Ways to Increase the Efficiency of Sucker Rod Pump Units in Oil Production

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ABSTRACT: The article shows that in the middle and late stages of oil field development, of all mechanized methods, the most common is oil extraction by sucker rod pump units (SRPU). However, due to inefficient management of them, their operating costs are increasing. The article presents the results of improving the efficiency of SRPU due to the use of NOISE technology for early diagnosis of the technical condition of equipment and frequency converters for controlling its induction motor. The results of the implementation of the "NOISE Control, Diagnostics and Management Complex for oil wells operated by SRPU" created at the Institute of Management Systems of the National Academy of Sciences of Azerbaijan are presented. A method for calculating the saving of electrical energy in the control of SRPU frequency converters has been developed. The results of calculation of electric energy savings for the oil and gas production facility Bibi-Heybat Oil of the Republic of Azerbaijan are also presented.

KEYWORDS: Oil production, Sucker rod pump units, Electric Drives, Induction motor, Efficiency, NOISE Technology, Robust Technology, Frequency Converters

1. Introduction

Currently, most oil fields are in the middle and late stages of development, where the reservoir pressure is not sufficient to lift the liquid to the surface of the earth. At the same time, the reservoir pressure is maintained by pumping water into the reservoir, which contributes to an increase in the water content in the total liquid. According to published data, the water content in the liquid extracted from an oil well in the USA is about 90% [1], and in the Russian Federation it is about 86% [2]. At the same time, they are forced to use mechanized methods of oil production. Currently, the main methods of mechanized mining are the use of sucker rod pump units (SRPU) and installations of electric submersible pumps (ESP). The published data indicate that in the Russian Federation 41% of wells are operated by SRPU and 54% by ESP [3], and in the USA more than 85% of wells with mechanized production are equipped with SRPU [4]. They are the main pumping system that provides mechanical energy for oil

production [5]. Advantages of SPRU are simplicity, reliability and the possibility of application in a wide range of operating conditions [6].

However, with the use of mechanized mining, due to inefficient management of them, the operating costs of production increase dramatically [7] and, consequently, the production benefits become lower [8]. Thus, at the same time, one of the important issues is to increase the efficiency of SPRU. Research conducted at the Institute of Control Systems of ANAS of Azerbaijan for many years, as well as experience in oil and gas production fields, have shown that the main sources of operating costs are:

- the costs of repairing ground and underground equipment of wells operated with SPRU due to untimely diagnostics and inadequate identification of technical conditions that lead to unnecessary downtime and material costs;

- electricity supply costs.

2. Problem Statement

Thus, one of the possible ways to increase the efficiency of SPRU by reducing the cost of repairing ground and underground equipment of wells using NOISE technology for diagnostics and adequate identification of technical conditions and power supply costs using frequency converters to control an induction motor is given. The task is also set to develop a methodology for calculating the savings of electrical energy when using a frequency-controlled drive of the SPRU.

3. Solving the problem. NOISE technology for early diagnosis and adequate identification of the technical condition of rod deep-pumping units

In the paper robust technology and control system of oil wells SPRU [9], a sequence of calculations is proposed, the totality of which constitutes the procedure for normalizing correlation functions:

1) According to the expression

$$R_{gg}(\mu) = \frac{1}{N}\sum_{i=1}^{N} g(i\Delta t)g((i+\mu)\Delta t);$$

estimates of the correlation function of the noisy signal are calculated for $\mu = 1, 2, 3, 4, \ldots$

2) According to the expression

$$D_g = \frac{1}{N}\sum_{i=1}^{N} g(i\Delta t)g(i\Delta t);$$

the estimate of the variance of the noisy signal is calculated.

3) According to the expression

$$D_\varepsilon = \frac{1}{N}\sum_{i=1}^{N}[g^2(i\Delta t) + g(i\Delta t)g((i+2)\Delta t) - 2g(i\Delta t)g((i+1)\Delta t)];$$

an estimate of the interference variance D_ε is calculated.

4) According to the expression

$$R_{UU}(\mu = 0) = D_g - D_\varepsilon;$$

the variance value $R_{UU}(\mu=0)$ of the useful signal $U_P(i\Delta t)$ is calculated.

5) According to the expression

$$r_{gg}^R(\mu) = \begin{cases} \dfrac{R_{gg}(\mu=0)}{D_g} = 1 & \text{by } \mu = 0 \\[2mm] \dfrac{R_{gg}(\mu)}{D_g - D_\varepsilon} = 1 & \text{by } \mu \neq 0 \end{cases};$$

estimates of the normalized correlation function $r_{gg}^R(\mu)$ of the noisy signal $g(i\Delta t)$ are calculated at $\mu = 0, 1, 2, 3, \ldots$

The proposed procedure makes it possible to calculate robust estimates (free from errors caused by interference in the signal composition) of the normalized autocorrelation function $r_{gg}^R(\mu)$ of the noisy signal $g(i\Delta t)$.

The main idea of robust analysis is to develop estimates that are resistant to outliers and at the same time show a result close enough to classical methods on data that do not contain atypical observations.

Applying what has been said to the measured output signal of the force sensor of the column of rods on the suspension of the SPRU, you can make the following procedure for calculating informative signs to identify the technical condition of the SPRU:

1. The swing period T_{ST} SPRU is divided into 8 equal time intervals ΔT_{ST} (For example, if T_{ST} = 1024 samples of discrete values of the force signal are taken during the swing period of the SPRU, then ΔT_{ST} will be equal to 128 samples);

2. The normalized correlation function $r_{gg}^R(\mu)$ of the noisy force signal $g(i\Delta t)$ is calculated;

3. The estimates of $r_{gg}^R(\mu=0)$, $r_{gg}^R(\mu=1\Delta T_{ST})$, $r_{gg}^R(\mu=2\Delta T_{ST})$, ..., $r_{gg}^R(\mu=7\Delta T_{ST})$ are calculated using the expressions:

$$\Delta r_{gg}^R(\mu = 1\Delta T_{ST}) = r_{gg}^R(\mu = 0) - r_{gg}^R(\mu = 1\Delta T_{ST}),$$
$$\Delta r_{gg}^R(\mu = 3\Delta T_{ST}) = r_{gg}^R(\mu = 2\Delta T_{ST}) - r_{gg}^R(\mu = 3\Delta T_{ST}),$$
$$\Delta r_{gg}^R(\mu = 5\Delta T_{ST}) = r_{gg}^R(\mu = 4\Delta T_{ST}) - r_{gg}^R(\mu = 5\Delta T_{ST}),$$
$$\Delta r_{gg}^R(\mu = 7\Delta T_{ST}) = r_{gg}^R(\mu = 6\Delta T_{ST}) - r_{gg}^R(\mu = 7\Delta T_{ST}).$$

4. The minimum value of the normalized correlation function of the noisy signal $r_{gg\,min}^R(\mu)$ and the corresponding value of μ_{min} are calculated.

5. Informative features are determined in the form of the following coefficients.

$$K_{N1}^R = \Delta r_{gg}^R(\mu = 1\Delta T_{ST}); K_{N2}^R = \Delta r_{gg}^R(\mu = 3\Delta T_{ST});$$
$$K_{N3}^R = \Delta r_{gg}^R(\mu = 5\Delta T_{ST}); K_{N4}^R = \Delta r_{gg}^R(\mu = 7\Delta T_{ST});$$
$$K_{N5}^R = \frac{\Delta r_{gg}^R(\mu = 1\Delta T_{ST})}{\Delta r_{gg}^R(\mu = 3\Delta T_{ST})}; K_{N6}^R = \frac{\Delta r_{gg}^R(\mu = 1\Delta T_{ST})}{\Delta r_{gg}^R(\mu = 5\Delta T_{ST})};$$
$$K_{N7}^R = \frac{\Delta r_{gg}^R(\mu = 1\Delta T_{ST})}{\Delta r_{gg}^R(\mu = 7\Delta T_{ST})}; K_{N8}^R = \frac{\Delta r_{gg}^R(\mu = 3\Delta T_{ST})}{\Delta r_{gg}^R(\mu = 5\Delta T_{ST})};$$
$$K_{N9}^R = \frac{\Delta r_{gg}^R(\mu = 3\Delta T_{ST})}{\Delta r_{gg}^R(\mu = 7\Delta T_{ST})}; K_{N10}^R = \frac{\Delta r_{gg}^R(\mu = 5\Delta T_{ST})}{\Delta r_{gg}^R(\mu = 7\Delta T_{ST})};$$
$$K_{N11}^R = \Delta r_{gg\,min}^R(\mu).$$

Below, the possibility of using the coefficients K^R_{N1}–K^R_{N11} as informative signs for identifying the technical condition of the SPRU will be shown.

The obtained informative signs in the form of coefficients K^R_{N1}–K^R_{N11} were used in the complex of NOISE control systems as informative signs for identifying the technical condition of the SPRU, for the oil and gas production facility Bibi-Heybat Oil [10].

4. The system of NOISE control, diagnostics and control of SPRU with the use of frequency converters

To ensure the effective operation of the SPRU, it is necessary to carry out continuous monitoring, identification of the technical condition and control (change in the swing number of the SPRU) of the object in real time, which easily implemented based on frequency converters.

Figure 1 shows a block diagram of the NOISE monitoring, diagnostics and control system of the SPRU using frequency converters and a view of the station on the installation. The block diagram consists of three levels:

1. The level of a deep-pumping unit consisting of a plunger deep pump "1"; plunger "2"; pumping pipes "3"; rods "4"; polished rod "5"; balancer head "6"; balancer "7"; connecting rod "8"; crank counterweight "9"; gearbox "10"; V-belt transmission "11"; induction motor "12"; balancing counterweight "13"; force sensor "14"; wellhead pressure sensor "15"; rotation angle sensor "16".

2. The level of the control station, consisting of a SPRU controller according to a dynamogram for collecting information from force sensors "14", wellhead pressure "15" and rotation angle "16"; a frequency converter for controlling the speed of the electric motor; a radio modem with an antenna for information exchange of the SRPU control system with a centralized control center using the MODBUS-RTU protocol.

3. The level of the centralized control center of the oil field consists of an industrial computer and a radio modem with an antenna and serves up to 200 wells [11].
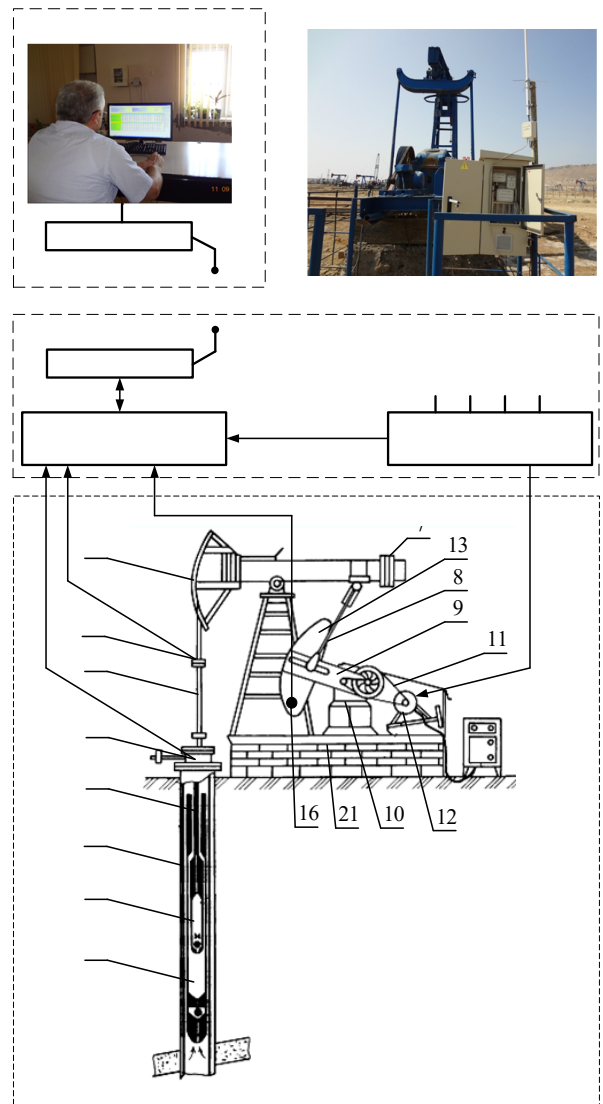

Figure 1: The block diagram of the NOISE control, diagnostics and control system of the SPRU with the use of frequency converters and the type of station on the installation

The SPRU control system uses the technology of dynamogram identification based on the estimates of the normalized correlation functions of the force signal $U_p(i\Delta t)$. To implement them, first of all, based on the duration of the interval of the swing period T_{ST}, the sampling step of the signal was determined [12]. For most oil wells, the duration of the T_{ST} time varies in the range of $5 = 20$ seconds. At the same time, we experimentally found that in order to obtain estimates of the robust correlation function $r^R_{gg}(\mu)$ with the necessary accuracy, it is sufficient to discretize the signal of the effort with a frequency $f = 50 - 100$ Hz. Experimentally, it was found that during the swing period, any slight change in the technical condition of the SPRU is reflected in the estimates of robust informative signs K^R_{N1}–K^R_{N11}. As a result of the SPRU operation process, the corresponding reference combinations of these coefficients are formed and stored for its various technical conditions. Identification of the technical condition of the SPRU is reduced to the formation of the current combination of informative features and their comparison with the corresponding

combinations of reference informative features K_{N1}^R–K_{N11}^R. Due to this, there is no need for a visual interpretation of the dynamogram to determine the current technical condition of the SPRU.

The signals from the frequency converter are sent to the induction motor and the SPRU Dynamometry controller. Further, after starting the installation in operating mode, the information is sent from the force sensors, wellhead pressure and rotation angle to the SPRU Dynamometry controller, to which a radio modem with an antenna is connected.

5. Improving the efficiency of SPRU by reducing the cost of power supply using frequency converters

As an electric drive of SPRU, induction motors (IM) with increasing starting torque of 0.4 kV, power from 7.5 to 55 kW, and synchronous rotation speed of 500 ...1500 rpm are mainly used. Electric motors (EM) of the 5A, 6A, and AIR series are widely used [13].

Induction motors are widely used in almost of industries (compressor and pumping stations, ventilation systems, conveyors, elevators, cranes, submersible pumps, etc.). The main advantages of induction motors are simplicity of design, high reliability, low cost, etc.

Interest in the use of IM has increased even more due to the appearance of a wide range of affordable and reliable frequency converters for regulating the rotation speed of electric motors in a large range [14]. Various energy-saving control stations (CS) for RDPU with the use of frequency converters began to be created, which provide significant advantages in comparison with conventional CS. Thus, the introduction and operation of CS RDPU in the fields of the Bibi-Heybat oil and gas production department showed its effectiveness. The sources of economic efficiency are the following factors [15,16]:

– saving of consumed electric energy by more than 30%;

– saving costs for the repair of wells and oil production equipment by more 20% due to the reduction of mechanical elements wear;

– reduction of production losses by more 2% due to the reduction of well downtime during repairs;

- a significant indicator of the system's performance is an increase in the inter-repair period of wells by more than 20%.

However, the calculation of electric energy savings raises doubts among consumers due to the lack of a sound calculating methodology. The article proposes a methodology for calculating the saving of electric energy when using a control station of SPRU with variable frequency drive.

6. The method of calculating the savings of electrical energy in the control of SPRU with a frequency-controlled drive

When calculating the consumed electric energy by oil-production equipment, it is necessary to take into account the active input (P_1) and output (P_2) powers of the frequency converter according to the following formulas [17], [18]:

$$P_1 = \sqrt{3} \cdot U_1 \cdot I_1 \cdot \cos \varphi_1, \tag{1}$$

$$P_2 = \sqrt{3} \cdot U_2 \cdot I_2 \cdot \cos \varphi_2, \tag{2}$$

where P_1, U_1, I_1, $\cos\varphi_1$ – power, voltage, current, and power factor at the inverter input, P_2, U_2, I_2, $\cos\varphi_2$ – power, voltage, current and power factor at the inverter output.

It is known that the value of the power factor at the inverter output $\cos\varphi_2$ varies depending on the degree of motor load from 0.17 to 0.85 [17], [18]. The values of the power factor at the inverter output, depending on the load for a common industrial induction motor, are shown in Table 1.

Table 1: Power Factor Dependence at the Inverter Output from the Load for a Common Industrial Induction Motor

Load, %	Power factor $\cos\varphi_2$	Power factor $\text{tg}\varphi_2$
0	0.17	5.80
25	0.55	1.52
50	0.73	0.94
75	0.80	0.75
100	0.85	0.62

The values of the power factor should be taken into account in the calculation of the energy consumed [19], [20], [21]. However, the data in Table 1 are given with great discreteness, which makes it difficult to use them in calculations. For this purpose, using piecewise linear approximation, the values $\cos\varphi_2$ for intermediate values of the IM load were determined (Table 2). The values of the power factor at the inverter output, depending on the load for a common industrial induction motor, are shown in Figure 2.
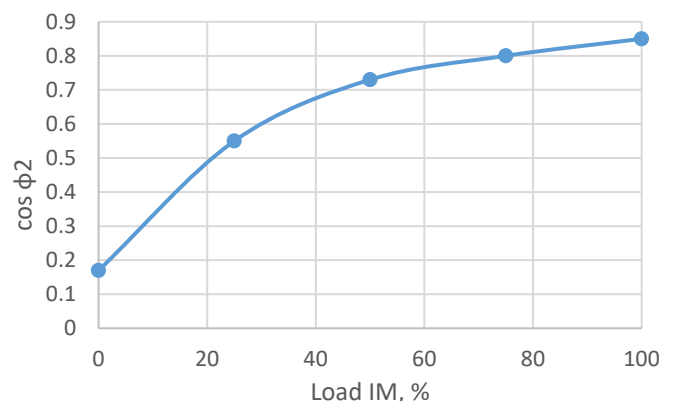

Figure 2: Dependence of Power Factor on Induction Motor Load

It should be noted that the values of $\cos\varphi_2$ were calculated using different formulas for different intervals:

$$f(x) = 0.0152 \cdot x + 0.17; (0 \le x < 25\%);$$
$$f(x) = 0.0072 \cdot x + 0.37; (25\% \le x < 50\%);$$
$$f(x) = 0.0028 \cdot x + 0.59; (50\% \le x < 75\%);$$
$$f(x) = 0.0020 \cdot x + 0.65; (75\% \le x < 100\%).$$

Given that the inherent electrical energy consumption of the inverter is much less than the energy transmitted in the load, it can be neglected and taken:

$$P_1 = P_2;$$

$$\sqrt{3} \cdot U_1 \cdot I_1 \cdot \cos\varphi_1 = \sqrt{3} \cdot U_2 \cdot I_2 \cdot \cos\varphi_2;$$

consequently

$$I_1 = \frac{U_2 \cdot I_2 \cdot \cos\varphi_2}{U_1 \cdot \cos\varphi_1}. \qquad (3)$$

Table 2: The Values $\cos\varphi_2$ Obtained Using the Piecewise Linear Approximation

Load IM, %	$\cos\varphi_2$	Load IM, %	$\cos\varphi_2$	Load IM, %	$\cos\varphi_2$
0	0.170	25	0.550	75	0.800
1	0.185	26	0.557	76	0.802
2	0.200	27	0.564	77	0.804
3	0.215	28	0.571	78	0.806
4	0.230	29	0.578	79	0.808
5	0.246	30	0.586	80	0.810
6	0.261	31	0.593	81	0.812
7	0.276	32	0.600	82	0.814
8	0.291	33	0.607	83	0.816
9	0.306	34	0.614	84	0.818
10	0.322	35	0.622	85	0.820
11	0.337	36	0.629	86	0.822
12	0.352	37	0.636	87	0.824
13	0.367	38	0.643	88	0.826
14	0.382	39	0.650	89	0.828
15	0.398	40	0.658	90	0.830
16	0.413	41	0.665	91	0.832
17	0.428	42	0.672	92	0.834
18	0.443	43	0.679	93	0.836
19	0.458	44	0.686	94	0.838
20	0.474	45	0.694	95	0.840
21	0.489	46	0.701	96	0.842
22	0.504	47	0.708	97	0.844
23	0.519	48	0.715	98	0.846
24	0.534	49	0.722	99	0.848
				100	0.850

It is also known that

1) the power factor at the input of the inverter, taking into account the total harmonic distortion, is taken equal to 0.89, that is, $\cos\varphi_2 = 0.89$;

2) with frequency regulation, the ratio of voltage to frequency is assumed constant. Since the input of the inverter

$$\frac{U_1}{F_1} = const = k,$$

for the value U_2 we get:

$$U_2 = F_2 \cdot k.$$

Then (3) can be rewritten in the form:

$$I_1 = \frac{F_2 \cdot k \cdot I_2 \cdot \cos\varphi_2}{F_1 \cdot k \cdot 0.89} = \frac{F_2 \cdot I_2 \cdot \cos\varphi_2}{F_1 \cdot 0.89}. \qquad (4)$$

Electric energy saving will be due to the difference in currents:

$$\Delta I = I_2 - I_1. \qquad (5)$$

Putting (4) in (5) we get:

$$\Delta I = I_2 \cdot \left(1 - \frac{F_2 \cdot \cos\varphi_2}{F_1 \cdot 0.89}\right). \qquad (6)$$

Electric energy saving in N hours will be in kWh:

$$EES_N = \sqrt{3} \cdot N \cdot U_1 \cdot \Delta I \cdot 0.89 \cdot 10^{-3} = \qquad (7)$$
$$= 1.5394 \cdot N \cdot U_1 \cdot \Delta I \cdot 10^{-3}.$$

For example, when powering the SPRU electrical motor from a network with a voltage U_1=380 V and a frequency 50 Hz, we obtain:

$$\Delta I = I_2 \cdot \left(1 - \frac{F_2 \cdot \cos\varphi_2}{50 \cdot 0.89}\right) = I_2 \cdot \left(1 - \frac{F_2 \cdot \cos\varphi_2}{44.5}\right); \qquad (8)$$

$$EES_N = EES \cdot N = 0.585 \cdot \Delta I \cdot N. \qquad (9)$$

Using the obtained expressions, the value of the electric energy saving parameters were calculated for the induction motor operation modes (P_{NOM} = 37 kW, $\cos\varphi_{NOM}$ = 0.85, I_{NOM} = 66 A) with different load, the calculation results are summarized in Table 3 and Figure 3.

The general algorithm for calculating the values of electric energy saving parameters:

1 The inverter output current I_2 is measured, i.e. the current consumed by the motor.

25	16.5	0.55	11.4		58505

2 The motor load value is calculated as the ratio of the actual output current I_2 to the nominal current I_{NOM}. The value of the motor load from Table II determines the value of the power factor $\cos\varphi_2$.

3 Using (6), the difference between the input and output currents ΔI is determined.

4 Using (7) and using the known input voltage U_1, the value of electric energy saving EES per hour is determined.

The particular algorithm for calculating the values of the parameters of saving electrical energy for the SPRU, where the power supply is carried out with a voltage U_1=380 V and a frequency of 50Hz. This algorithm differs from the general one in that formulas are used here, respectively (6), (7), (8), (9).

Table 3: Electric Energy Saving Parameters Depending on the Operation Mode of an Induction Motor

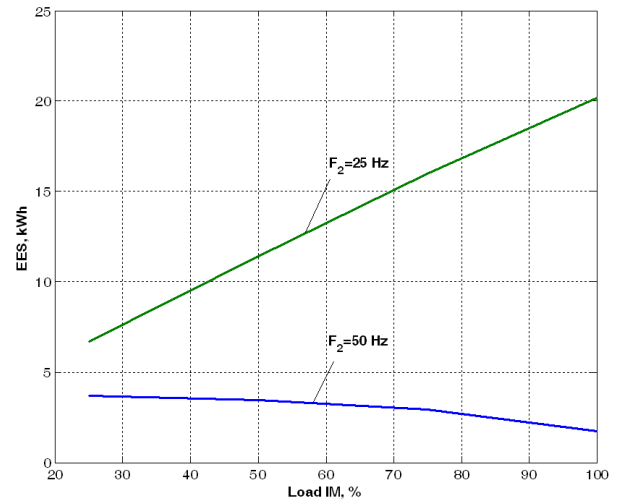| Load IM, %	I_2, A	$\cos\varphi_2$	Current difference, ΔI, A	Annual savings, kWh
100% rotation speed, F_1=50 Hz, U_1=380 V, $\cos\varphi_1$=0.89, F_2=50 Hz				
100	66.0	0.85	2.97	15220
75	49.5	0.80	5.01	25685
50	33.0	0.73	5.93	30441
25	16.5	0.55	6.30	32344
100% rotation speed, F_1=50 Hz, U_1=380 V, $\cos\varphi_1$=0.89, F_2=25 Hz				
100	66.0	0.85	34.5	176942
75	49.5	0.80	27.3	139841
50	33.0	0.73	19.5	99886

Figure 3: Electric Energy saving of an Induction Motor

Table 4: Calculation of Energy Savings for 20 Wells of the Bibi-Heybat Oil and Gas Production Unit Equipped with Developed Control Stations with Inverters (August 2015)

Well number	P_{FC}, kW	P_{IM}, kW	I_{2max}, A	F_2, Hz	$\cos\varphi_1$	U_1, V	I_1, A	Load IM, %	$\cos\varphi_2$	U_2, V	I_2, A	ΔI, A	SEE, kWh
3882	22	22	48.4	47	0.89	380	10.77	34.2	0.614	357	16.6	5.83	3.41
3097	30	30	66.0	49	0.89	380	20.06	41.5	0.665	372	27.4	7.34	4.29
3845	22	22	48.4	45	0.89	380	15.74	45.8	0.701	342	22.2	6.46	3.78
3098	30	30	66	50	0.89	380	12.97	29.8	0.586	380	19.7	6.73	3.94
3658	22	22	48.4	45	0.89	380	9.883	33.2	0.607	342	16.1	6.22	3.64
3844	22	22	48.4	45	0.89	380	14.0	42.5	0.672	342	20.6	6.6	3.86
3814	30	30	66.0	45	0.89	380	19.03	42.4	0.672	342	28	8.97	5.25
3617	30	30	66.0	49	0.89	380	15.14	33.9	0.614	372	22.4	7.26	4.25
3841	18.5	22	48.4	30	0.89	380	10.11	44.6	0.694	228	21.6	11.5	6.73
1245	18.5	18.5	40.7	49	0.89	380	9.398	34.1	0.614	372	13.9	4.5	2.63
3261	18.5	15	33.0	42	0.89	380	14.83	62.4	0.763	319	20.6	5.77	3.37
3146	18.5	22	48.4	45	0.89	380	19.11	52.8	0.738	342	25.6	6.49	3.80
3677	30	30	66.0	49	0.89	380	5.707	17.7	0.443	372	11.7	5.99	3.51
3826	22	22	48.4	48	0.89	380	21.51	55.3	0.744	364	26.8	5.29	3.10
811	18.5	18.5	40.7	45	0.89	380	9.712	37.1	0.636	342	15.1	5.39	3.15
1150	18.5	18.5	40.7	45	0.89	380	10.71	39.5	0.658	342	16.1	5.39	3.15
1192	18.5	18.5	40.7	38	0.89	380	12.72	50.1	0.73	288	20.4	7.68	4.50
3279	18.5	18.5	40.7	46	0.89	380	16.11	52.0	0.735	349	21.2	5.09	2.98
557	18.5	18.5	40.7	48	0.89	380	9.594	35.1	0.622	364	14.3	4.71	2.75
3929	18.5	22	48.4	40	0.89	380	7.326	29.1	0.578	304	14.1	6.77	3.96
Total savings of all wells in 1 hour, kWh													76.1
Total working time in a year (when working 11 months a year), h													8040
Total annual energy savings, thousand kWh													612.2

Total annual savings in money (at an electric power cost of 0.05 $ / kWh), $	30608

Currently, the Institute of Control Systems of the National Academy of Sciences of Azerbaijan (ANAS) has developed a CS based on frequency converters of the Altivar 71 and 930 type, which is manufactured by the special design bureau "Cybernetics" of ANAS. These SUS are being widely implemented in the oil fields of Azerbaijan. At the moment, more than 400 wells are equipped with frequency converters based control stations as part of a measurement, monitoring, diagnostics and management complex. At the same time, the electric energy savings are calculated according to the proposed methodology. Table 4 shows the results of calculating energy savings for 20 wells of the Bibi-Heybat Oil and Gas Production Unit equipped with the developed CS.

7. Conclusion

1. Using the normalized correlation functions, the normalized coefficients K_{N1}, K_{N2}, …, K_{N11}, free from the indicated interferences, are determined.

2. In each field for wells with the same depth, the range of change in the values of the same coefficients $K_{N1} - K_{N11}$ under the same technical conditions is insignificant (no more than 5-10%), which allows using them as informative parameters for identifying the technical condition of the SPRU.

3. A robust remote control system has developed for the SPRU in real-time based on a frequency-controlled driver.

4. A methodology for calculating the savings of electrical energy in the control of SPRU frequency converters has compiled. The results of the calculation also reveal the available additional energy saving reserves, such as:

– the need for accurate balancing counterweights of SPRU;

– measures to increase power factor $\cos\varphi_2$;

– the need to maintain the operating mode with motor load within 70...75% of the nominal and the frequency within 80...85% of the nominal.

Conflict of Interest

The authors declare no conflict of interest.

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