PRACTICAL APPLICATION OF VARIABLE FREQUENCY DRIVES IN PUMPING INFRASTRUCTURE

Khafizov Islom Ikramovich
Ph.D., dotsent, Asia International University

Abstract

The article presents a methodology for a feasibility study for the use of a frequency-controlled electric drive in pumping units. A method for calculating the use of a frequency-controlled electric drive in pumping units is given and it is proved that the application makes it possible to use large pumping units in the low flow mode and, therefore, reduce their total number. The problem of determining the technical and economic indicators of pumps of the D series is also considered and it is shown that the linear dimensions of pumping units grow much more slowly than their power and flow. An expression was cited for determining the relative linear dimensions of the compared aggregates.

For pumping units of the D series, a regularity was established that the linear dimensions of the enlarged unit, compared with the base unit, increase to a lesser extent than its flow increases. The results of the calculation of the relative parameters of pumps of the D series, the pump unit equipped with the D320-70 pump are presented.

Due to the equipment of pumping units with a frequency-controlled drive, a decrease in the number of units at pumping stations does not reduce the operational possibilities for changing their operating modes caused by changes in water consumption.

Thus, the use of a frequency-controlled electric drive under certain conditions not only does not increase capital investments, but also reduces them somewhat.

Calculations have shown that the use of a frequency-controlled electric drive in combination with an increase in unit power, depending on the purpose of the station and other specific conditions, can reduce the reduced costs by 20–50%.

The sequence of the feasibility study for the use of a frequency-controlled electric drive in pumping units is given.

It has been proved that, in a pumping unit, the creation of an energy-saving ACS based on the use of a frequency-controlled electric drive pays off in a fairly reasonable time, even without taking into account water savings.

Introduction

In view of the obvious advantages, the frequency-controlled electric drive is becoming quite widespread in pumping installations. At the present time, conditions have developed that make it possible to use it everywhere. The development of semiconductor technology made it possible to create reliable and relatively inexpensive frequency-controlled electric drives on the basis of static converters. As a result, work on research, development and creation of pumping units equipped with an automated frequency-controlled electric drive has expanded [1,2].

2009

The use of a frequency-controlled electric drive in pumping units makes it possible to use large pumping units in the low-flow mode and, consequently, reduce their total number. Here it is appropriate to say that more powerful units have higher technical indicators, including higher efficiency (Table 1).

Table 1. Technical and economic indicators of D-series pumps

Parameter	D320-70	D1250-65	D2500-62	D3200-75	D4000-95	D6300-80
Power, kW	100	320	630	800	1250	1600
Pump EFFICIENCY	0.78	0.86	0.87	0.87	0.88	0.88
The efficiency of the engine	0.92	0.922	0.935	0.953	0.962	0.962
The efficiency of the unit	0.716	0.79	0.816	0.83	0.846	0.846
Weight, kg	1130	4245	8730	11660	12780	18666
Specific gravity, kg / kW	11.3	13.3	13.9	14.6	10.3	11.7

It is shown in [3] that the linear dimensions of pumping units grow much slower than their power and supply. As is known, the volumes (dimensions) of machines (electric motors, pumps, etc.) are proportional to the nominal values of their torque:

$$V = kM \qquad (1)$$

where $M-$ is the torque; $k-$ is the coefficient of proportionality.

If we express the moment in terms of the operating parameters of the pumping unit and extract the cubic root from both parts of the equation (1), we get the dependence of the linear dimensions of the unit on its main parameters:

$$L = \sqrt[3]{kM} = \sqrt[3]{k} * \sqrt[3]{\frac{QH}{\eta n}}, \qquad (2)$$

where $Q-$ is the pump unit feed; $H-$ is the pump unit head; $n-$ is the pump unit rotation speed; $\eta-$ is the unit efficiency.

Main part.

We believe that for the specific installation under consideration, the head values of the compared units are approximately the same. We take the parameters of the smallest of the

compared aggregates as the basic ones. For these conditions, after some transformations, we obtain an expression for determining the relative linear dimensions of the compared aggregates

$$L^* = \sqrt[3]{\frac{Q_l / \eta_l n_l}{Q_b / \eta_b n_b}}, \qquad (3)$$

where Q_l, η_l, n_l − are the nominal parameters of the larger unit; Q_b, η_b, n_b −are the nominal parameters of the base unit;

From the expression (3), it follows that the linear dimensions of the enlarged unit in comparison with the basic unit increase to a lesser extent than its feed increases. This pattern has been tested on common domestic pumping units of the D series. Based on the actual dimensions of the D-series units taken from the catalog [4], the relative linear dimensions of six standard sizes of pumps in this series are calculated using the equation

$$L^*_{actual} = \sqrt[3]{\frac{l_l b_l h_l}{l_b b_b h_b}}, \qquad (4)$$

where l_l, b_l, h_l — dimensions (length, width, height) of the larger unit; l_b, b_b, h_b — dimensions (length, width, height) of the base unit.

The unit equipped with the D320-70 pump is accepted as the basic unit. The results of the calculation are shown in table. 2.

Since the linear dimensions of pumping units increase more slowly than their supply increases, increasing the unit capacity of the units allows you to reduce their total number and reduce the size of buildings, simplify the hydraulic scheme of the station, reduce the number of pipe fittings and the number of cells in the electrical switchgear, etc.

Table 2.Relative parameters of D-series pumps

Type of the pump	Pressure, M	Rated power of the unit, kW	Relative feed	Relative linear dimensions	
				by calculation [formula (3)]	by catalog [formula (4)]
D 320-70	70	100	1	1	1
D 1250-65	65	320	3,9	1.93	1.62
D 2500-62	62	630	7.8	2.73	2.32
D 3200-75	75	800	10	2.94	2.71

D 4000-95	95	1250	12,5	3.15	2.78
D 6300-80	80	1600	19.7	4.0	3.6

Thanks to the equipment of pumping units with a frequency-controlled drive, reducing the number of units at pumping stations does not reduce the operational possibilities for changing their operating modes caused by changes in water consumption.

Thus, the use of a frequency-controlled electric drive under certain conditions not only does not increase the capital investment, but also reduces it somewhat (by a certain amount of dK).

Calculations have shown that the use of a frequency-controlled electric drive in combination with the enlargement of the unit power, depending on the purpose of the station and other specific conditions, can reduce the specified costs by 20-50 % [5].

Conclusions

The feasibility study of the use of a frequency-controlled electric drive in pumping units is carried out in the following sequence:

- Make up hydraulic and electric circuit diagrams compare the pumping systems;
- Determine the composition of the main equipment of the compared pumping units: pumping units, valves, valves, check valves, cells of switchgears, control devices (frequency converters, etc.);
- They assemble the main equipment of the compared pumping units;
- Determine the capital costs for the basic and new options for electrical equipment Kel, pumping equipment Kpum, hydro-mechanical equipment Khm, and construction part Kcon. The cost of electrical and hydro-mechanical equipment is determined in accordance with the price lists of companies and equipment manufacturers. For a preliminary estimate of the cost of a frequency-controlled electric drive and additional capital costs associated with the use of a frequency-controlled electric drive, the graphs shown in fig. 1. and 2. can be used. The cost of the construction part can be determined by the aggregated specific indicators of the cost of construction of pumping stations, contained, for example, in [6], taking into account the current inflationary coefficients of the cost of construction.
- Determine the depreciation deductions A from the cost:

    electrical equipment $$A_{el} = A_{rel.un}K_{el};$$

    pumping equipment $$A_{pum} = A_{rel.un}K_{pum};$$

    hydro-mechanical equipment $$A_{hm} = A_{rel.un}K_{hm};$$

    construction part of the pumping station $$A_{con} = A_{rel.un}K_{con};$$
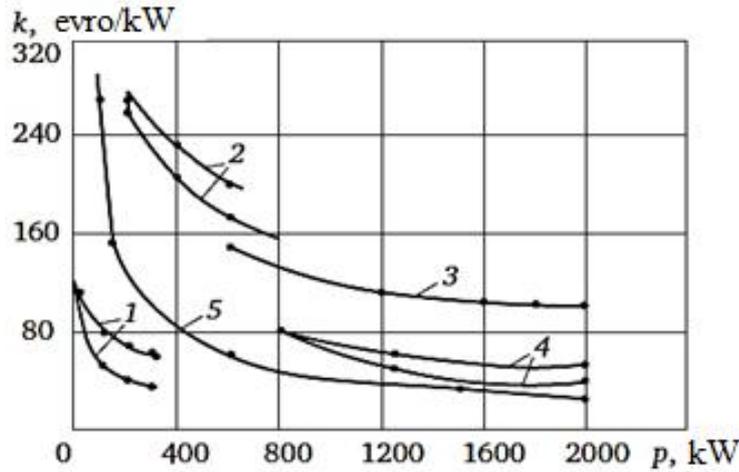
Fig.1. Specific cost of converters and control devices of various types of adjustable electric drive: 1 — low-voltage frequency converters; 2 — high-voltage frequency converters with dual voltage; 3 — high-voltage frequency converters; 4 — high-voltage transformer-free converters according to the valve motor system; 5 — hydraulic variator "Twin-Disk".
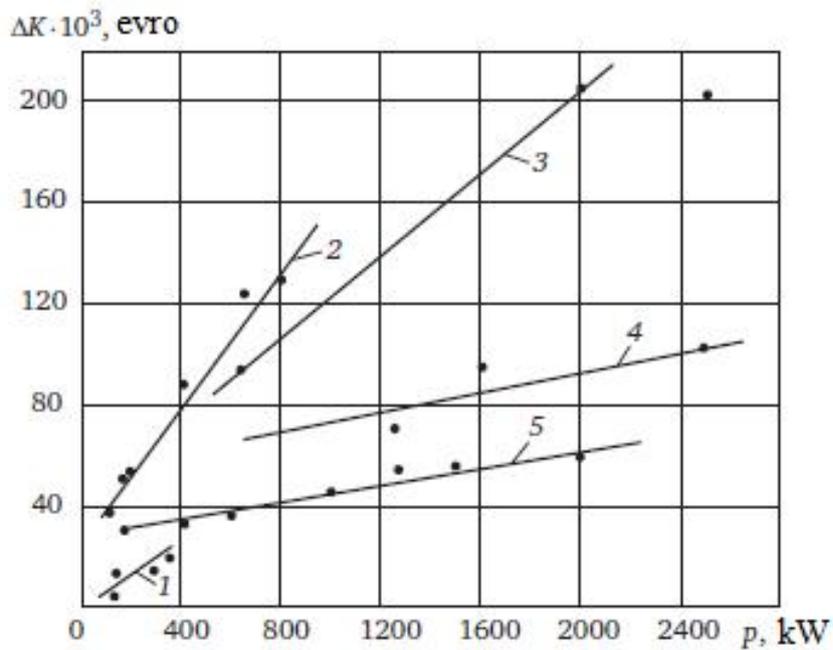

Fig.1. Additional costs associated with the use of converters and various types of controlled electric drive control devices: 1—5 — the same as in fig. 1

Approximate values of depreciation rates for various types of equipment are given in table 3.

Table 3.Depreciation rates by type of main equipment.

serial number	Equipment types	Amortization rate	
		A, %	$A_{rel.un}$

2013

1	Pump equipment	19	0,19
2	Gate valves, gates, valves	21.3	0.213
3	Electrical equipment	8.3	0.083
4	Building part	2.6	0.026

- Determine the energy consumption W_{reg} in use frequency-controlled drive (FCD) in the automatic control system of the pumping unit, kWh,

$$W_{reg} = 0.25 \frac{N_b T_{cal}(1+\lambda)}{\eta}\left(1+H_{b.p}^*\right)+\lambda^2\left(1-H_{b.p}^*\right)$$

- Determine the energy savings W_{reg} , obtained as a result of a decrease in overpressure when using the FCD in the ACS of the pumping unit;

- Determine the energy savings ΔW_η obtained as a result of the use of large capacity pumping units with a higher efficiency η_{big} , in comparison with the units of the basic version η_b, kWh,

$$\Delta W_\eta = W_{reg}\left(1-\frac{\eta_b}{\eta_{big}}\right)$$

where $\eta_{big} > \eta_b$;

- Determine the energy consumption $W_{n.reg}$, kWh, of the pumping unit when the units are operating according to the basic version, without a frequency-controlled electric drive:

$$W_{n.reg} = W_{reg}+W_{rec}+W.$$

- Determine the amount of water lost due to non-productive costs when operating in the basic mode. This volume of water corresponds to the volume of water saved when using a variable frequency drive in the ACS of the pumping unit $V_{sav.year}$;

- Determine the decrease in the volume of non-productive water consumption, dumped into the sewer, when operating in the basic mode;

$$V_{dec.dum.year} = (0,80 \quad 0,85)V_{sav.year} ;$$

- Determine the electricity costs for the base case;

$$C_{el.b} = W_{n.reg}P_{el}$$

where P_{el} — electricity tariff;

- Determine the electricity costs for the new option (with the use of aggregates of enlarged capacity and FCD in the automatic control system of the pumping unit)

$$C_{el.n} = W_{reg}P_{el} ;$$

- Determine the costs of covering the non-productive flow of clean water during the operation of the pumping unit without FCD

2014

$$\Delta C_Q = P_Q P_{sav.year},$$

where P_Q — cost of 1m3 of clean water;

- Determine the costs of processing and transporting waste water in the wastewater system (sewers)

$$\Delta C_q = P_q P_{dec.dum.year},$$

where P_q — the cost of pumping and processing $1m^3$ of wastewater;

- Determine the amount of capital costs for the basic $K\Sigma b$ and new $K\Sigma n$ options for electrical, hydraulic and construction parts

$$K_{\Sigma b} = K_{el.b} + K_{pum.b} + K_{hm.b} + K_{con.b}$$

$$K_{\Sigma n} = K_{el.n} + K_{pum.n} + K_{hm.n} + K_{con.n};$$

- Determine the amount of depreciation for the base $A_{\Sigma b}$ and new $A_{\Sigma n}$ options

$$A_{\Sigma b} = A_{el.b} + A_{pum.b} + A_{hm.b} + A_{con.b}$$

$$A_{\Sigma n} = A_{el.n} + A_{pum.n} + A_{hm.n} + A_{con.n};$$

- Determine the amount of operating costs for both options $C_{\Sigma b}$ and $C_{\Sigma n}$, taking into account energy consumption, saving clean water, reducing the discharge of effluents into the sewage system and depreciation deductions

$$C_{\Sigma b} = C_{el.b} + \Delta C_Q + C_q - A_{\Sigma b};$$
$$C_{\Sigma n} = C_{el.n} - A_{\Sigma n};$$

- Determine the reduced costs for both options

$$3_b = C_{\Sigma b} + EK_b;$$
$$3_n = C_{\Sigma n} + EK_n;$$

where E—is the coefficient of efficiency of capital investments, depending on the adopted payback period for additional capital investments:

$$E = 1/T_{pb}$$

Payback period Tpb, year.	2	3	4	5	6
Coefficient E .	0,5	0,33	0,25	0,2	0,166

- The reduction of the reduced costs $\Delta 3$,%, is calculated according to the new variant 3_n in comparison with the basic variant 3_b,%

$$\Delta 3 = \frac{3_b - 3_n}{3_b} 100.$$

2015

The payback period of an ACS equipped with an adjustable electric drive, taking into account the saving of clean water, a decrease in the discharge of effluents into the sewage system, an increase in the unit capacity of pumping units is determined by the expression

$$T_{pb} = \frac{\Delta K - dK}{\Delta C_{el} + \Delta C_{n.w} + \Delta C_{w.w} - A_{el}\Delta K + A_c dK},$$

where $\Delta K = K_{fcd} + K_{acs}$ —additional capital costs associated with the creation of an energy-saving ACS based on FCD; $dK = K_{\Sigma b} + K_{\Sigma n}$ —reduction of capital costs due to the enlargement of the unit capacity of pumping units and a decrease in their number;

$\Delta C_{el} = C_{el.b} - C_{el.n}$ — reduction in operating costs due to the use of a variable frequency drive in the ACS of a pumping unit and an increase in the efficiency of pumping units due to the enlargement of their unit capacity;

$\Delta C_{n.w} = \Delta C_Q$ — reduction in operating costs due to a decrease in excess pressure in the network and a reduction in non-productive water consumption due to the use of a variable frequency drive in the ACS of a pumping unit;

$\Delta C_{w.w} = \Delta C_q$ — reduction in operating costs due to a decrease in excess pressure in the network and a reduction in wastewater discharge into the sewage system due to the use of a frequency-controlled electric drive in the ACS of the pumping unit;

$A_{el} = 0,083$ — depreciation rate for electrical equipment;

$A_c = 0,026$ — depreciation rate for the construction part.

Depending on the calculated payback period of the ACS equipped with a variable frequency drive, a decision is made on the expediency of its use in a pumping unit. At present, 2-3 years are considered an acceptable payback period. In any case, the payback period should not exceed the service life of the ACS equipment and the frequency-controlled electric drive, that is, 10-11 years.

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