0 \\ 0 & A_r \end{bmatrix} \end{bmatrix} \\ Q_1 \qquad\qquad Q_2 \end{matrix} \tag{51}$$

and,

$$_1^T WB \ _2^T B \ _1 \begin{bmatrix} I & 0 \\ Z & N \end{bmatrix} \begin{bmatrix} B \\ B_r \\ 0 \end{bmatrix} \begin{bmatrix} B \\ B_r \\ Z \begin{bmatrix} B \\ B_r \end{bmatrix} \end{bmatrix} . \tag{52}$$

Then,

$$ {}^{T}_{1}C \begin{bmatrix} \begin{bmatrix} -C & C_r & C \end{bmatrix} \begin{bmatrix} Q & I \\ M^T & 0 \end{bmatrix} \end{bmatrix}^T \begin{bmatrix} Q \begin{bmatrix} -C^T \\ C_r^T \end{bmatrix} \\ -C_r^T \\ C_r^T \end{bmatrix} \tag{53} $$

where,

$$ \begin{array}{l} Q_1 \;\; Z \begin{bmatrix} A & 0 \\ 0 & A_r \end{bmatrix} Q \;\; N \begin{bmatrix} B_c & C & 0 \end{bmatrix} Q \;\; Z \begin{bmatrix} -BC_c \\ 0 \end{bmatrix} M^T \\ NA_cM^T, \\ Q_2 \;\; Z \begin{bmatrix} A & 0 \\ 0 & A_r \end{bmatrix} \;\; N \begin{bmatrix} B_c & C & 0 \end{bmatrix} \end{array} \tag{54} $$

Thus,

$$ \begin{array}{l} A \;\; Z \begin{bmatrix} A & 0 \\ 0 & A_r \end{bmatrix} Q \;\; N \begin{bmatrix} B_c & C & 0 \end{bmatrix} Q \;\; Z \begin{bmatrix} -BC_c \\ 0 \end{bmatrix} M^T \\ NA_cM^T, \\ B \;\; NB_c, C \;\; C_cM^T \end{array} . \tag{55} $$

Therefore, (45) and (46) are equivalent to (40) and (41).

6. Validation Tests

In this section, RSOFC and DDOFC controllers depicted in Sections 4 and 5 are validated in linearized full model and nonlinear model and compared with the other controllers presented in Sections 2 and 3.

6.1. Linearized model validation

The model tested in this section is the linearized model from EUROSTAG and tested in Matlab with a step disturbance on angle difference $\Delta\theta$. They are shown in Fig. 8. The modes can be identified by measuring their frequency from two peaks. The description of these results are shown below:

1. at $t \;\; 8s$, mode 2: compared to the classic POD and RSOFC, DDOFC POD and LQG POD give better damping.

2. from $t \;\; 2s$ to $4s$, mode 5: The performance of DDOFC POD, LQG POD, and mixed sensitivity H_∞ POD give less undershoot and sufficient damping.

3. from $t \;\; 1s$ to $3s$, mode 1 (in zoomed figure of open-loop curve): Only observed in the curve with LQG.

Based on Table 2 analysis, it can be observed that, the proposed DDOFC POD gives the desired target damping of modes 1 and 2 without disturbing the others and a better damping in a wide range frequency band. The damping for each mode is over 10% for DDOFC POD, LQG POD, and H_∞ POD while the classic POD enhance the damping of mode 2, but encumber mode 4. Mode 3 damping is reached highest value for LQG POD but it's acceptable for mixed sensitivity POD during mode 4 and 5. On the other hand, damping for each mode is decreased excepting for mode 5 when RSOFC is used.

6.2. Nonlinear system validation

The study and robustness analysis is more difficult due to the system nonlinearities. In addition, each response curve is the result of several modes mixed with a nonlinear dynamic. It is therefore difficult to highlight each mode individually. Disturbance scenarios must be well chosen. Moreover, the observability of the modes depends on the selected output signal. To validate the performance and robustness of the proposed controllers, two situations are considered: for the first one, called *nominal operation case*, the simulations are carried with the same grid situation considered for the synthesis of the controllers. For the second one, called *robust operation case*, the grid is disturbed (with load variations, line/generators tripping) for simulation without recomputing the controllers.

The performances and robustness of proposed strategies are validated on nonlinear model with Eurostag software. A short-circuit is performed at generator GE_918 terminal bus. Due to the fact that generator GE_918 is closed to GE_911, which is the most participating machine in mode 2 (ff.Table 1), this disturbance excites the modes of interest.

6.2.1. Nominal operation case

Fig. 9 shows the response of the proposed strategies in the nominal operation case.

According to the zoom of Fig. 9, one can see that for mode 2 (we recognize it by measuring the frequency between the peaks of the curves from the oscillation 8^{th}), the DDOFC, the mixed sensitivity H_∞ POD and LQG POD give more damping compared to RSOFC and classic POD. In addition, at $t \;\; 3s$, the contributions of several mixed modes with nonlinear dynamics are observable. Moreover, between the 4^{th} and 8^{th} oscillations (the period during which mode 1 can be observed), (cf. table 2).

6.2.2. Robust operation cases

Different disturbed grid situations are considered to validate the proposed strategies in uncertainties case. These cases correspond to the robustness issue: variation of some of its parameters - called *parametric robustness* (see details in [22]).

Responses obtained with the same controllers considered above are now shown in Fig. 10, 11, 12, 13.

- **Reverse power flow case (in Fig. 10)**

  1. at $t \;\; 12s$ (mode 2): RSOFC POD and mixed sensitivity H_∞ POD give more damping.
  2. From oscillation 3^{rd} (mode 4): Although the RSOFC POD give more damping compared to the other controllers, but it gives insufficient damping nominal operation case.
  3. from $t \;\; 3s$ to $t \;\; 5s$: With the mixed sensitivity H_∞ the POD gives small oscillation at $t \;\; 3.5s$ (cf. Fig. 10).

- **Increased load case (in Fig. 11)**

Table 2: Comparison of damping

No.	damping (ξ) without POD (%)	damping (ξ) with classic POD (%)	damping (ξ) with LQG POD (%)	damping (ξ) with Mixed sensitivity H_∞ POD(%)	damping (ξ) with RSOFC POD (%)	damping (ξ) with DDOFC POD(%)
1	19.5	30.5	21.7	20.29	18.6	23.3
2	4.5	6.1	10.9	11.67	4.2	12.6
3	10.1	12.0	14.9	12.33	9.6	10.8
4	8.3	8.1	11.4	12.41	7.9	10.6
5	10.1	12.4	13.6	14.97	14.2	14.1

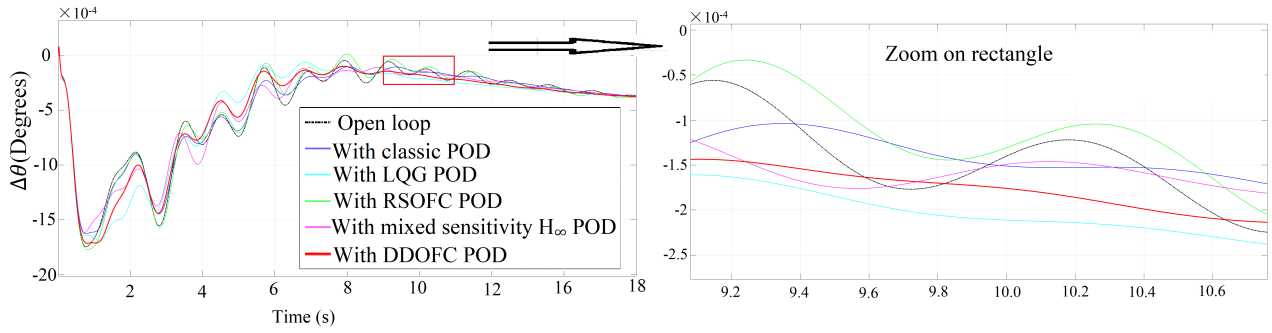

Figure 8: Comparison of linearized model.

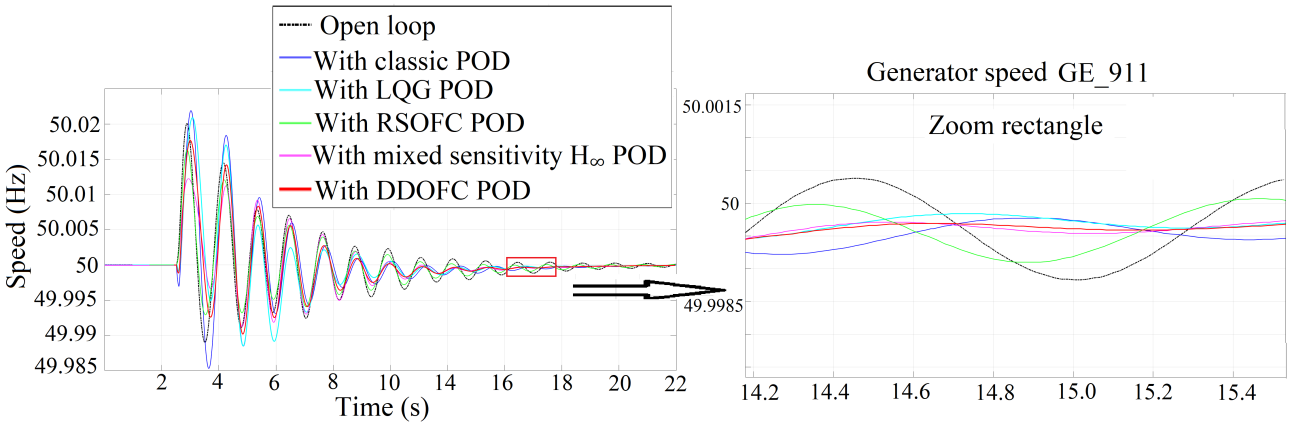

Figure 9: Nominal operation case.

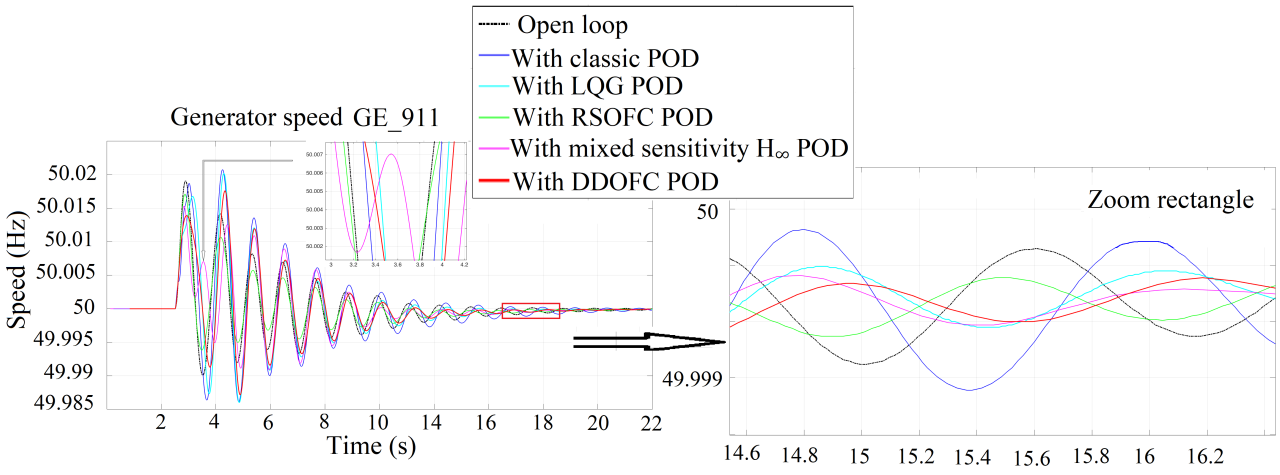

Figure 10: Reverse power flow case.

1. at t 12s (mode 2): H_∞, LQG and DDOFC POD

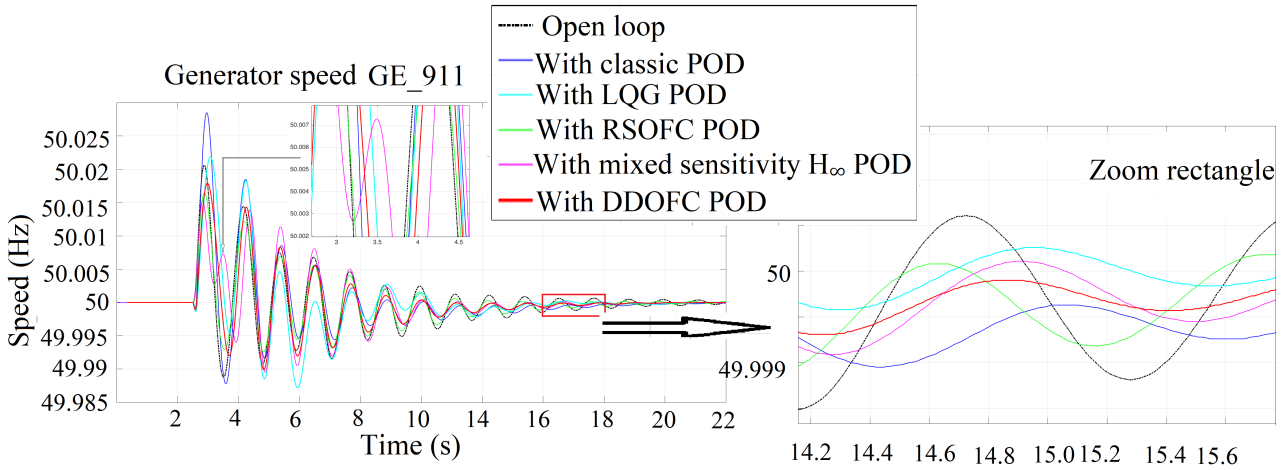

Figure 11: Increase load case.

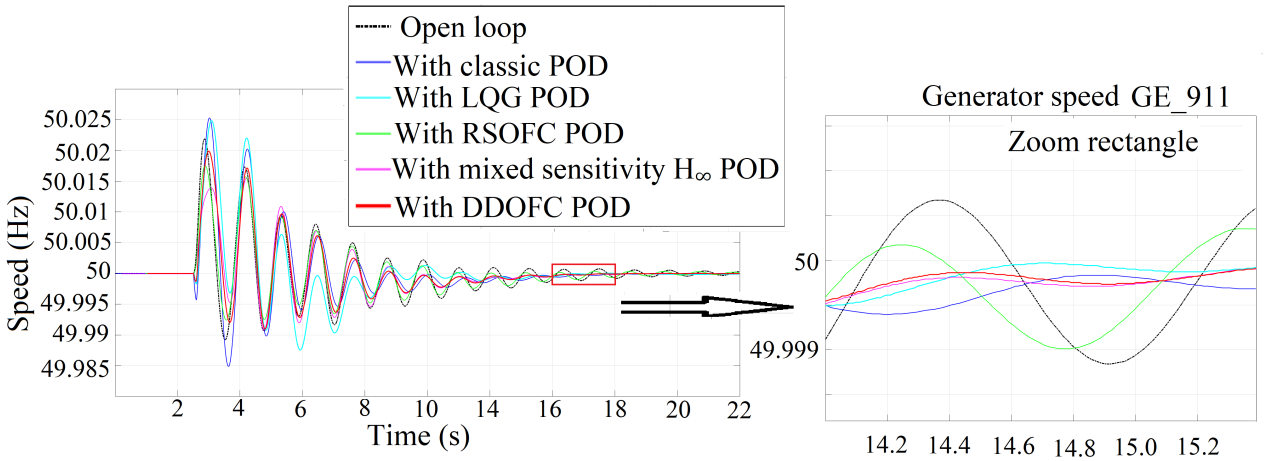

Figure 12: Tripping generator case.

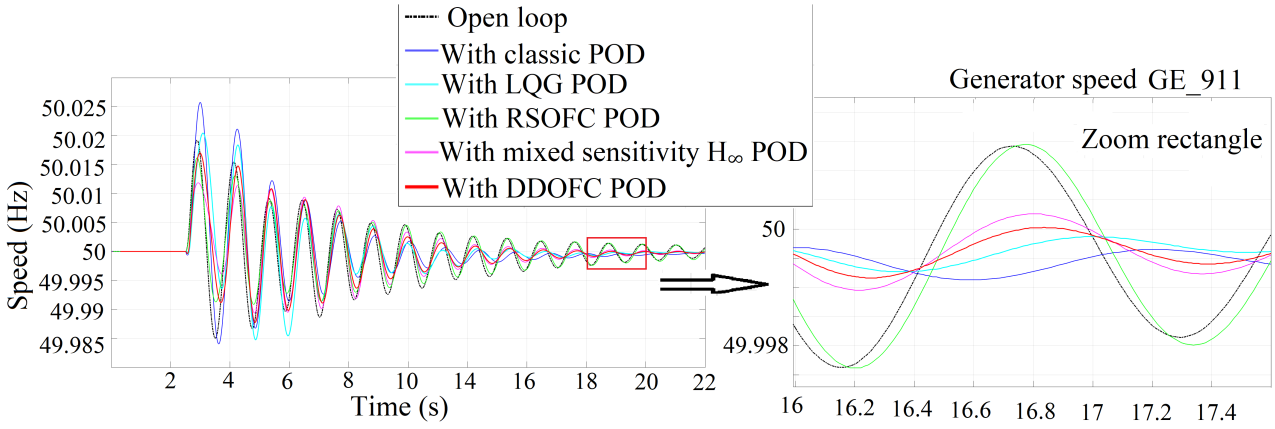

Figure 13: Tripping lines case.

give the same acceptable damping.

2. From the oscillation 3^{rd} to 5^{th}: the damping provided by the H_∞ POD is not sufficient for mode 4. In addition, the overshoot with LQG POD in the first oscillation is undesirable.

- **Tripping generator case (in Fig. 12)**

1. During the first two oscillations: the POD LQG as well as the classic POD even increase the oscillations during the first two swings.

2. From t 12s (mode 2): The DDOFC, the mixed sensitivity H_∞ and the LQG POD, have more damping compared to the other controllers.

3. DDOFC POD gives more damping than the other controllers during the 3^{th} to the 6^{th} swing (mode 1).

- **Tripping lines case (In Fig. 13)**

1. 4^{th} to 8^{th} oscillation (mode 1): Classic, LQG, and DDOFC POD give more damping during the 4^{th} to the 8^{th} swing (mode 1).
2. In the zoomed figure (mode 2), the damping is greater with the DDOFC than with the mixed sensitivity H_∞ and the RSOFC POD.
3. The overshooths is greater with LQG POD than with open-loop during the first two swings.

In summary, the proposed DDOFC POD is more robustness and better damping for all the cases.

7. Conclusion

In this paper two robust model-matching based POD are studied. Sufficient conditions are derived for robust stabilization, in the sense of Lyapunov method and based on a reference model and have been formulated using an LMI format to obtain the controllers' gains. The robustness of the proposed controller is finally tested and compared to LQG, mixed sensitivity H_∞ and standard (IEEE) POD controllers on a realistic benchmark of 19 generators connected by a meshed AC grid.

Paper contributions are: (i) improves damping and robustness subject to the unstable zeros compared with standard controller structures (LQG, mixed sensitivity H_∞ and standard POD controllers); (ii) the proposed controller is validated using Eurostag, which is an industrial software for grid dynamics ; (iii) it can be easily implemented in real case and it consists in a simple output-feedback.

The control methodology is applied here for Q modulation but can be extended to coordinate P and Q modulation of the HVDC link.

It is planned in the near future to implement the overall proposed control strategy on the France-Spain and France-Italy HVDC interconnection in real grid situations.

8. Appendix

8.1. LQG controller:

Based on LQG 3.1, the gains are given by:
L=[-164.18 47.48 80.33 57.635 96.34 -19.51 2.81 48.01 35.078 8.58 -7.82 -0.33 -9.20^T;
K_r=[13.7682 -3.3704 -4.0354 6.5771 7.0691 4.3546 2.4524 -1.5362 1.1628 0.7133 -0.4256 -0.6244 -0.5161].
u to Q_{pod} Transfer Function(TF) is H_1, and TF fomr $\Delta\theta$ to u is H_2:

$$H_1 \quad \begin{matrix} n-1 & n \\ i0 & j0 \end{matrix} \frac{N1_i s}{D1_j s} \quad \frac{N1_{n-1}s_n \ \dots \ N1_1 s \ N1_0}{D1_n s_n \ \dots \ D1_1 s \ D1_0} \tag{56}$$

$$H_2 \quad \frac{N2_{n-1}s^{n-1} \ \dots \ N2_1 s \ N2_0}{D2_n s^n \ \dots \ D2_1 s \ D2_0} \tag{57}$$

n 13 (including the wash-out filter (dimension 1))(cf. Table 3).

Table 3: TF of LQG POD paramaters

i,j=	N1	D1	N2	D2
13	/	1	/	1
12	-3.681	43.19	1781	43.19
11	-189.3	785.2	1.814e04	785.2
10	-3051	1.092e04	3.614e05	1.092e04
9	-3.894e04	1.087e05	2.343e06	1.087e05
8	-3.575e05	8.942e05	2.358e07	8.942e05
7	-2.571e06	5.837e06	9.686e07	5.837e06
6	-1.513e07	3.203e07	6.336e08	3.203e07
5	-7.04e07	1.431e08	1.381e09	1.431e08
4	-2.672e08	5.266e08	6.488e09	5.266e08
3	-8.032e08	1.557e09	-3.658e08	1.557e09
2	-1.735e09	3.469e09	5.733e09	3.469e09
1	-2.923e09	5.716e09	-9.87e10	5.716e09
0	-1.42e09	4.454e09	-1.387e11	4.454e09

8.2. Mixed sensitivity H_∞ controller:

The H_∞ controller TF in 3.2 is:

$$K s \quad \frac{N_{n-1}s^{n-1} \ \dots \ N_1 s \ N_0}{D_n s^n \ \dots \ D_1 s \ D_0} \tag{58}$$

In (58), n 15 (including the wash-out filter (dimension 1) and frequency weights (dimension 2)). H_∞ controller parameters are given in Table 4

Table 4: TF of H_∞ POD paramaters

i=	N	D
15	/	1
14	9.4e05	4.6e05
13	9.4e7	7.8e06
12	1.1e9	1.5e08
11	1.9e10	1.5e09
10	1.38e11	1.5e10
9	1.3e12	9.8e10
8	5.95e12	6.3e11
7	3.51e13	2.91e12
6	1.1e14	1.3e13
5	4.3e14	3.9e13
4	7.4e14	1.17e14
3	1.8e15	2.15e14
2	1.1e15	3.9e14
1	-3.3e13	2.6e14
0	3.3e14	1.1e13

8.3. Reference model:

The reference model TF used in proposed two controller:

$$f_r s \quad \frac{Nr_{n-1}s^{n-1} \ \dots \ Nr_1 s \ Nr_0}{Dr_n s^n \ \dots \ Dr_1 s \ Dr_0} \tag{59}$$

n 12 (cf. Table 5).

Table 5: Reference model TF

i=	Nr	Dr
12	/	1
11	0.02143	19.54
10	0.1264	355.5
9	0.9629	3773
8	- 1.255	3.6e4
7	- 126.5	2.5e5
6	- 1088	1.6e6
5	- 9771	7.2e6
4	- 5.1e4	3.1e7
3	- 2.3e5	9.2e7
2	- 8.7e5	2.7e8
1	- 1.8e6	4.1e8
0	- 4.7e6	7.3e8

8.4. ROSCF controller:

The gains calculated in (31):
Y=1.150696148547366e-12;
X=2.009746646814367e-13.
Then, the gain of the controller is: K 5.725578148724988. Notice that the dimension of the ROSCF controller is 13 (equal to the dimension of the reference model (12) + the one of the wash-out filter (1)).

8.5. DDOFC controller:

The transfer function of controller DDOFC Ks:

$$Ks \quad \frac{Nd_{n-1}s^{n-1} \quad \dots \quad Nd_1 s \quad Nd_0}{Dd_n s^n \quad \dots \quad Dd_1 s \quad Dd_0} \tag{60}$$

Since the order of the controller depends on the control model plus reference model, n 26 (dimension of the plant (12) + dimension of the reference model (12) + wash-out filters for the plant and reference model (2)). Parameters are shown in Table 6.

Table 6: Transfer function of DDOFC POD paramaters

i=	Nd	Dd
26	/	1
25	5.267e05	4.057e04
24	1.713e07	1.465e06
23	4.532e08	4.032e07
22	8.033e09	7.692e08
21	1.225e11	1.234e10
20	1.496e12	1.621e11
19	1.616e13	1.865e12
18	1.481e14	1.856e13
17	1.217e15	1.65e14
16	8.672e15	1.3e15
15	5.573e16	9.242e15
14	3.119e17	5.888e16
13	1.568e18	3.402e17
12	6.764e18	1.768e18
11	2.567e19	8.326e18
10	7.833e19	3.519e19
9	1.879e20	1.341e20
8	1.951e20	4.546e20
7	- 7.141e20	1.372e21
6	- 6.079e21	3.617e21
5	- 2.359e22	8.277e21
4	- 6.919e22	1.593e22
3	-1.507e23	2.516e22
2	- 2.483e23	3.057e22
1	- 2.907e23	2.551e22
0	- 1.568e23	1.08e22

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