Reducing reactive energy consumption by optimizing operating modes of irrigation pumping stations

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Abstract. The article develops energy and resource efficiency modes of the technological process that meet the requirements of the "frequency converter - asynchronous motor - pump - pressure pipeline" system as a control object. Methods for regulating water pressure and water flow produced by pumping units are considered in order to ensure a schedule for water supply to irrigation pumping stations. The active, reactive and total electrical energies received by an asynchronous motor to change water flow by changing the position of the pressure valve in the pressure pipeline are calculated. In order to optimize water flow and water pressure by changing the speed of rotation of the pump impeller, the frequency converter system of an asynchronous motor with a squirrel-cage rotor was calculated and compared with the method of changing water flow using a push valve, by calculating active, reactive and total electrical energy from the network.

1 Introduction

In Uzbekistan, scientific research is being conducted aimed at optimally managing the necessary water consumption and pressure stability in the pipeline, changing the speed of the working blades in the pump unit, improving technological schemes and methods for parallel operation of centrifugal pumps when changing the height of the water level in the blade chamber and optimizing their energy performance [1,5,6,7]. In this direction, among other things, priority is given to research to improve the efficiency and reliability of control of an asynchronous motor system with a frequency converter for the speed of rotation of the pump blades, ensuring the required water flow at irrigation pumping stations. At the same time, an urgent task is also the development and improvement of existing technological water supply systems that meet modern requirements for automated electrical operations and automatic control systems designed to achieve energy-saving modes [8,9,10].]. The most effective method of energy-efficient control of pumping units is the use of variable-frequency electric drives [11,12,13].

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2 Results and discussion

In irrigation systems for irrigating agricultural crops, more than 2000 lifting pumping stations of various capacities supply water during the irrigation season. In addition, pumping stations of the main water-lifting canals operate year-round. More than 5000 pumping units are installed at these pumping stations, of which about 1000 are D5000-32 type pumping units. Technical parameters of the D5000-32 pumping unit are given in Table 1

Table 1. Technical parameters of the D5000-32 pumping.

Pump model	Blade diameter, mm	Nominal water flow, m^3/hour	Pressure (pressure), m	Rotation speed (rpm)	efficiency, %,	Engine power, kW
D5000-32	700	5000	32	730	88	800

To start the D5000-32 pumping unit, asynchronous motors with a squirrel-cage rotor model A4 – 800 – 4U3, power 800 kW, voltage U_n=10000 V, rotation speed n=740 rpm, efficiency η=94.5 % are used as an electric drive, power coefficient cosφ=83%, stator current I_c=77.5 A.

The generated active power on the shaft of the pumping unit at its rated values is calculated as follows:

$$P_{\text{pump}} = \frac{\gamma * Q_{\text{H}} * H_{\text{H}}}{102 * \eta_{\text{pump}}} = \frac{1000*1,4*32}{102*0,8} = 549 \text{ kVt} \quad (1)$$

Where, H_n, Q_n – nominal pressure and water consumption of the pumping unit, γ is the density of the liquid, η_ us is the efficiency of the pump, it decreases due to erosion of the pump working blade and an increase in the gap between the working blade and the housing.

The active power consumed by an asynchronous motor driving the pump from the network is equal to:

$$P_{\text{AD}} = \frac{P\_pump}{\eta_{\text{AD}}} = \frac{549}{0,945} = 581 \text{ kVt} \quad (2)$$

The reactive power consumed by an asynchronous motor driving a pump from the network is equal to

$$Q_{\text{AD}} = P_{\text{AD}} * tg\varphi = 581 * 0,67 = 389 \text{ kVar} \quad (3)$$

here,

$$tg\varphi = \frac{\sqrt{1 - cos\,\varphi_{\text{H}}^2}}{cos\varphi} = \frac{\sqrt{1-0,83^2}}{0,83} = 0,67;$$

The total power consumption of an asynchronous motor driving the pump from the network is equal to

$$S = \sqrt{P_{AD}^2 + Q_{\text{AD}}^2} = \sqrt{581^2 + 389^2} = 699 \text{ kVA} \quad (4)$$

The schedule for water supply to irrigation pumping stations has been approved and water is supplied during the season monthly, daily and throughout the day. To meet the requirements of these schedules, the water flow of the pumping units is regulated using push valves. Adjustment of water flow is carried out within the working area of the technical description of the pump. Let's determine the values of water consumption and water pressure at point A at point N in the technical description of the D5000-32 pump, shown in Figure 1:

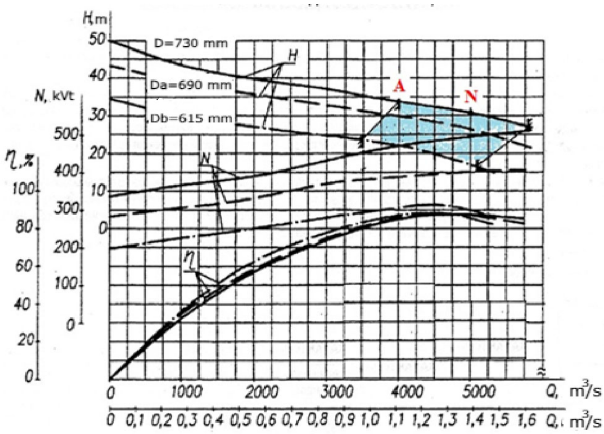

Fig. 1. Technical characteristics of pump type D5000-32.

The part marked separately in the technical description of the pump corresponds to the highest values of pump efficiency and is called the “working area”. In the “working zone” the pump water flow can be varied from 1.1 m^3/s to 1.4 m^3/s. When the pressure valve is closed, the pressure increases and the operating point of the pump changes from N to A. In this case, the water supply decreases to a value of 4000 m^3, the pressure created by the pump increases to a water column value of 34 m, and the pressure in the pipe behind the pressure valve decreases to a value of 32 m (Figure 2). The pressure drop downstream of the draft valve is due to the loss of pressure in the draft valve.

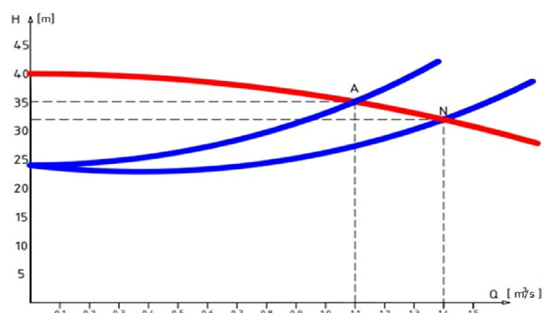

Fig. 2. Characteristics of the pump D5000 – 32.

Due to the opening of the pressure valve, the vertical properties of the pipe profile are reduced. As a result, water flow increases, the pressure created by the pump decreases, and the pressure in the pipe behind the stop valve increases. This method, called “Choke”, is less economically efficient [2,8,14], since additional energy is required to overcome the additional hydraulic resistance in the draft valve.

1) Q_N=5000 m^3/ s =1,4 m^3/s; H_N=32 m;

2) Q_A=3800m^3/ s =1,06 m^3/ s; H_A= 34 m;

Taking into account the values of water consumption Q_A = 1.06 m^3/s, water pressure H_A = 34 m, pump efficiency $\eta_н = \eta_a$ = 80%, water density γ = 1000 kg/m^3, for point A from the technical characteristics we calculate the active, reactive and total power consumed from the network:

$$P_A = \frac{\gamma * Q_A * H_A}{102 * \eta_{pump} * \eta_{\text{AD}}} = \frac{1000 * 1{,}06 * 34}{102 * 0{,}8 * 0{,}945} = 467\ kVt$$

$$Q_A = P_A * tg\varphi = 467 * 0{,}67 = 313 \text{ kVAr} \tag{5}$$
$$S = \sqrt{P_A^2 + Q_A^2} = \sqrt{467^2 + 313^2} = 562 \text{ kVA}$$

An energy-efficient control method is to change the rotation speed of the impeller of centrifugal pumps [2,15]. When the speed of rotation of the pump impeller changes, the state of water pressure and the characteristics of water consumption at the outlet of the pump change (Figure 3).

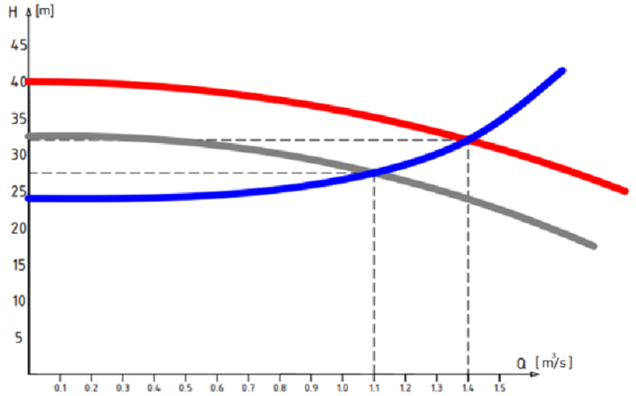

Fig. 3. Characteristics of the pump blade when adjusting the rotation speed.

According to the description, reducing the rotation speed of the pump blade will lead to a decrease in water flow and a parallel pressure to this (Figure 3). An increase in the rotation speed of the centrifugal pump blade causes an increase in the pressure it creates and the pressure in the pipe, as a result of which the water flow accelerates and the water consumption increases [3,11,12]. In a squirrel-cage induction motor system with a frequency converter, the rotation speed of the pump blade can be smoothly varied over a wide range.

Using the graph of the technical description of the D5000-32 pump (Fig. 1), we calculate the resulting values of the characteristics based on the values of water flow and pressure when changing the rotation speed:

For the nominal speed n=730 rpm /mini we use the ratio.

$$\frac{Q_\text{A}}{Q} = \frac{n_\text{A}}{n}, \tag{6}$$

With a known

$$n_\text{A} = \frac{Q_\text{A} * n}{Q} = \frac{1.1 * 730}{1.4} = 584 \text{ rpm}/min.$$

$$\frac{H_\text{A}}{H} = \frac{n_\text{A}^2}{n^2} \tag{7}$$

We determine water flow and water pressure at values equal to the control frequency of the frequency converter $f = 40$ Hz.

$$Q_{\text{f}(40HZ)} = 3800 \text{ m}^3/hours = 1{,}06 \text{ m}^3/s; \quad H_{40HZ} = 28 \text{ m};$$

We determine the active power consumption of the frequency converter of an asynchronous motor

$$P_{\text{f}(40Hz)} = \frac{\gamma * Q_{\text{f}(40Hz)} * H_{\text{f}(40Hz)}}{102 * \eta_{pump} * \eta_{\text{АД}}} = \frac{1000 * 1{,}06 * 28}{102 * 0{,}8 * 0.945} = 385\ kVt \tag{8}$$

The active energy consumption from the system network of an asynchronous frequency converter (FC) motor system is equal to:

$$P_{\text{ПЧ}} = \frac{P_{\text{f}(40HZ)}}{\eta_{\text{пч}}} = \frac{385}{0{,}98} = 393 \text{ kVt} \tag{9}$$

Thanks to the use of modern wide pulse modulation frequency converters, their power factor is at least 0.96, so the consumption of reactive energy from the power grid is equal to [4,14-17].

$$Q_{f(40HZ)} = P_{пч} * tg\varphi = 393 * 0{,}29 = 114 \text{ kVar} \quad (10)$$

Here $tg\varphi = \frac{\sqrt{1-cos\,\varphi_{Н}^{2}}}{cos\varphi} = \frac{\sqrt{1-0{,}96^2}}{0{,}96} = 0{,}29;$

The total energy consumption of the induction motor system of the frequency converter from the network is equal to:

$$S = \sqrt{P_{пч}^2 + Q_{f(40HZ)}^2} = \sqrt{393^2 + 114^2} = 409\text{kVA} \quad (11)$$

3 Conclusion

Comparing the electricity consumption of a pumping unit of type D5000-32, defined above, by regulating water flow and water pressure using a push valve and changing the rotation speed of the pump working blade, we obtain:

By active power

$$\Delta \mathrm{P_A} = \mathrm{P_A} - \mathrm{P_{пч}} = 467 - 393 = 74 \text{ kVt} \quad (12)$$

By reactive power

$$\Delta Q_P = Q_{\mathrm{A}} - Q_{пч} = 313 - 114 = 199 \text{ kVar} \quad (13)$$

The irrigation season of agricultural fields is T = 3600 hours per year, during which the reduction in active energy costs is equal to:

$$\Delta E_{A1} = \Delta \mathrm{P_A} * \mathrm{T} = 74 * 3600 = 266400 \text{ kVt}* hour,$$

The reduction in reactive power consumption is equal to:

$$\Delta E_{P1} = \Delta Q_P * T = 199 * 3600 = 716400 \text{ kVt}* hour.$$

The annual active and reactive energy fee for using an induction motor control system with frequency converter is:

$$\mathrm{P_{A1}} = \Delta \mathrm{E_{A1}} * \mathrm{t_A} = 266400 \text{ kVt} * hour * 450 \text{ so}'\text{m/kVt} * hour = 119880000 \text{ so}'\text{m},$$

$$\mathrm{P_{P1}} = \Delta \mathrm{E_{P1}} * \mathrm{t_P} = 716400 \text{ kVAr} * hour * 19{,}12 \text{ so}'\text{m./kVAr} * hour = 13697570 \text{ so}'\text{m},$$

Thus, the active and reactive electrical energy consumed from the network is optimal when using an induction motor system with a frequency converter. Useful work is done with minimal energy loss. At the same time, the requirements of electricity suppliers of electrical networks regarding the amount of reactive energy are fully satisfied.

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