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Control of high-voltage pump motor using a frequency sine-wave filter converter

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Abstract. The method of control of a pump motor using a frequency converter as the most promising for saving energy in pumping units is described in the article. The installation of a two-transformer circuit with a low-voltage frequency converter at a pumping station in Krasnoyarsk with three network pumps equipped with DASO4-450X high-voltage asynchronous electric motors with a power of 630 kW and a voltage of 6 kV was also tested. The introduction of a two-transformer circuit and a low-voltage frequency converter with the inclusion of a sinus filter reduces the energy costs by 37%, reduces the temperature of the entire pump unit to 44 ° C and reduces the number of stops by 10%. In addition, the use of a frequency converter allows to increase the reliability of the entire system, as well as to reduce the risk of a breakthrough of the pipeline network, which is achieved by automatically maintaining pressure within the specified limits.

In accordance with the Energy Strategy of Russia for a possible period of development until 2030, approved by the decree of the Russian Federation Government provisions have been defined according to which fuel and energy complex (FEC) companies must pursue an internal policy aimed at energy saving.

The relevance of this study is due to the massive re-equipment and modernization of electric drives in water supply systems based on the use of frequency regulation algorithms and the need to maintain the operating performance of high-voltage electric motors at an optimal level.

Such scientists as Belkin V V, Gaintsev Yu V, Leznov B S, Braslavsky I Ya, Scheka V N, Volkov A V and others were engaged in research in the field of energy efficiency and operational reliability of asynchronous electric motors. Common flaws in research in this area are the lack of definition and justification of the limits of the frequency control range of asynchronous electric motors for general industrial purposes, as well as the lack of a comparative assessment of the effect of motor control algorithms on their operational reliability.

According to Belyakin V V, the following methods of controlling the rotational speed of an electric motor on a network pump can be distinguished: pump control method using throttling, pump control method using bypass and pump control method using frequency converter [1].

The method of control of the pump motor using a frequency converter (FC) as the most promising for energy saving in pumping units is described this article.

Mainly, the network pumps used in the heat supply systems of the Russian pumping stations are connected directly to the power supply network.

Hydraulic throttling is often used to regulate the performance of network pumps. In this case, the flow of water is regulated due to its restriction by valves; the electric motors themselves operate at almost the nominal mode [2].

According to the results of the study, today in the Siberian Federal District the percentage of heat and water supplying organizations using the “direct” start of electric motors reaches 56%.

The simplicity and versatility of the frequency converter favorably distinguish it from other methods of controlling the frequency of the motor shaft rotation.

The frequency converter allows you to adjust the speed of rotation of the motor shaft by changing the input frequency. The operation of the network pump during the season does not occur so often at the nominal (maximum) power, which necessitates the regulation of water supply [3].

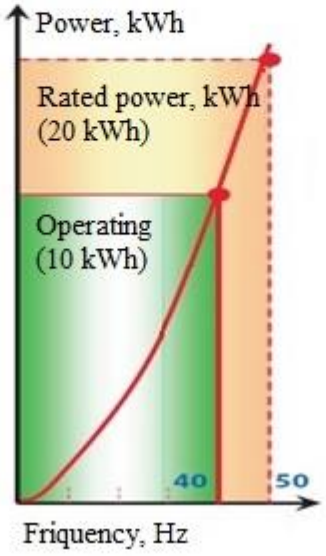

Figure 1. Power plot of rate of power dependence from the frequency of the mains.

In the case of the use of an inverter for the operation of the network pump, a decrease in the operating speed leads to a cubic reduction in power consumption. Due to the significant energy savings, the payback period of the frequency converter is reduced.

In general, the use of frequency converters for controlling electric motors saves at least 30% of electricity compared to traditional methods of controlling electric motors. For example, if the operating frequency is reduced by only 20% (from 50 to 40 Hz), then, as one can see in Figure1, the power consumption will be halved. In addition to energy saving, the inverter increases the service life of the electric motor and pipeline valves, increases the reliability of the entire system, and the frequency of maintenance significantly decreases. This is achieved through a soft start (in the case of a “direct” start there are starting currents 5-7 times the nominal) and the pump stops, the empty pipe filling mode, these functions allow to avoid water hammer in the system. Reducing the risk of a breakthrough of the pipeline network is achieved by automatically maintaining pressure within the specified limits. [4]

The inverter allows to carry out the main technological tasks: control and regulation of the water pressure in the system; temperature, volume (cubic capacity) of water in the system; technical condition of the entire pump unit (temperature, vibration, noise); leak detection, protection against dry running [5].

These protective functions increase the service life of the pumps and increase the reliability of their operation, eliminating possible emergency shutdowns.

Frequency converters do not require maintenance, unlike mechanical valves and DC motors. Depreciation of mechanical parts is reduced, which allows increasing equipment reliability, avoiding accidents and unwanted equipment downtime. As a result, it becomes possible to reduce the number of staff at the pumping station [6].

The frequency converter can have a wide range of communication capabilities (protocols and interfaces) for connecting to a PLC or a station control system. Thus, it is possible to increase the level of automation and quickly receive data from the equipment [7].

The main consumer of electrical energy in a typical booster pumping station is an asynchronous motor. The study was conducted on the example of a pumping station in Krasnoyarsk with three network pumps. The network pumps at this pumping station are equipped with DASO4-450X asynchronous electric motors with a capacity of 630 kW and a voltage of 6 kV. At this pumping station, the motor control method of the pump using throttling was used. The performance of the pumping equipment is shown in Table 2.

As it can be seen from the table, the electric motor is not used at full capacity, the efficiency is small, the cost of electricity is high.

It can be assumed that the use of a frequency converter to control the pump motor at this station will save energy in case of variable load. For their control can be used as high-voltage frequency converters, and also low-voltage (two-transformer circuit) [8]. Let us consider both options for controlling high-voltage electric motors: using a two-transformer circuit and a low-voltage frequency converter and a two-transformer circuit using a high-voltage frequency converter [9].

The first scheme involves the use of two transformers (stepdown-input and step up-output), low-voltage frequency converter and one or two sine-wave filters depending on the power of the converter [10].

This method of transformation is relatively simple and is considered a fairly cheap method of frequency conversion. It allows to use an inexpensive frequency converter in the design, while high-voltage frequency converters are relatively more expensive. However, on a closer look, it turns out that the investment with a two-transformer circuit is higher than expected.

The main disadvantage of this connection scheme is its limited range of adjustment of the motor shaft frequency of rotation. At first glance, the range looks impressive, but with large deviations from the nominal, the entire efficiency of the drive drops sharply. Frequency control, without loss in efficiency and the appearance of higher harmonics, in this scheme is in the range of 0.8 to 1 of nominal [11].

Now let us consider a two-transformer circuit with a low-voltage frequency converter (Figure 2).

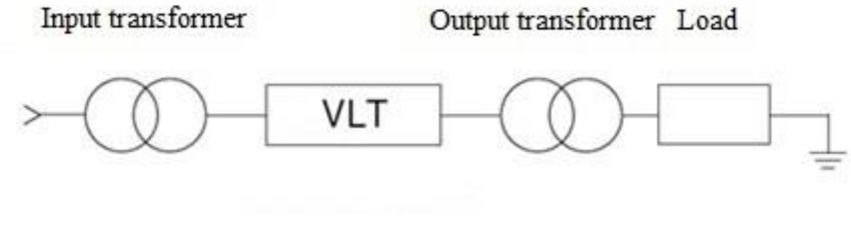

Figure 2. Two-transformer circuit.

The advantages of this scheme in comparison with high-voltage frequency converters are: a two-transformer circuit is cheaper by an average of 30% in the range up to 1 MW, galvanic isolation is achieved through the use of transformers, easier maintenance of the frequency converter, easier commissioning [4].

The disadvantages of this scheme are: relatively low efficiency, large mass-dimensional characteristics, a narrow range of regulation (ranging from 0.8 to 1 of nominal)

Now let us consider a two-transformer circuit with a low-voltage frequency converter (Figure 2). Table 1 presents the main indicators of the system using a low-voltage FC and a high-voltage FC.

Table 1. The main indicators of the system with the use of low-voltage FC and high-voltage FC converter.

Characteristic	Two-transformer circuit using a low-voltage frequency converter	High-voltage frequency converter with a multi-winding transformer
Efficiency	85-90% taking into account losses on 2 transformers and filter	From 96.5%, no losses in the electric motor from higher harmonics
Regulation	0.8-1 from nominal	Over the whole range
The presence of the output filter	Required obligatory	Not required
The presence of higher harmonics	Of 5-10%, depending on the filters	Less than 4%
Resistance to changes in input mains voltage	Not more than -10% + 10%. When power surges occur emergency shutdown of the frequency	-20% + 15%
Resistance to frequency deviation of the supply voltage	49-51 Hz	45-55 Hz

Implementing a two-transformer circuit and a low-voltage frequency converter at the object under study, system performance indicators were obtained. Table 2 presents the performance of the system using a two-transformer circuit and a low-voltage frequency converter in comparison with the previous indicators.

Table 2. System performance using a two-transformer circuit and a low-voltage frequency converter in comparison with previous indicators.

Characteristics	Network pump No. 1 (1D1250-125, electric motor DAZO4-450H-4, 630 kW, 1500 rpm, 6000 V)	
	Before implementation	After implementation
Water supply, m3 / h	840	840
Current of the electric motor, A	42,3	26,8
Frequency of a power line, Hz	50	18-27
Motor temperature, degrees C	87	81
Efficiency of the network pump,%	64	57
Consumed power, P, kWh	253,8	160,8
Number of repairs per year, rub.	8	9
Number of emergency stops, pieces / year	4	5
Electricity costs, rubles / year	14 580 000,00	9 262 080,00

As it can be seen from the table below, the power consumption has decreased, which has led to a reduction in costs by 37% compared with the period of operation without a frequency-controlled drive.

As a result of measurements over the course of 1 year, the following disadvantages were revealed when using a two-transformer circuit and a low-voltage frequency converter. This is increased heating of the electric motor due to the appearance of higher harmonics at a network frequency of less than 0.8 n, a decrease in pump efficiency by 7%, as well as an increase in the number of emergency stops. Harmonic currents have led to an increase in losses in the motor and cable in the form of excess heat.

It can be concluded that the frequency-controlled method of controlling network pumps gave a financial effect, but adversely affected the operation of the entire pump unit at low frequencies less than 40 Hz. In order to minimize this drawback, it was proposed to use a sinus filter, which was supposed to bring the output voltage to a sinusoidal form, as well as smooth out rectangular voltage pulses at the output of the frequency converter.

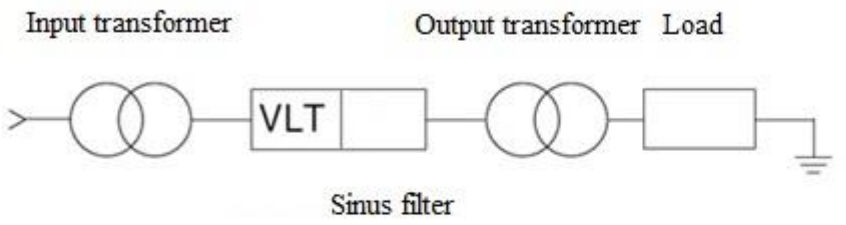

Figure 3. A two-transformer circuit with the inclusion of a sinus filter.

After the introduction of this scheme, measurements were made and it was found that the inclusion of a sinus filter into the frequency converter favorably affected the operation of the entire pump unit, namely: the number of higher harmonics decreased, as a result, the temperature of the entire pump unit decreased to 440C, the number of stops decreased by 10 %.

Thus, in the general case, the use of frequency converters for controlling electric motors saves at least 30% of electric power in comparison with traditional methods of controlling motors. In addition to energy saving, the inverter increases the service life of the electric motor and pipeline valves, increases the reliability of the entire system, and the frequency of maintenance decreases significantly. In addition, the reliability of the entire system as a whole is significantly increased. And when used in a particular case at a pumping station in Krasnoyarsk with three network pumps equipped with high-voltage asynchronous electric motors, a two-transformer circuit and a low-voltage frequency converter with a sinusoidal filter, it reduces energy costs by 37% and reduces the temperature of the entire pump unit to 44 ° C and reduce the number of stops by 10%.

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