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Experience in using methods for monitoring the energy efficiency of hydraulic systems

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Abstract. The purpose of this research is to improve the system of water resources management and operation of water facilities, reduce the energy consumption of irrigation pumping stations, which is one of the urgent modern problems in the Republics of Central Asia. The authors decide on the choice of such a set of subsystems and elements from the universal set, in which the value of the design parameters is provided with minimal costs. The recommendations developed by the authors use methods for monitoring the energy efficiency of hydraulic systems and are aimed at reducing electricity consumption, primarily through effective methods for regulating the operation of pumping stations. The main feature of assessing the technical condition of the units of pumping stations is the use of diagnostics of the dynamic level of elements of hydraulic units during operation. Monitoring of operating parameters of pumping stations was carried out on two pilot canals according to special tables of basic parameters. As an optimality criterion, options are accepted that differ in terms of reconstruction, duration of development of the capacity of electrical networks, interface structures of pumping stations, taking into account the time factor. By carrying out these activities, the water supply of the irrigation array will increase and crop yields will increase. After analyzing the data obtained, it will be possible to make a decision on the further use or modernization of the units of pumping units and structures. At the same time, the conditions for energy efficiency and reliability of the operation of the PS will improve.

1. Introduction

In the Decrees of the President of the Republic of Uzbekistan and the Cabinet of Ministers of the Republic of Uzbekistan, in order to further improve the system of water resources management and operation of water facilities, priority areas have been identified to ensure the effectiveness of the implementation of irrigation and melioration projects, as well as the development of science in this area [1]. One of the principles of water resources management at the grassroots level is the solution of problems associated with the use of limited water resources, increasing the efficiency of their use and impact on sustainable development. Instructions and recommendations for the use of methods for monitoring the energy efficiency of hydraulic systems should be aimed at reducing electricity consumption at water facilities by at least 10 percent through the widespread introduction of energy-saving and energy-efficient technologies, as well as the introduction, first of all, of effective methods for regulating the operation of pumping stations (PS).

In the system of the Ministry of Water Resources of the Republic of Uzbekistan, there are more than 20 systems of machine water lifting for irrigation, which provide water resources for more than 2.1 million hectares of irrigated lands of the Republic [2]. For their normal functioning, channels with hydraulic structures, pumping stations with power equipment are operated [3, 4].
Currently, a project is being carried out to modernize 299 of the largest state pumping stations in the system of the Ministry of Water Resources of the Republic of Uzbekistan. Large pumping units are very energy intensive facilities. They annually consume approximately 20% of the generated electricity, which for the CIS is about 300 billion kWh per year.
The distribution of energy-saving systems will save 70-80 million kW per year in the Republic's MWUS, that is, approximately 1% of the required electricity. This means that with an annual increase in electricity generation of 3-4%, the commissioning of new energy capacities can be reduced by 1/3. As a result, burning of 1.8-2 million tons of standard fuel or 2-3 million tons of real coal will be prevented, and a significant effect will be obtained by reducing harmful emissions. In addition, these systems reduce the likelihood of hydraulic shocks, prevent the destruction of pipelines and, as a result, the outflow of water onto the surface of the earth and into water bodies. Reducing resource and energy intensity is one of the main problems for the water supply system. The works of foreign researchers [5,6,7,8] describe approaches to improving the energy efficiency of pumping equipment of water supply systems by regulating the operating modes of pumping units and coordinating the characteristics of the pump and hydraulic structures, taking into account their operating conditions. In all the above sources, the work of the pumping station is considered within the framework of the "channel - pumping unit" system. In most of the above sources, when choosing the system control parameters, the energy characteristics of pumping units in terms of efficiency are practically not taken into account. Therefore, the selected system parameters during regulation may go beyond the range of permissible values for reducing efficiency, and the use of innovative technology, which requires additional costs, will lead to total negative results. This paper considers the development of a strategy for upgrading and stimulating the efficiency of operation of irrigation PSs based on new resource-saving PS technologies that save electricity and water consumption.

2. Materials and Methods

Table 1. Summary table of the main PS parameters

PS	Year of construction completion	Number of pump units			Pump brand	PS supply, m^3/s	Elevating height, m	Electric motor brand	Electric motor power, kW	Water intake source	Data for the year				
		By project	including the reserve	Ready to work, pcs							Volume of water supply, m^3	Electricity consumption, kW	Operating costs thousand soums	The cost of electricity, thousand soums	Suspended area, hectare

The article uses methods for analyzing the results of field and laboratory experiments on changing the parameters of operation of the main structures and pumping and power equipment of the pumping station, the characteristics of water sources with an elevated temperature regime and contaminated with

sediment, fin, and mineral products. This analysis is based on the development of procedures for linking the work schedules of the pumping station to ensure an uninterrupted and efficient water supply strategy in the Amudarya and Zarafshan river basins, especially in mixed river feeding zones (water supply from Amu-Bukhara machine channel (ABMK)).
Monitoring of the operation mode of the PS was carried out on two pilot channels according to special tables, including a survey of the operating personnel of these facilities.
The development of methods for studying and analyzing a modern system of pumped water lifting and energy consumption using new designs and technological modes of the PS is carried out when the efficiency of the equipment in operation is much lower compared to the new one. In this case, it is necessary to determine the replacement period for the old equipment and the type of newly selected equipment according to the methods for implementing the indicated goals and objectives of energy saving.

Table 2. PS performance monitoring

Number of pumps in operation		PS submission per period / thousand m3		Consumed elektr energy, kW		Refusals at work				Simple, hour			Control of hydrometric parameters and electricity meters
fact	according to the water supply schedule	fact	according to the water use plan	pumping unit	for own needs	hydraulic	mechanical	electrical	others	planned	unscheduled	due to power outage	Upstream and downstream levels

3. Results and Discussion

In order to reduce the energy consumption of irrigation PSs, which is one of the urgent modern problems in the Republic, the choice is being made from a universal set of such a set of subsystems and elements, which ensures the value of design parameters at minimal cost. The machine water uplifting system (MWUS) has a control and controlled part, which is in constant motion water flow, temperature change, turbidity, fin amount, head (pressure). At present, there is a need to consider the scientific and methodological side of this problem in order to determine the area and tasks of energy efficiency, its structure and the main directions for the development of the dynamics of changes in the characteristics of the main equipment of the MWUS [9,10]. The article provides monitoring and clarification of the technical condition of the pumping station to the working projects of their reconstruction according to the methodology for performing work according to tables 1, 2 (Table 3).
Monitoring determined the main technical characteristics of PS.
1. PS Gus-1 is located on the territory of the “Mekhnatabad” farm. Supply - 0.6 m^3/s. PS «Gus-1» operated since 1975. The station supplies water to the fore-chamber of the PS Gus-2. Water intake is carried out from the “Yangi”

canal. PS is equipped with 3 pumps 300D90 with M315 MK4 engines with power N=250 kW, U=380 V, n=1500 rpm. The pumps supply water to the pressure pipeline Du=500 mm (1 thread) 1300 m long.

Table 3. Brief technical characteristics of the PS of the Zarafshan basin

№	Name PS and location by lot	Number of pumps/reserve	Pump type	P.S. supply Q=m^3/s	Power of electric motors kW	Uplifting height H=m	Pressure pipeline diameter, mm	Suspended area, hectare
1	2	3	4	5	6	7	8	9
1.	Gus-I	3	300Д90	0,6	815	52	500	
2.	Gus-II	3	300Д90	0,9	815	50	500	
3.	Navali	4	300Д90	1,2	1000	68	1200	331,3
4.	Pakhtakor -I	6	400Д190	2,7	1000	21	1020	
5.	Shur	4	300Д90	0,9	470	28	400	927
6.	Maibulak	3	20Д6	1,6	2400	95	730	1086
7.	Yangi-Khaet	5	300Д90	1,5	1315	52	800/300	460

Hydro mechanical and electrical equipment has exhausted its standard service life, has been repeatedly repaired, and therefore does not currently reach the design parameters. As a result, the actual maximum discharge of PS is 0.42 m3/s instead of 0.6 m^3/s according to the project. There are cases of breakdown of the insulation of the stator windings of motors. Reduced cable insulation resistance.

2. PS Gus-2 is also located on the territory of the “Mekhnatabad” farm. Supply - 0.6m^3/s. PS Gus-2 has been in operation since 1975. The station supplies water to the antechamber of the PS "Gus-3". Water intake is carried out from the fore-chamber. The PS is also equipped with 3 pumps 300D90 with similar parameters and disadvantages of the PS "GUS-1". 3. PC "Navali" is located on the territory of the farm "B. Khasanov". Supply - 1.2 m^3/s. PS “Navali” has been in operation since 1981. The station irrigates 331.3 hectares of land from the “Korasow’ canal. The main direction of economic activity is cotton growing, viticulture, horticulture and grain growing. PS is equipped with 4 pumps 300D90 with M315 MK4 engines with power N=250 kW, U=380 V, n=1500 rpm. Pumps supply water to the pressure pipeline D_u=1000 mm (1 thread). The actual maximum flow of PS is 0.63 m^3/s instead of 1.2 m^3/s according to the project.

4. PS Pakhtakor-1 is located on the territory of the Pakhtakor farm. Supply - 2.7 m^3/s. PS Pakhtakor-1 has been in operation since 1978. The station irrigates 554 hectares of land from the “Narpay” canal. The main direction of economic activity is cotton growing and grain growing. PS is equipped with 6 pumps 400D190 with M280M6 engines with power N=250 kW (1 piece), U=380 V, n=1000 rpm. The actual maximum discharge of PS is 1.35 m^3/s instead of 2.7 m^3/s according to the project.

5. PS "Shur" is located on the territory of the farm "Akhunbabaeva". Supply - 0.9 m^3/s. PS “Navali” has been in operation since 1964. The station irrigates 927 hectares of land from the Inter-farm canal (IFC). The main direction of economic activity is cotton growing, viticulture, horticulture and grain growing. PS is equipped with 4 pumps 300D90 with AL102-6 engines with power N=125 kW, U=380 V, n=1000 rpm. The pumps supply water to the pressure pipeline Du=400 mm (4 threads). The actual maximum flow rate of PC is 0.63 m^3/s instead of 0.9 m^3/s according to the project. There are cases of breakdown of the insulation of the stator windings of motors. Reduced cable insulation resistance.

6. PS "Maibulak" is located on the territory of the "Nazarov" farm. Feed - 1.6 m^3/s. PS “Yangi-Kent” has been in operation since 1991. The station irrigates 1086 hectares of land from the “Akdarya” River. The main direction of economic activity is cotton growing, viticulture and grain growing. PS is equipped with 3 pumps 20D6 with motors SD 13-52-8 with power N=8000 kW, U=6000 V, n=1000 rpm. Pumps supply water to pressure pipelines Du=730 mm (1 thread). The actual maximum flow rate of PS is 1.12 m^3/s instead of 1.6 m^3/s according to the project.

7. PS "Yangi-Khayot" is located on the territory of the farm "Yangi-Khayot". Supply - 1.5 m^3/s. PS “Kurgoncha” has been in operation since 1980. The station irrigates 460 hectares of land from the “Chiganok” canal. The main direction of economic activity is cotton growing, viticulture, horticulture and grain growing. PS is equipped with 5 pumps 300D90 with M315 MK-4 engines with power N=250 kW, U=380 V, n=1500 rpm. Pumps supply water to the pressure pipeline Du=800 mm (2 threads). The actual maximum flow rate of PS is 0.9m^3/s instead of 1.5m^3/s according to the project.

The projects for the reconstruction of the PS should include the following measures: to replace the main pumping and power and auxiliary equipment; to replace pipeline fittings; carry out a partial replacement of the pressure pipeline; replace control cabinets. Water-energy calculations are also performed in tabular form. For each period of the water supply schedule, the operating point (points) is determined from the curve of dependence of H_g on Q (at different water flow rates along several curves), that is, the actual supply values are found, pump head, find the actual flow through each pipeline and the entire station, as well as the actual pump efficiency (efficiency, taking into account energy losses in power lines, is usually taken as 0.98 ... 0.99). Next by value Q_f, H_f, η_n calculate the actual power consumption of each pump, $N_f = 9{,}81 H_f Q_f\, \eta_n$, expended energy $E = N_f T_f$, volume of water supplied per year $W = Q_f T_f 3600 m^3$.

Calculation of the weighted average geodetic elevation Hg are kept in tabular form (Table 4).

Table 4. Calculation of the weighted average geodesic elevation

PS work period, i	The number of days in the period t_i	P.S. supply Q_i, m^3/c	Average marks of water levels, m		Geodetic lift height Hg, m	$Q_i H_{г.} t_i$	$Q_i t_i$
			upstream	downstream			
11.04…20.05	40	2,1	51,5	28,5	23	1932	84
21.05…20.06	31	4,2	51,8	29	22,8	2969	130,2
21.06…20.08	61	6,3	52	27,75	24,25	9319	384,3
21.08…10.09	21	4,2	51,5	27,25	24,25	2139	88,2
	$\sum$=153	-	-	-	-	$\sum$=16359	$\sum$= 686,7

An important consequence of the reconstruction of large PSs is an increase in the unit capacity of adjustable pumping units and a decrease in their number, which provides additional energy savings and reduces the technological volumes of PS buildings by 15-20%.

The main role in the development of new technologies for the operation of the PS is played by the energy component. The energy assessment is carried out simultaneously with the hydro technical assessment in all PS modes and determines:

N - power on the pump shaft (power consumption),

n_n - pump shaft speed, min-1,

N_e - effective engine power,

K_z - engine load factor, %,

g - specific energy intensity (in the optimal mode),

η - PS efficiency.

The load factor of the electric motor is determined by the formula (1):

$$K_z = \frac{P \cdot \eta_e}{P_n} \cdot 100\% \tag{1}$$

where: P – power consumed from the network, kW,

P_n – nominal (passport) power of the electric motor, kW,

η_e - nominal (passport) efficiency.

efficiency pump (the ratio of useful power to consumed) is determined by calculation according to the formula: $\eta_n \frac{N_n}{N} \cdot 100\%$

The useful power of the pump N_n is determined by calculation according to the formula (2):

$$N_n = \frac{\gamma \cdot Q \cdot H}{102}, kW \tag{2}$$

PS operation in steady state (H_g, Q_{PS}, η_{NS} -const) requires for every 1000 m^3 of water supplied energy costs in the amount shown in the formula (3),

$$e = \frac{2.72 \cdot H_g}{\eta_{NS}}, \text{ kW*h/thousand*m}^3 \quad (3)$$

where e is the specific cost of electricity per PS for every 1000 m^3 of water supplied at the geometric height H_g of the lift.

For a period of time t, the PS supplies W (thousand m^3) of water and consumes the amount of electricity directly for water uplifting is shown in the formula (4).

$$E_v = e * W, \text{ kW/h}, \quad (4)$$

where E_v is the consumption of electricity PS for the period t. The existing methods for determining the optimal option for the development of energy systems recommend conducting comparative calculations by comparing the reduced costs for the modernization and operation of energy facilities [11,12].
Reduced costs (Z_{pr}) are calculated by the expression (5):

$$Z_{pr} = E_n K + I, \quad (5)$$

where K is the capital investment in the considered option for the development and modernization of the system; I-annual production costs for this option; E_n is the normative coefficient of efficiency of capital investments, for the power industry, taken equal to 0.12 [13].
The option with the lowest reduced costs is taken as the optimality criterion (Eq. 6):

$$Z_{pr} = \min. \quad (6)$$

If the compared options differ in terms of reconstruction and the duration of development of the capacity of electrical networks, interface structures of the PS, then when making calculations, it is necessary to take into account the time factor [14, 15]. To do this, in the methodological literature, it is recommended to bring Z_{pr} to the first year of the billing period according to the expression (Eq. 7):

$$Z_{pr}(T_{count}) = \sum_{t=1}^{T_{count}} \frac{E_n K_t + \Delta I_t}{(1+E_{n.p})^{t-1}}, \quad (7)$$

where T_{count}— duration of the billing period;
K_t — investments in the t-the year of the calculation period;
$\Delta I_t = I_t - I_{t-1}$— change in annual operating costs in the t-the year in relation to the previous t-1st year; $E_{n.p}$ is the normative reduction factor for multi-time costs, in the energy sector taken equal to 0.08. When reducing costs to the final year of the billing period, we should use the following dependence (Eq. 8):

$$Z_{pr}(T_{count}) = \sum_{t-1}^{T_{count}} E_n(K_t + I_t)\,(1 + E_{n.p})^{T_{count}} + I_{n.e}, \quad (8)$$

where $I_{n.e}$ - annual operating costs outside the estimated period of normal operation with design indicators [16, 17]. One of the necessary requirements for the compared options is their equivalence in terms of energy effect, that is, all compared options must provide the same volume and mode of electricity consumption in the area under consideration. And this can be achieved by the appropriate development and placement of generating capacities of power plants, providing the necessary throughput of the electrical network and the same level of reliability of the MWUS. If the first two conditions can be realized, then bringing the variants to the same level of reliability is a rather difficult task.

Table 5. Energy efficiency of reconstruction of PS ABMK

PS	2015 year			2021 year		
	N kWxh	Q mln.m^3	N/Q	N kWxh	Q mln.m^3	N/Q
Kiziltepa	471,334	2006,47	0,2349	342,479	1657,57	0,2066
Kuyumazor	116,579	1344,79	0,0866	98,59	1492,73	0,0660
Kiziltepa-1	41,552	149,4	0,2781	28,255	94,27	0,2997

During the reconstruction of the PS Amu-Bukhara machine channel (ABMK) with the participation of the authors, projects were carried out to modernize the layout of the water supply facilities of the largest PSs: Kiziltepa, Kuyumazor, Kiziltepa-1. The main data on the effectiveness of the reconstruction of structures with Chinese equipment are given in Table 5.

The energy efficiency of the reconstruction has been achieved for the main PS, and the reconstruction of the auxiliary PS "Kiziltepa-1" is in progress (Figures 1 and 2).

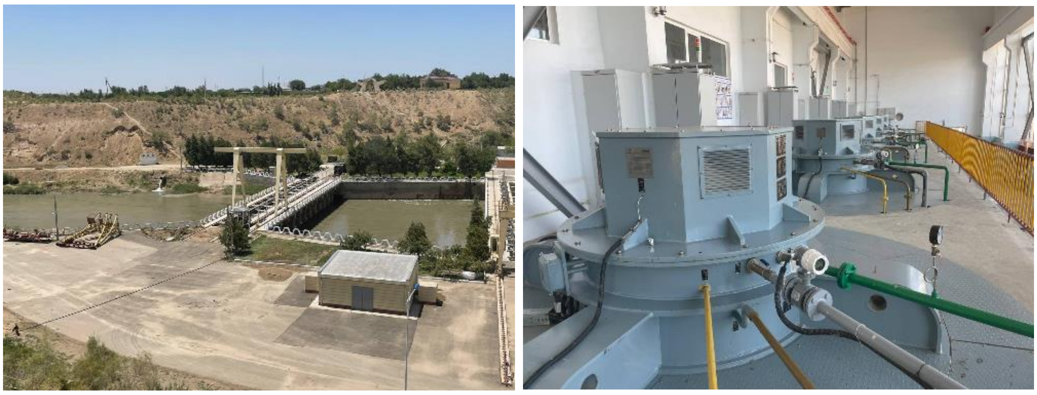

Figure 1. Reconstruction of the fore chamber of the hydroelectric complex of the PS "Kiziltepa" and the engine room of the PS "Kuyumazor" with new Chinese equipment

Figure 2. Reconstruction of suction pipelines (2022 compared to 2020) and cleaning of the water intake of the PS "Kiziltepa-1"

Reserves of production capacities of power facilities, created to improve the reliability of PS power supply, actively participate in the production process only in case of power system equipment failures, that is, no more than 0.1-1.0% of the time of the year, while these reserves are not used during the normal operation of the power supply system .

Numerically, these economic costs of losses (Z) in each t-the year of the development period can be determined as the difference between the actual costs for the modernization of MWUS facilities in the t-the year Z_t and the conditional minimum necessary costs Z_t^{min}corresponding to the optimal operation mode of the object in the normal operation mode (Eq. 9 and 10):

$$З = З_t - З_t^{мин} = V_t(з_t - з_t^{мин}), \quad (9)$$

$$Z = Z_t - Z_t^{min} = V_t(Z_t - Z_t^{min}), \quad (10)$$

where V_t is the volume of water supply of the MWUS in the t-the year;

$з_t$ - actual reduced unit costs for modernization in the t-the year; Z_t^{min}- minimum specific reduced costs corresponding to the optimal mode of operation of the facility during normal operation.

4. Conclusions

a) This article discusses the development of a strategy for modernizing and stimulating the efficiency of operation of irrigation PSs based on new resource-saving technologies that save electricity and water consumption. The results of field surveys of the introduction of new layouts of the main structures and pumping and power equipment in the Zarafshan basin of the Bukhara, Navoi and Samarkand regions of the Republic of Uzbekistan were used.

b) Based on the results of experiments on changing the parameters of operation of the main structures and pumping and power equipment of the PS, the characteristics of water sources with elevated temperatures and contaminated with sediment, fin, and mineral products, the monitoring of the operation mode on two pilot channels was carried out according to special tables.

c) The main role in the development of new technologies for the operation of the PS is played by the energy component. The energy assessment was carried out simultaneously with the hydro technical assessment in all PS modes. By carrying out these activities, the water supply of the irrigation array will increase and crop yields will increase. At the same time, the conditions for energy efficiency and reliability of operation of the PS will improve [18, 19].

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