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Operating characteristics of pumping installations and analysis of ensuring energy saving modes

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Operating characteristics of pumping installations and analysis of ensuring energy saving modes

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Abstract. Improving the energy efficiency of the technological process in the water supply of reclamation pumping stations as well as the development of energy and resource-saving modes of hydromechanical equipment and electrical systems of pumping stations in a number of priority areas.

INTRODUCTION

Pumping stations are widely used in mining, metallurgical, oil, gas, chemical and other industrial technological systems, as well as drainage and water supply systems, heat supply infrastructure and energy, housing and communal service facilities. As an important part of the transportation and distribution network, pumps represent one of the largest infrastructure assets of an industrial society. About 4% of the world's electricity consumption is used for pumping water in water supply systems, and up to 89% of this consumption is generated by electricity. In addition, increasing the irrigated area by improving the efficiency of electricity and water use in reclamation systems, the development of irrigated agriculture, is one of the most powerful means of developing the rehabilitation economy in general. Analysis of the structure of electricity consumption shows that the main consumers are pumping stations and water supply stations. This leads to the research and application of energy-saving electric drives of pumping units [1-4]. A modern pumping station is a set of pumps with its own control system, which operates in automatic mode according to a certain law, has a full range of electrical and technological protections. In real systems, the number of pumps varies from two to seven and is determined by the optimal ratio between the efficiency zone, the cost of the control system that consumes when pumping water from one place to another, and encourages to increase the necessary reliability and reserve [5-7]. Taking into account the variability of water demand in the world, non-constant irrigation time, crop rotation and other environmental factors, special importance is attached to the issue of increasing the energy efficiency of pumping stations in the reclamation system on the basis of adjustable electrical control. Therefore, in automated control systems of pumping devices, frequency-controlled electric drives are used to coordinate the operation mode of pumps with the operation mode of the water supply system [8].

EXPERIMENTAL RESEARCH

The use of frequency-controlled driving allows the implementation of effective intelligent control systems for the technological mode of the pump using pressure sensors. Accordingly, scientists of many countries are currently conducting research on the introduction of frequency control of pump units and thus the smooth coordination of the operation mode of the pump unit and the operation modes of the technological process of pumping water from one place to another. In the implementation of these tasks, in particular, increasing the energy efficiency of pumping stations based on the management of the water level in the BASIN, determining the most important factors affecting its power consumption, systematic management of the "frequency-adjustable electric drive-asynchronous motormelioration pump" and determining the optimal operating mode of the pumping equipment and their research is important.

It is important to develop automated systems aimed at managing reclamation networks in the efficient use of energy resources. Single-pump pumping stations allow for high performance, while multi-pump stations are able to meet real wastage requirements with less energy consumption [9-12]. Increasing the efficiency and reliability of centrifugal pumps in the conditions of small and medium-capacity multi-unit pumping units is very relevant, especially in water supply systems with a variable organization of loading, for example, in systems with recovery and low static pressure. Presents the results of the study of determining the efficiency of pumping stations under conditions of variable water consumption . The main reasons for the decrease in efficiency of pumping stations are identified. Affects the time the driven pump unit spends in the ineffective zone the main factors are identified. A method of controlling a group of pump groups is proposed, taking into account the simultaneous operation of each of them. Thus, at the current stage, the characteristics of the pump station control system are closely related to the changes in the consumption of energy resources (electricity water). One of the main goals of pumping stations is to increase energy efficiency, to meet the requirements of the technological process in terms of both pressure and productivity. The introduction of group control shows a reduction in power consumption of the pumping station by 20-24%, a reduction in the number of catastrophic situations is achieved by 85% [13-16]. In meliorational systems, a change in the entire structure of land areas is observed with interconnected hydraulic and other devices, such as canals, collectors, pipes, reservoirs, dams, pumping stations, water intakes, which ensure the creation of optimal water, air, heat and nutrient regimes on reclaimed lands. It is known that 4.3 million hectares of 6.3 million hectares of irrigated land in our Republic are supplied with water through pumping stations. In terms of capital costs of ameliorative irrigation, infrastructure development is one of the main sectors of water management of our country. 1,693 pumping units with a total capacity of about 7,000 m3/s were installed at 5,301 pumping stations on the balance sheet of the Ministry of Water Management of the Republic of Uzbekistan.

The technological scheme of the Polkan reclamation pumping station of the Pumping Stations and Energy Department of the Lower Zarafshon BASIN Irrigation Systems Department is presented.

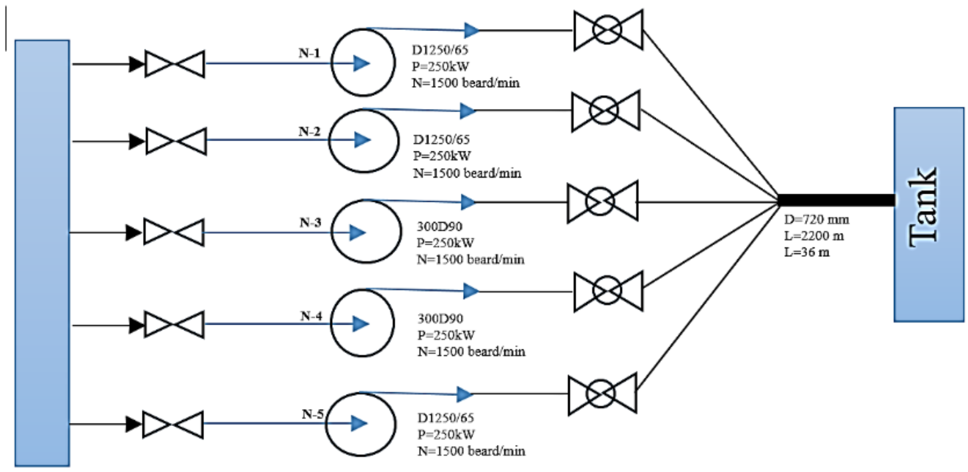

FIGURE 1. Connection diagram of 5 pump units

According to Fig. 1. 5 asynchronous motor pump units with a capacity of 250 kW are operating at the Polkan reclamation pumping station. The pumps are designed to fill the reservoir (pond) with water at a distance of 2.2 km. Descriptions of pumps of type D1250 / 65 in operation are shown in Fig. 2. this technological scheme is used in most reclamation pumping stations in Uzbekistan (when the number and power of pumping units change) [17-20].

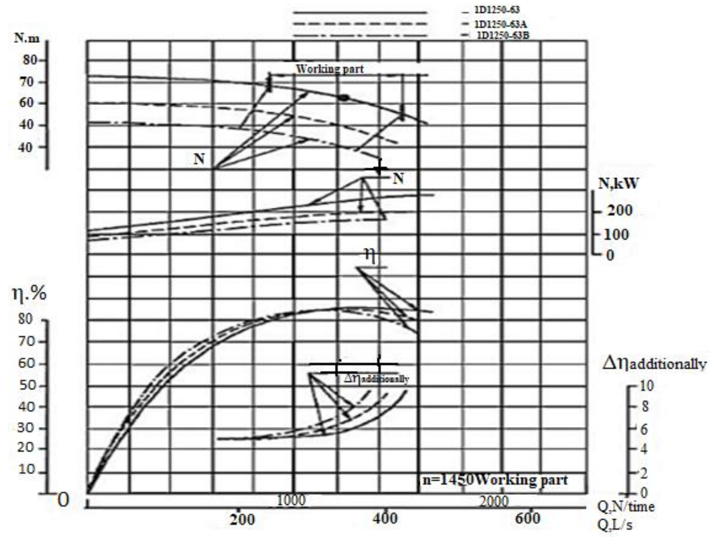

FIGURE 2. Specifications of the D1250 / 65 pump

In fig. 3. shows the descriptions of the pumping stations of the Lower Zarafshon BASIN Irrigation Systems Department and the Polkan reclamation pumping station of the Energy Department. As can be seen from the research result and Figure 3, this pumping station works in an inefficient mode, because due to the parallel operation, there is a need to optimally distribute the supply and loads between the pumping units [21-24]. To meet the requirements of the technological process, the operation of the pump is regulated by water management (Fig. 3. 1 - when the valve is fully opened, when the valve 2 is opened at 30 degrees). In cases of parallel operation of the pump, it was found that difficulties arise due to the complexity of the implementation of the technological task of dividing the load between the units and ensuring the stability of the water level in the pool. In addition, the increase in energy prices in recent decades has created the need to pay more attention to the efficient use of energy. Since many water distribution systems require large amounts of energy to drive, transport and deliver water, improve pump control, and reduce energy consumption and operating costs, making the network more efficient should be considered a priority. When solving this problem, it is necessary to take into account the efficiency of pumps, the structure of consumer demand and the possibility of having a control system in the system. The interrelationship between pump unit controls, resulting in pump power consumption, power consumption, and network current regime should be considered through network nonlinear hydraulics and pump specifications.

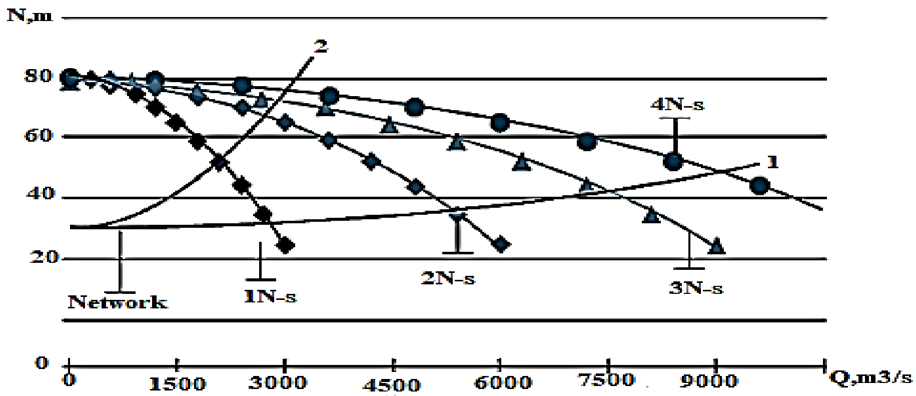

FIGURE 3. Pump stations of the Lower-Zarafshon Basin Reclamation Systems Department and Operational Description of the Polkan Reclamation Pumping Station of the Energy Department

In addition, the increase in energy prices in recent decades has created the need to pay more attention to the efficient use of energy. Since many water distribution systems require large amounts of energy to drive, transport and deliver water, improve pump control, and reduce energy consumption and operating costs, making the network more efficient should be considered a priority. When solving this problem, it is necessary to take into account the efficiency of pumps, the structure of consumer demand and the possibility of having a control system in the system. The interrelationship between pump unit controls, resulting in pump power consumption, power consumption, and network current regime should be considered through network nonlinear hydraulics and pump specifications. It is known that pumping stations are one of the facilities that require the largest amount of electricity. In this regard, the provision of their energy-saving modes is of particular priority, which allows to save a large amount of electricity (about 15-18% of the consumed) on the scale of the Republic in the implementation of the technological process of water supply. The tasks of development of energy-resource saving modes of reclamation pumping stations should be based on the following:

- strict compliance of the water consumption schedule in the supply of the pumping station;
- choosing a reasonable option of energy-hydromechanical equipment with controlled electric drive capable of fully automating the technological process of supplying water to reclamation pumping stations.

To date, the method used in reclamation pumping stations to manage productivity is to change the number of work units that provide step-by-step (unit-wise) management of the supplied water [31-60]. At the same time, there is a discrepancy between the actual schedule of water consumption in most of the controlled reclamation pumping stations and its compensation by the operation of the reclamation pumping stations. Therefore, in order to exclude the loss of productivity of planted crops, reclamation pumping stations work with an overload schedule, which in turn leads to unreasonable consumption of water resources and electricity. Another characteristic of pumping stations is their transfer to controlled electric operation instead of an uncontrolled system, which of course allows efficient use of electricity and water, transition to complex automation of the technological processes of water supply to the pumping station, increases the flexibility of managing the loads of electrical equipment, the control of the load of electrical equipment is power and hydromechanical extends the overall life of the equipment [25-30].

RESEARCH RESULTS

The assessment of the energy efficiency of the reclamation pumping station can be determined taking into account the characteristics of each pumping station and can be obtained only taking into account the characteristics of the pump, pressure pipeline and basin. In this regard, we have developed a mathematical model on the example of the Polkan reclamation pumping station to determine the operating mode of the "asynchronous motor - reclamation pump - pipe - basin" system.

$$H = H_0\left(\frac{\omega}{\omega_н}\right)^2 - AQ^2 \tag{1}$$

here $A=(H_0-H_н)/Q_н^2$, H – pressure, Q – efficiency, H_0 – pressure at Q=0 and ω=ω, (i.e. in working condition); ω- angular speed of the pump unit, H_H, Q_H, $\omega_н$ – nominal values, respectively, pressure, performance and rotation speed of the pump unit (in accordance with passport values).

The pressure description is presented in the following formula.

$$H = H_{ST} + KQ^2 \tag{2}$$

here: H_{st} is the static height, K is the resistance coefficient of the pressure pipe, which can be determined as follows.

Taking into account these equations, the power of the pump unit is determined as follows

$$Q = \sqrt{\frac{H_0\left(\frac{\omega}{\omega_н}\right)^2 - H_{ст}}{A+K}} \tag{3}$$

The efficiency of the pumping device can be determined by the well-known formula [15]

$$\eta_N = \frac{N}{N_{мех}} \tag{4}$$

where is the useful power of the N-pump unit; N_{mex}-mechanical power on the shaft of the pump unit. As a function of pressure and performance, the useful power of the pump unit is determined according to the following

$$N = \frac{\rho HQ}{102} \tag{5}$$

where r is the density of the pumped liquid.

Depending on the speed of rotation, the mechanical power on the shaft of the pump device is determined by the following equation

$$N_{мех} = N_0\left(\frac{\omega}{\omega_н}\right)^3 + B\left(\frac{\omega}{\omega_н}\right)^2 Q \qquad (6)$$

here B=($N_{мex.x}$ - N_0)/$Q_н$,

H_0- pure working power of the pumping device, mechanical power of the pumping unit according to the $N_{mex.n}$-passport.

The moment of resistance is defined by the following expression

$$M_c = M_0\left(\frac{\omega}{\omega_н}\right)^2 + (M_н - M_0)\frac{\omega}{\omega_н}Q \qquad (7)$$

here: $M_н$- nominal torque resistance

The power consumption of the pumping device is determined by the following expression

$$P_1 = \frac{mU_н{}^2}{D^2}\left\{r_1\left[\left(\frac{r_2}{s}\right)^2 + x_r{}^2 + \frac{r_2'}{s}x_{\mu н}{}^2\right]\right\}$$

$$D = \sqrt{\left(\frac{r_1 r_2'}{s} - x_s x_r \sigma\right)^2 + \left(\frac{r_2'}{s}x_s + \frac{r_1}{s}x_{\mu н}\right)^2} \qquad (8)$$

m- the number of phases in the stator,

$x_r = x_{2н}' + x_{\mu н}$

x_1- active and inductive resistance of the stator coil,

r_2' and x_2'- active and inductive resistance of the rotor coil,

s- engine slippage,

$x_{\mu н}$- inductive resistance of the magnetization process of the motor.

In addition, the electromagnetic power of the pumping device is determined according to the following expression

$$P_e = \frac{mU_n{}^2 r_2' x_{\mu n}{}^2}{sD^2} \qquad (9)$$

useful power on the shaft of the motor of the pump unit is determined according to the following expression

$$P_2 = \frac{mU_n{}^2 r_2' x_{\mu n}{}^2}{sD^2}(1 - s) \qquad (10)$$

The electromagnetic torque of the drive motor of the pump device is determined by the Kloss equation

$$M_e = \frac{2M_{эк}(1+qs_к)}{\frac{s}{s_к}+\frac{s_к}{s}+2qs_к} \qquad (11)$$

here sk-critical slip; Mek-critical electromagnetic torque, which can be determined by the following expression

$$M_{ek} = \frac{aU_n^2 x_{\mu n}^2/2}{x_r\sqrt{[(r_1)^2+x_S^2][(r_1)^2+(x_S\sigma)^2]}+r_1 x_{\mu n}^2} \qquad (12)$$

The relative value of the motor resistance is determined by the following formula

$$q = \frac{r_1 x_{\mu n}^2/r_2'}{r_1{}^2+x_S^2} \qquad (13)$$

In addition, the relative value of the resistance torque of the geared motor is determined by the following expression.

$$M_c = \frac{2\lambda(1+qs_к)}{\frac{s}{s_к}+\frac{s_к}{s}+2qs_к} \qquad (14)$$

At here λ- the difference of the critical electromagnetic torque with respect to the nominal value. Gear motor slippage can be determined by the following expression

$$s = \frac{b_1}{M_{c*}} - b_2 + \sqrt{\left(\frac{b_1}{M_{c*}} - b_2\right)^2 - s_K^2} \qquad (15)$$

where the following correction factors are adopted

$$b_1 = \frac{s_n D_n^2}{2x_r^2(r_1^2+x_S^2\sigma^2)} \qquad (16)$$

$$b_2 = \frac{r_1 r_2' x_{\mu n}^2}{x_r^2(r_1^2+x_S^2\sigma^2)} \qquad (17)$$

In addition, taking into account the parameters of the induction motor, the performance of the pumping device is determined according to the following expression

$$Q = Q_n \sqrt{\frac{H_0 \frac{1-2s}{1-2s_{\text{н}}} - H_{\text{ст}}}{H_0 - H_{\text{н}} + RQ_{\text{н}}^2}} \tag{18}$$

Also, taking into account the parameters of the induction motor, the useful power of the pump motor is determined according to the following expression

$$N = \frac{\rho HQ}{102} \sqrt{\frac{H_0 \frac{1-2s}{1-2s_{\text{н}}} - H_{\text{ст}}}{H_0 - H_{\text{н}} + KQ^2}} \tag{19}$$

In equations (18) and (19), the parameters of the pump unit are expressed by the parameter of the asynchronous motor, that is, by its slip. Thus, the possibility of combining the electrical and mechanical parts of the "asynchronous motor-pump" system is shown.

Then, we express the parameters of the pump device in terms of the parameter of the asynchronous motor, including the mechanical power and the resistance torque of the pump device [25, 26].

$$N_{\text{мех}} = N_0 \frac{1-3s}{1-3s_{\text{н}}} + BQ_{\text{н}} \frac{1-2s}{1-2s_{\text{н}}} \sqrt{\frac{H_0 \frac{1-2s}{1-2s_{\text{н}}} - H_{\text{ст}}}{H_0 - H_{\text{н}} + RQ^2}} \tag{20}$$

$$M_c = M_0 \frac{1-2s}{1-2s_{\text{н}}} + (M_{\text{н}} - M_0) \frac{1-s}{1-s_{\text{н}}} Q_{\text{н}} \vartheta \sqrt{\frac{H_0 \frac{1-2s}{1-2s_{\text{н}}} - H_{\text{ст}}}{H_0 - H_{\text{н}} + RQ^2}} \tag{21}$$

here ϑ- coefficient that takes into account external completeness $\vartheta = 1{,}05 \div 1{,}2$

In the same way, we determine the efficiency of the pumping device through the asynchronous motor parameter

$$\eta_N = -(6\rho HQ\varsigma s_{\text{н}}{}^2 + 5\gamma HQ\varsigma s_{\text{н}} - \rho HQ\varsigma)/\,(12\varsigma N_0 s_{\text{н}} - 612\varsigma s N_{\text{мехн.н}} s_{\text{н}} - -204\varsigma s N_0 s_{\text{н}} + 204\varsigma s N_{\text{мехн.н}} - 306\varsigma N_0 s_{\text{н}} + 306\varsigma s N_{\text{мехн.н}} - 6612 s N_0 s_{\text{н}} + 102\varsigma N_0 - 102\varsigma N_{\text{мехн.н}} + 306 N_0 s_{\text{н}} + 204 N_0 s_{\text{н}} - 102 N_0 s_{\text{н}}) \tag{22}$$

In expression (20), the pressure parameter is determined by the following relation

$$\varsigma = \sqrt{\frac{2sH_0 - 2H_{\text{ст}}s_{\text{н}} - H_0 + H_{\text{ст}}}{2Q^2Rs_{\text{н}} - Q^2K + 2H_0 s_{\text{н}} - 2H_{\text{н}}s_{\text{н}} - H_0 + H_{\text{н}}}} \tag{23}$$

Then, the efficiency of the traction motor can be expressed by the following formula.

$$\eta_D = \frac{r_2' x_{\mu\text{н}}^2 \left(\frac{1}{s} - 1\right)}{r_1\left(\frac{r_2'^2}{s^2} + x_r^2\right) + \frac{r_2'}{s} x_{\mu\text{н}}^2} \tag{24}$$

by analogy, we define a driven asynchronous motor

$$\cos\varphi = \frac{s r_1 x_r^2 + r_1 r_2' + r_2' x_{\mu H}^2}{s\sqrt{-\frac{\left(-s^2 r_1{}^2 x_r{}^2 + s^2 \sigma x_r x_s - 2 s r_1 x_r x_s - r_2'^2 x_s{}^2 - s r_1 r_2'\right)\left(x_s{}^2 x_r{}^2 + r_2'^2\right)}{s^4}}}, \tag{25}$$

CONCLUSIONS

Therefore, taking into account the technological and electromechanical parameters of the reclamation pumping station, a mathematical model of the "asynchronous motor - pump - pressure pipe - basin" system was developed, and the possibility of influencing the energy parameters and conditions for its increase was also shown.

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