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Development of Recommendations for Increasing Energy Efficiency in Water Supply Systems

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ABSTRACT: This article is dedicated to developing recommendations for increasing of energy efficiency in water supply systems using the example of the water providing enterprise "Toshkent Shahar Suv Ta'minoti" Joint-stock company Water providing facility. During the research, the main directions for reducing energy consumption were identified and calculated, including the application of frequency control of pumps, replacement of underloaded electric motors with modern models of lower power, and the renewal of outdated transformers. The proposed measures are aimed at optimizing the operation of the water supply system to reduce energy costs and increase its efficiency.

KEYWORDS: energy efficiency, energy saving, water supply, pumping stations, frequency control, transformer, electric motor, optimization.

I. INTRODUCTION

The unconditional necessity for the implementation of processes supplying the urban population with drinking water is the availability of electricity, as the technical devices of urban supply systems are operated by electricity. To ensure economical and efficient use of electricity, as well as uninterrupted water supply, it is necessary to use appropriate energy-saving equipment.

The goal No. 31 in the development strategy of the New Uzbekistan for 2022-2026 "Implementation of a state program for radical reform of the water resources management system and water conservation," is dedicated to the following tasks outlined: "... (1) saving at least 7 billion m^3 of water through efficient use of water resources; (2) reducing electricity consumption at water management facilities; (3) implementing a management system for water management facilities ...". To implement these tasks, it is necessary to study issues such as problems with ensuring energy and water conservation modes at pumping stations, as well as studying the operating modes of electric motors and the power supply network of pumping stations for water lifting machine systems [1,2].

II. RESEARCH METHODS.

Two research methodologies are employed in this study. These methodologies draw upon theoretical and practical investigations, synthesizing extensive practical experience in assessing the overall energy intensity of products. They incorporate findings from scientific works conducted at the Institute of Energy Problems of the Academy of Sciences of the Republic of Uzbekistan and the Inspection for the Control of the Use of Electricity, Oil Products, and Gas responsible for electricity energy issues. The practical research utilized both standard and custom-developed techniques, with the reliability of outcomes assessed through result verification.

III. RESULTS AND DISCUSSION.

The "Toshkent Shahar Suv Ta'minoti" joint-stock company is one of the largest communal enterprises in the city, whose main task is to ensure uninterrupted supply of drinking water to the city of Tashkent, as well as the drainage and treatment of urban wastewater. The enterprise includes large water intake structures, water distribution nodes, third-lift and fourth-lift pumping stations, water mains and networks, sewage treatment plants, pumping stations, sewage collectors, networks, and their structures.

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The water supply of the city of Tashkent is carried out from eight water intake structures with a total capacity of 2,326,000 cubic meters per day, with over 70% of the water supplied to the city coming from the open-source of the Boz-Su canal.

There are 166 third-lift and fourth-lift pumping stations and three water distribution nodes in the city: Mirzo-Ulugbek, Chilanzar, and Sergeli.

To increase the energy efficiency of water supply, it is recommended to maximize the efficient use of electricity, reduce electricity losses, implement modern energy-saving technologies, and develop a series of appropriate measures [5].

For one of the objects of the "Toshkent Shahar Suv Ta'minoti" joint-stock company studied in this research, the following energy-saving measures are recommended:

- Application of frequency control of pumps in water supply systems.
- Replacement of underloaded electric motors with motors of lower power.
- Replacement of outdated transformers with modern ones of appropriate capacity.

The application of frequency regulation of pumps in water supply systems.

The efficiency of using regulation installations with frequency-controlled electric drives is determined by comparing the indicators of the existing and recommended equipments' options [7, 11].

The economic efficiency of using frequency-controlled electric drives is achieved through the following components: saving electrical energy and resources [4], i.e.,

$$E = Ee + Er \tag{1}$$

where Ee – economic effect due to electrical energy saving for one year,

Er – The economic effect due to equipment resource conservation for one year.

Through equipment resource conservation, i.e., increasing the lifespan of electric motors and drive mechanisms through frequency regulation, the lifespan of electric motors and drive mechanisms is increased, resulting in extended maintenance intervals and reduced equipment maintenance and repair costs. In this case, the calculated value of economic efficiency due to frequency regulation can be increased by 10-15%. If we assume an increase in economic efficiency of 10%, then this component will be equal to [6, 8]:

$$Er = 0{,}10 * Ee, \tag{2}$$

The total economic effect of the two components will be:

$$E = 1{,}10*Ee, \tag{3}$$

When implementing an automatic control system for pump stations, electricity savings of 3 to 5% can be achieved.

To calculate the active power of the pump units №3, №5, and №6, with capacities of 37, 22, and 52 kW correspondingly with a frequency converter for controlling the electrical drive:

$$W=K*P, \tag{4}$$

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$$P1=\sqrt{3}*I*U*\cos\varphi*t, \quad (5)$$

$$W1= K*P1 =3*1.73*37*380*0.85*24=1488.61$$

where K – quantity of pump units;

t – working time of pump unit.

The annual electricity savings when replacing the main electric drive with the "thyristor frequency converter - pump unit" system amount to [9]:

$$W2=K*P *10\%, \quad (6)$$

$$P2=\sqrt{3}*I*U*\cos\varphi*t*10\%, \quad (7)$$

$$W2= K*P =1339.75$$

The average energy-saving potential amounts to:

$$Ea=W1-W2=1488,61-1339.75= 148.86$$

Replacement of underloaded electric motors with motors of lower power.

Enterprises should systematically carry out modernization and replacement works of morally obsolete equipment, in particular, by replacing ineffective electric motors with motors of new series that meet modern energy efficiency requirements [3, 10].

To make a decision on equipment replacement, it is necessary to conduct an inspection of the technical condition of the mechanisms' electric motors, analyze operating modes, actual loads, and operating conditions of the electric motors, as well as develop recommendations for improving methods of operation and increasing operational reliability.

It is also necessary to assess the possibility and feasibility of using adjustable electric drives for specific mechanisms.

It is desirable to participate in the acceptance at the manufacturer's plant of new electric motors (according to the developed project), as well as to conduct experimental research of their characteristics on-site.

Currently, there are also ЭЦВ brand pump units at the facility. These pumps have served their service life.

If the average load of the electric motor is less than 45% of the rated power, then replacing it with a less powerful electric motor is always justified, and calculations are not required. With an electric motor load exceeding 70% of the rated power, it can be considered that its replacement is not justified.

When the electric motor load is within 45…70% of the rated power, the feasibility of their replacement should be confirmed by a reduction in the total losses of active power in the electrical system and in the electric motor.

These total losses of active power can be determined by the expression:

$$\Delta P_{total}= [Q_{nl} \cdot (1 - k_r^2)+k_r^2 \cdot Q_r] \cdot \ k_э + \Delta P_{nl} \ + к_r^2 \cdot \Delta P_{al.}, \quad (8)$$

where $Q_{nl} = \sqrt{3} \cdot U_r \cdot I_{nl}$ – reactive power consumed by the motor from the grid under no-load conditions, kVAR;

I_{nl} - no-load current of the motor, A;

$k_l = P/P_r$ - motor load factor;

P - average motor load, kW;

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P_r - motor rated power, kW;

$Q_r = \frac{P_н}{\eta_r} \cdot tg\varphi_r$ - reactive power of the motor at rated load, kVAR;

η_r - motor efficiency at rated load;

$tg\varphi_r$ – tangent of the nominal power factor of the motor;

k_e - coefficient of loss variation;

$\Delta P_{nl}=P_{avl}\left(\frac{1-\eta_r}{\eta_r}\right)\cdot\left(\frac{\gamma}{1+\gamma}\right)$ - active power losses under no-load conditions of the motor, kW;

$\Delta P_{al}=P_r\cdot\left(\frac{1-\eta_r}{\eta_r}\right)\cdot\left(\frac{1}{1+\gamma}\right)$ - increase in active power in the motor at 100% load, kW;

$\gamma=\frac{\Delta P_{nl}}{\Delta P_{al}}$ – calculated coefficient, depending on the motor construction and determined, for example, from the expression:

$$\gamma=\frac{\Delta P_{nl},\%}{(100-\eta_r,\%)-\Delta P_{nl},\%}; \quad (9)$$

where ΔP_{nl}, % - no-load losses as a percentage of active power consumed by the motor at 100% load.

It is necessary to verify the profitability of replacing motor A92-2 with a rated power of P_r=75 kW, operating at a load of P=50 kW, with motor A82-2 with a rated power of P_r=55 kW.

The coefficient of loss variation is assumed to be equal to k_e=0.1 kW/kVAR.

Solution:

The parameters of motor A92-2 are: P_r= 75 kW; U_r=380 V; η_r= 0,91; $\cos\varphi_r$ = 0,92; I_{nl}= 42,6 A; ΔP_{nl}= 3,2 kW.

We determine:

$Q_{nl} = \sqrt{3}\cdot U_r\cdot I_{nl} = \sqrt{3}\cdot 380\cdot 48.6\cdot 10^{-3}$= 31.94 kVAR;

$Q_r=\frac{P_r}{\eta_r}\cdot tg\varphi_r=\frac{75}{0,91}\cdot 0.486$= 40.05 kVAR;

$\kappa_r= P/P_н$= 50/75 = 0.66;

$\Delta P_{nl} = \frac{\Delta P_{xx}}{P_н}\cdot 100 = \frac{3,2}{75}\cdot 100$ = 4.27 %;

$\gamma=\frac{\Delta P_{nl},\%}{(100-\eta_r,\%)-\Delta P_{nl}"\%}=\frac{4.27}{(100-91)-4.27}$= 0.9;

$\Delta P_{al}= P_r\cdot\left(\frac{1-\eta_r}{\eta_r}\right)\cdot\left(\frac{1}{1+\gamma}\right) = 75\cdot\left(\frac{1-0.91}{0.91}\right)\cdot\left(\frac{1}{1+0.9}\right)$ = 3.9;

$\Delta P'$ = [31.94 (1-0.66^2)+0.66^2 · 40.05] · 0.1 + 3.2 + 0.66^2 · 3.9 = 8.50.

The parameters of motor A82-2 are: P_r= 55 kW; U_r=380 V; η_r= 0.91; $\cos\varphi_r$ = 0.92; I_{nl}= 40 A; ΔP_{nl}= 3.2 kW.

We determine:

$Q_{nl} = \sqrt{3}\cdot U_r\cdot I_{nl} = \sqrt{3}\cdot 380\cdot 48.6\cdot 10^{-3}$= 25 kVAR;

$Q_r=\frac{P_r}{\eta_r}\cdot tg\varphi_r=\frac{75}{0,91}\cdot 0.486$= 38 kVAR;

$\kappa_r= P/P_r$= 50/55 = 0.90;

$\Delta P_{nl},\% = \frac{\Delta P_{nl}}{P_r}\cdot 100 = \frac{3,2}{55}\cdot 100$ = 5.81 %;

$$\gamma=\frac{\Delta P_{nl},\%}{(100-\eta_r,\%)-\Delta P_{nl}"\%}=\frac{5.81}{(100-91)-5.81}= 1.82;$$

$$\Delta P_{al}= P_r\cdot\left(\frac{1-\eta_r}{\eta_r}\right)\cdot\left(\frac{1}{1+\gamma}\right) = 55\cdot\left(\frac{1-0.91}{0.91}\right)\cdot\left(\frac{1}{1+0.9}\right) = 2.86;$$

$$\Delta P'' = [25*(1-0.9^2)+0.9^2*38]*0.1 + 3.2 + 0.9^2*2.86 = 6.77.$$

As a result of replacing the underloaded 75 kW electric motor with a motor of lower but suitable rated power, equal to 55 kW, we achieve a reduction in active power losses in the motor and electrical network, which is:

$$\Delta W_{el.en.sav} = P' - P'' = 8.50 - 6.77 = 1.73$$

$$W_{day.el.en.sav} = \Delta W_{el.en.sav} * t = 1.73 * 24 = 41.52$$

$$W_{month.el.en.sav} = W_{day.el.en.sav} * t = 41.52 * 30 = 1245.6$$

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Energy saving in transformers.

When a power transformer is loaded to 30%, the load losses of power are approximately equal to the no-load losses. On average, up to 7% of the transmitted power is lost on each transformer. The operation of the transformer in no-load or near-no-load mode causes excessive energy losses not only in the transformer itself but also in the entire power supply system (from the transformer to the power source) due to the low power factor.

To calculate the energy losses in a two-winding transformer, data on the technical characteristics of the transformers are required, for example, from a handbook, as well as data on the consumption of active W_a (kWh) and reactive W_r (kVAR·h) energy for the calculation period.

Technical characteristics of the transformer at the investigated object:

- Rated power of the transformer S_r - kVA;
- No-load losses (core losses) of the transformer ΔP_{nl} - kW;
- Short-circuit losses (active power losses in the copper windings) of the transformer at rated load ΔP_{sc} - kW;
- No-load current of the transformer I_{nl} - %;
- Short-circuit voltage of the transformer - U_{sc} - %;
- Reactive power losses at no load of the transformer are calculated by the expression, kVAR:

$$\Delta Q_{nl} = S_r \cdot \frac{I_{nl},\%}{100}, \tag{10}$$

- Reactive power losses during transformer short-circuit are calculated by the expression, kVAR:

$$\Delta Q_{sc} = S_r \cdot \frac{I_{nl},\%}{100}, \tag{11}$$

The calculation of energy losses in the transformer is performed in the following sequence:

a) Actual or calculated data on the consumption of electrical energy for the calculation period are determined based on the readings of reactive energy meters – W_r (kVAR·h);

b) The average power factor tgφ_{avg} is calculated from the relationship:

$$\mathrm{tg}\varphi_{avg} = W_r / W_a, \tag{12}$$

and then - the average power factor - cosφ_{avg}.

For enterprises where electricity meters are installed on the primary voltage side (up to the customer's transformer with higher voltages of 35 kV and above), tgφ_{avg} is calculated by the expression:

$$\mathrm{tg}\varphi_{avg} = (W_r - \Delta W_r)/(W_a - \Delta W_a), \tag{13}$$

c) the loading factor (load) of the transformer K_{load} is determined by the expression:

$$K_{load} = \frac{W_a}{S_r \cdot T_n \cdot cos\varphi_{cp}}, \tag{14}$$

where T_n - the total number of hours of operation of the transformer per month, which is assumed to be: in January, March, May, July, August, October, December - 744 hours; in April, June, September, November - 720 hours; in February - 672 hours (for a leap year - 696 hours).

If the transformer is disconnected on holidays or weekends, the specified time T_n should be reduced by this disconnection time.

The losses of active electrical energy in the transformer are calculated by the expression:

$$\Delta W_a = \Delta P_{nl} \cdot T_n + \Delta P_{sc} \cdot K_3^2 \cdot T_{work}, \tag{15}$$

And the losses of reactive electrical energy in the transformer are calculated by the expression:

$$\Delta W_r = \Delta Q_{nl} \cdot T_n + \Delta Q_{sc} \cdot K_{load}^2 \cdot T_{work}, \tag{16}$$

where T_{work} - the number of hours of operation of the transformer at rated load per month, which is assumed to be for enterprises operating in one shift - 200 hours; in two shifts - 450 hours; in three shifts - 700 hours.

Let's consider the replacement of transformers based on one transformer of a drinking water supply object.

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Table №1

Activities for replacing transformers at TS №8 and TS №4 of Object №1												
№ п/п	Equipment name, type	Quantity	Experimental data									
			T_n	Power, kVA	Δ_{Pnl}	β^2	ΔP_{sc}	$\Delta E_{tr}=\Delta P_{nl}*T_n+\beta^2*\Delta P_{sc}*T$	Voltage, V	Current A	T_{work}	$\Sigma\Delta E_{tr}$, kWh
Calculation of energy losses in existing transformer of Object №1												
1	TS №8 TM 400	2	24	400	1.08	0.24	5.5	33.4	380	145	24	66.8
1	TS №4 TM 250	2	24	400	0.78	0.12	3.7	20.1	380	75	24	40.1
Daily electrical energy losses									W (kWh)			**106,97**
Calculation of energy losses after transformer replacementin Object №1												
1	Replacement of TM-400 kVA to TM -160 kVA in TS №8	2	24	160	0.45	0.29	2.65	16.1	380	70	24	32.1
1	Replacement of TM-250 kVA to TM -160 kVA in TS №4	2	24	160	0.45	0.29	2.65	16.1	380	70	24	32.1
Daily electrical energy losses									W (kWh)			**64.24**

Calculation of losses with existing transformers of Object №1:

$$W_{ex.losses\ TS\ №8}= 66.8$$
$$W_{ex.losses\ TS\ №4}= 40.1$$

Calculation of losses after replacement of transformers of Object №1:

$$W_{repl.losses\ TS\ №8}=32.21$$
$$W_{repl.losses\ TS\ №4}=32.21$$

Determining energy savings due to changes in energy losses when replacing with a transformer of lower rated power:

$$E_{day}= W_{ex.losses\ TS\ №8} - W_{repl.losses\ TS\ №8}=66.8-32.21=34.71$$
$$E_{day}= W_{ex.losses\ TS\ №4}- W_{repl.losses\ TS\ №4}=40.1-32.21=8.02$$
$$\Sigma\ E_{day} = 42.73$$
$$E_{month}= \Sigma\ E_{day} * t = 42.73*30=1281.81$$
$$E_{year}= E_{month} * t = 1281.81*12=15381.67$$

IV. CONCLUSION

The study considers a pump station of the urban water supply system as the object of research. As a result of examining the operation of this station, excessive electricity consumption was identified in existing equipment. To reduce these expenses, corresponding recommendations have been developed.

The research indicates that implementing frequency control in water supply pump stations allows for reducing energy consumption and operational costs by regulating the rotation frequency of motors and pumps based on actual water consumption, ensuring the required pressure and system mode, as well as conducting monitoring and diagnosing possible faults or malfunctions, which contributes to increasing the reliability and effectiveness of the system. Implementing automatic performance control of pump units through frequency-controlled electric drives represents a promising and economically justified approach to optimizing the operation of water supply pump stations.

Replacing underloaded electric motors represents a potential opportunity to reduce energy consumption and operational costs while maintaining the required system performance. The feasibility of replacing underloaded electric motors at pump stations with more efficient models with lower power becomes increasingly relevant in the context of energy conservation and improving energy efficiency. When replacing underloaded electric motors, it is necessary to compare the potential energy-saving opportunities with the costs of new equipment.

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The feasibility of replacing high-power transformers with lower-power transformers to enhance energy efficiency and reliability is a relevant issue in modern energy systems. Transitioning to transformers with lower but more suitable power can optimize the operation of the energy system, reduce losses during electricity transmission, and increase the efficiency of devices. Additionally, new transformers typically have more modern technical characteristics, contributing to increased overall reliability of the energy system. In this context, a comprehensive analysis of technical, economic, and environmental aspects of transformer replacement is necessary to determine the optimal solution that takes into account the needs of the energy system and pump station.

REFERENCES

[1]. Decree of the President of the Republic of Uzbekistan dated January 28, 2022 No. PF-60 "On the Strategy for the Development of New Uzbekistan for 2022-2026."
[2]. Allayev K.R. Modern energy and its development prospects. - T .: "Fan va texnologiyalar nashriyot matbaa uyi", 2021. - 952 p.
[3]. Kamalov T.S. Frequency-controlled electric drive of pump stations for machine irrigation. - T .: Fan, 2014. - 368 p.
[4]. Kamalov T.S., Shavazov A.A., Sayfullayeva L.I. Issues of commissioning and regulation of the performance of a pump unit of pump stations of machine irrigation systems // Energy Saving and Water Treatment. - Moscow, 2019. No.3 (119), P. 51-54. (05.00.00; No. 97).
[5]. Leznov B.S. Energy saving and adjustable drive in pumping installations. - M .: IK "Yagorba-bioinformservice", 1998. - 381 p.
[6]. Shavazov A.A., Ishanova D.A. // Mathematical models and transfer functions of frequency-controlled asynchronous motor. // Volume-08 Oct. - 2022 Website: www.ejird.journalspark.org ISSN (E): 2720-5746.
[7]. Ishnazarov O., A. Shavazov, D. Ishanova. // Closed Frequency Control System of Asynchronous Motor in Irrigation Pump. // Pioneer: Journal of Advanced Research and Scientific Progress (JARSP) Volume: 01 Issue: 04 | 2022 ISSN: 2751-7551.
[8]. Isakov A., A Shavazov and A Elmuratova. Management efficiency of pumping aggregates through frequency converter. IOP Conf. Series: Earth and Environmental Science 1076 (2022) 012050 AEGIS-2022.
[9]. Isakov A., Shavazov A., Ismailova Z., Rakhmankulova B. Frequency control of asynchronous motor for an irrigation pump of machine irrigation systems. E3S Web of Conferences 402,10004 (2023).
[10]. Ishnazarov O.X., Shavazov A.A., Ishanova D.A. Issues of automatic adjustment of torque and speed in pump units // Qarshi Engineering-Economic Institute, "Journal of Innovative Technologies", 2023/2 (50), 45-50 p.
[11]. Shavazov A.A., Eshquziev Kh.M., Zokhidov I.Z. Interconnected systems of pumping stations with asynchronous frequency electric drives. Scientific-technical journal STJ FerPI, 2023, Vol. 27. Special editions No. 15, 99-105.
[12]. Xamudxonov M.M., Abdullabekov I.A., Do'smatov R.K., Xamudxonova N.B., Fayzullayev B.X. Management of operation modes of a pumping station with an electric motor controlled by frequency // Web of Conferences, II International Scientific Conference. IOP Conf. Series: Materials Science and Engineering 862 (2020) 062048IOP. Published https://iopscience.iop.org/article/10.1088/1757-899X/862/6/062048