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Methods of regulating the work of units at irrigation pumping stations

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Abstract. Irrigation pumping stations are one of the main elements of irrigation systems and the main consumer of electricity in the agricultural sector of the Republic of Uzbekistan. Therefore, the question of choosing a method for regulating the operation of pumping units is very important. Most irrigation pumping stations in the Republic of Uzbekistan are equipped with centrifugal pumps of type "D". The main types of regulation for such pumps are: impeller trimming, changing the frequency of rotation of the impeller, the pumping unit switching on and off control method. The specific features of the operating modes of irrigation pumping stations revealed are. The analysis of various methods for regulating pumping units during the operation of irrigation pumping stations showed that, according to the degree of coverage of the water consumption schedule, the most optimal methods are valve control and a change in the rotational speed of the impeller shaft. Regulation by changing the speed of rotation and the pumping unit switching on and off control method more suitable according to the economy criterion. Calculations for the pumping stations "Ulugbek II", "Kizil-Bayrak", "Ittifok", "Navoi" and "Turkiston" showed that with a change in the diameter of the impeller, the energy savings can reach 21.1-63.5%. When using a frequency converter at the same pumping stations, energy savings can reach 16.5-35.4 5%. It must be taken into account that, when turning, regulation is possible only in the direction of decreasing parameters.

1. Introduction
The pumping station is the most complex, responsible and energy-consuming facility in the irrigation system. Effective and reliable operation of pumping stations directly affects the operation of the entire irrigation system, the cost of water supplied and the yield of cultivated crops. Irrigation pumping stations of the Republic of Uzbekistan annually consume up to 7.0-8.0 billion kW * h of electricity for water lifting. Therefore, issues of energy conservation, the energy efficiency of pumping unit operation are important and priority [1,2,3,4,5].

More than 1600 reclamation pumping stations work in the system of the Ministry of Water Resources. The largest share (up to 55%) among the installed pumps belongs to horizontal double-entry centrifugal pumps (type "D") with a water supply of 320 to 2000 m^3 / h and a lifting height of 21 to 125 meters. In practice, many pumping stations have problems of inefficient operation of equipment [2,3,4]. Many pumping stations have equipment that does not answerable to the technical

requirements. The stations have pump's technical characteristics increased in comparison with the necessary operational performance.

The operation of the power equipment of such pumping stations significantly affects the cost of electricity for water lifting. There is an over-expenditure of electricity for water lift and pumping of excess water. This is especially important in conditions of acute water shortage and energy resources of the Republic [2,3,4,5].

The operational efficiency of the pumping station depends primarily on the selected operating mode of the pumping units. Pump regulation is often used during the operation of pumping stations [7,8,9]. Pump regulation is the process of artificially changing its parameters (supply and pressure) to ensure the required values [10,11,12]. The operation of pumps outside the working area of the Q-H field leads to reduced energy efficiency, increased energy consumption. According to some data [1,2], as a result of the operation of pumping stations in uneconomical modes and the absence of effective methods for regulating the operating modes of pumping units, up to 5-25% of the consumed electricity is lost. In view of the above, it is extremely important for each pumping station to identify the optimal operating modes of the pumping units, i.e. to choose the most effective method of regulation.

The control methods currently used at pumping stations can be divided into two groups: quantitative and qualitative [8,9,10,11]. The method of controlling a valve on a pressure pipe (throttling) is the most common among quantitative methods. The regulation by changing the frequency of rotation of the impeller shaft and the cutting (or turning) of the impeller is the most used methods among the qualitative methods. Also, the method of controlling the operating time of the pumps (i.e., turning on / off the units) is widely used.

Irrigation pumping stations differ from water supply pumping stations both in terms of the requirements and operational conditions. Therefore, when choosing a regulatory method, these features must be taken into account.

2. Methods

The research methodology is based on a review of existing and applied control methods at irrigation pumping stations, comparative analysis, and comparison of these methods, taking into account the operating conditions of irrigation pumping stations.

When comparing control methods, the operational data of the Kizil-Bayrak, Ulugbek II, Ittifok, Navoi, Turkiston and Teshiktash-1 pumping stations were taken. Kizil-Bayrak, Ulugbek II, Ittifok, Navoi and Turkiston pumping stations have overestimated technical performance compared to the actual required. Teshiktash-1 pumping station has very different water consumption and water supply schedules. When processing data, standard statistical techniques and programs were used.

When comparing and economic evaluation of the chosen method of regulation, we used the results of studies conducted at the Department of "Use of water energy and pumping stations" of the Tashkent Institute of Irrigation and Agricultural Mechanization Engineers on the issues of reliable, safe and energy-efficient operation of hydropower objects [14,15,16].

Research was also carried out to study the operational modes of irrigation pumping stations, which included experiments of pumps with frequency converters on the stand, field inspections of pumping stations, field testing of pumping equipment and calculations on economic efficiency evaluation. [5,17].

For calculation of energy saving at impeller turning were used widely known methods and recommendations [8,9,10,11,24] at change of speed were used empirical dependences of change of efficiency of pump unit at change of speed received by experimental researches on special stands equipped with centrifugal pumps and frequency converters and recalculated for nature [5,17].

3. Results

3.1. Operating modes of irrigation pumping stations
There are three characteristic modes of pumping equipment at pumping stations: uniform, repetitive and non-uniform [8,9,10,18].

Uniform operation of the pumping equipment is characterized by relatively constant flow and pressure over a certain period of time. At the same time, the pump must operate under optimal conditions with the highest efficiency.

Repeated short-term operation of the equipment is used for step-by-step control of the supply by switch in on and off the pump electric motors. Non-uniform pump operation is characterized by the condition that the pump supply is equal to the corresponding water consumption at any time.

At irrigation pumping stations (as opposed to water supply pumping stations), the pumping equipment mode is usually uniform over a certain period of time (decade, month) and less frequently repeated and short-term. In water supply systems, the water consumption schedule varies greatly depending on the time of day, day of week and season. Irrigation pumping stations, unlike water supply pumping stations, do not have exacting requirements to maintain any technological parameters (flow or head). These features should be taken into account when comparing control methods.

3.2. Selection of criteria and comparison of different regulatory methods

The criterion of efficiency of the pumping station is the degree of completeness of the water consumption schedule coverage by the water supply schedule, provided that minimum operating costs, health and safety requirements are met. It is in accordance with such requirements that different methods of pumping equipment operation control should be compared: by the degree of completeness of water consumption schedule coverage and energy efficiency of the units.

Each of the ways of regulation has its disadvantages and advantages. The following types of regulation have the greatest prospects for application at irrigation pumping stations: impeller trimming (turning), change of impeller speed, regulation by a gate valve (throttling), by-passing of liquid part from the pressure pipeline and regulation by operating time.

Comparison of different regulation methods.

1) Comparison of water consumption schedule by a degree of coverage.

The throttling method can achieve full coverage of the water consumption schedule.   When using this method, the flow is regulated by opening-closing the gate valve. When closing the gate valve in the pressure pipeline, additional losses are created in the system, the curvature of the system's characteristics changes and it is possible to achieve such a curvature that the operating point will be at the point with the necessary feed coordinates. In other words, by changing the degree of opening the gate valve can achieve full coverage of the water consumption schedule.

The motor speed can be controlled by various devices: mechanical variator, hydraulic coupling, and frequency converter. Frequency converters also make it possible to provide more complete coverage of the pumping station water consumption schedule.

When trimming (turning) the impeller, the pump parameters can only be reduced.

The main method currently used at irrigation pumping stations of the RUz is regulation of switching on and off of the units in accordance with the water consumption schedule. This method is simple enough and does not require any additional devices. The disadvantage is that the pumping equipment wears out quickly at frequent shutdowns and cannot be regulated at head level (only the flow rate of the pumped water can be adjusted). The method of regulating the operating time of the pumps can ensure that the volume of water pumped corresponds to the volume of water in the water consumption schedule for a certain period of time. The more switching on and off, the more complete the coverage will be, but full coverage cannot be achieved in this way. This method noticeably loses out to the previous two by the criterion of completeness of coverage of the water consumption schedule.

2) Comparison by economic criterion.

This criterion plays an important role since energy efficiency is one of the most pressing and challenging tasks of today's machine water-lifting [19,20,21,22,23].

Taking into account the peculiarities of the requirements and operating modes of irrigation pumping stations (discussed above), this criterion becomes the main one when choosing the regulation

method. Qualitative methods of regulation are more suitable by the criterion of "economy": regulation by changing the speed and regulation by changing the diameter of the impeller (turning).

3.3. Methodology for evaluating the effectiveness of the selected regulatory method
The recommended method to evaluate the effectiveness of the selected method (using the frequency regulator as an example) is given below. The procedure on an estimation of efficiency of a method of the regulation (Fig.1):
   1. Collection of source data.
   The technical characteristics of the pump and drive motor, the scheme of connection of pump units and pipelines, the schedule of water consumption and water supply of the pump station, technical data on the frequency converter are required.
   2. Conducting tests on site.
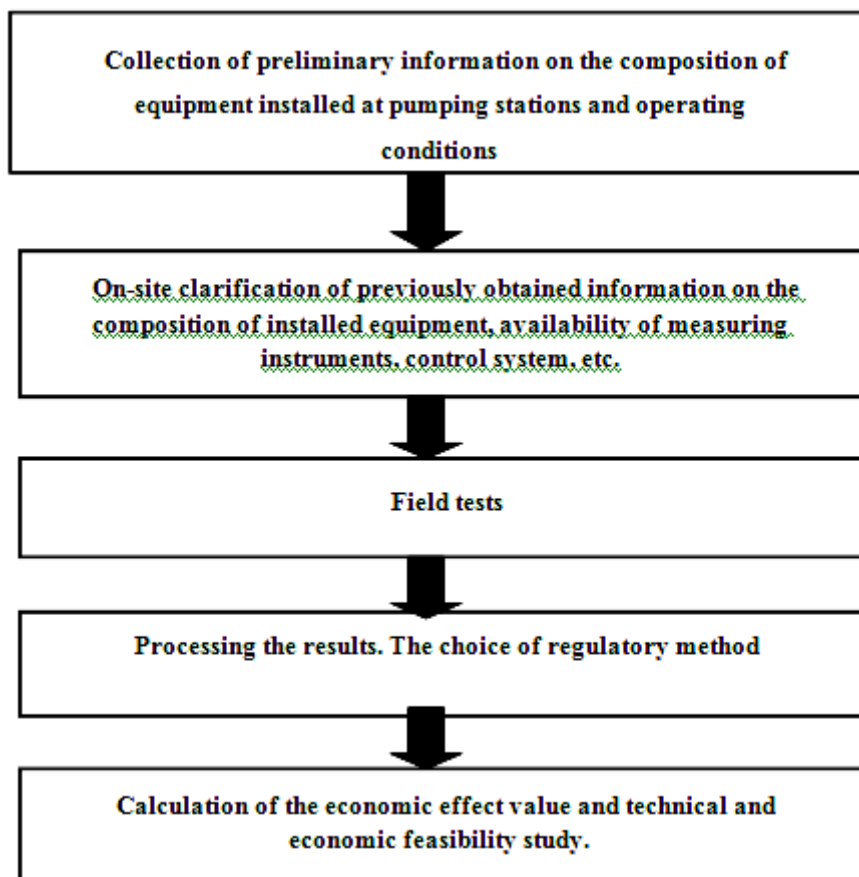   3. Calculation of the economic effect value.

Figure 1. Algorithm for selecting the method of control of the irrigation pump station units.

The calculation of economic efficiency is based on determining the difference between the values of electricity consumption when the pump station is operated without regulation and when it is controlled by a frequency converter. Knowing the cost of saved electricity and resources for one year and the cost of a frequency converter, you can determine the term of occupation and, accordingly, the economic efficiency of using a frequency converter.
   The results of economic efficiency calculation are presented in Table 1. As an example, we took pumping stations: Kizil-Bayrak, Ulugbek II, Ittifok, Navoi and Turkiston with similar characteristics

and with "excessive" pressure. Table 1 shows the recommended trim values, speed changes, and the resulting energy savings.

Table 1. Results of the calculation of energy savings when turning and changing speeds.

Pumping Station	Pump Type	When changing the diameter of the impeller				When changing speed			
		D, mm	D_{trim}, mm	Trimming %	Savings, %	n rpm	n_1 rpm	Changes, %	Savings, %
Kizil Bayrak	300D90	460	420	8.7	33.4	1450	1114	23	19.3
Ulugbek II	20NDS	765	665	13	63.5	980	694	29	35.4
Ittifok	300D90	460	430	6.5	31.0	1450	1208	17	21.1
Navoi	300D90	460	418	9.1	40.7	1450	1149	21	26.0
Turkiston	300D90	460	442	3.9	21.1	1450	1291	11	16.5
Kizil Bayrak	300D90	460	420	8.7	33.4	1450	1114	23	19.3
Ulugbek II	20NDS	765	665	13	63.5	980	694	29	35.4

If the "excessive" parameters are only characteristic for certain periods, it is not possible to adjust the "trim" of the impeller.

The comparison of control methods carried out on the example of the Teshiktash-1 pumping station in Andijan region is given below. Members of the department "Use of water energy and pumping stations" of TIIAME at this station in 2017 conducted field tests of the pump unit equipped with a frequency converter.

Table 2. Comparison of different control methods on the example of Teshikosh-1 pump station.

Periods	the actual flow, m^3/sec	the required flow, m^3/sec	the excessive flow, m^3/sec	throttle control		frequency converter		
				$h_ç$	N_{lost}	n_P/n	η_p / η	N_{lost}
III	0.077	0.047	0.03	0.000069	40.57	0.61039	0.6	8.11
VI	0.136	0.118	0.018	0.000879	101.87	0.86764	0.8	20.37
VII	0.111	0.103	0.008	0.000766	88.92	0.92792	0.94	17.78
VIII	0.097	0.034	0.063	0.000012	29.35	0.35051	0.3	5.87

Graphical dependencies of change of energy parameters of the pump unit at a change of speed of a shaft of the impeller were received as a result of field tests of the pump unit with the frequency converter. These dependencies were used when comparing the methods [5,17].

Teshiktash-1 pumping station is open all year round. Months with excess water supply were taken for comparison when it is possible to regulate the gate valve - March, June, July and August. The "lost energy" at regulation N_{lost} is accepted as a quantitative parameter of estimation of the economic efficiency of applied methods. Naturally, the minimum of this parameter will be the criterion of effectiveness. The results of the comparison are presented in Table 2.

4. Discussions
The calculations showed that at the pumping stations Ulugbek II, Kizil-Bayrak, Ittifok, Navoi and Turkiston, the energy consumption will decrease when the impeller diameter changes. Energy savings can reach 21.1-63.5%. When using the frequency converter at the same pumping stations, energy savings can reach 16.5-35.4 %.

Analysis of results of calculation of electric energy saving presented in Table 1 shows that at the change of impeller diameter (turning) the effect is more essential. However, during turning, regulation is only possible in the direction of parameter reduction. If it is necessary to increase the parameters (change of pump parameters due to wear, wear of pipelines, change of water levels in the water source and in the machine channel, etc.) it is necessary to change the impeller.

Table 2 shows the results of the comparison of different control methods by the example of the Teshikosh-1 pump station. The results of the comparison show that the "lost energy" when using the method with the shaft speed change is 4-5 times less than when throttling. Energy losses when the impeller shaft speed changes reach 10-20% of the power consumption of the pump.

 When using the control method by changing the operating time of the pump, the pump operates in the working (design) ranges and there is no additional energy loss.

But it is necessary to take into account that at frequent switching on and off of the pump unit there is a fast deterioration of the equipment (as a practice has shown, first of all, half couplings of connection of a shaft of the pump and a shaft of the electric motor fail). It is also necessary to take into account the indirect effect of using a frequency converter at the pumping station (which is difficult to quantify in advance):

- reduced wear in the clutches, engine and pump bearings as well as the impeller by smoothly changing the speed;
- no high inrush currents (with asynchronous motors);
- simultaneous protection of the motor against short-circuit currents, earth faults, overload currents, single-phase operation, inadmissible over voltages, etc.;

Due to the peculiarities of operating modes of irrigation pumping stations, the economic effect due to the use of a frequency converter at irrigation pumping stations at regulation is not as significant as at water pumping stations. The effect is water conservation and the indirect effects outlined above. Energy-saving due to the use of a frequency converter at irrigation pumping stations is possible only if during operation there is a need for precise regulation or maintenance of any technological parameter (flow or pressure). Based on a comparison of the savings of different control methods in pumping stations with "excess" heads, a change in diameter can be recommended. In each case, a decision must be made according to the specific conditions of use.

5. Conclusions

1. At irrigation pumping stations, the pump equipment mode is usually uniform. Irrigation pumping stations, unlike water supply pumping stations, do not have strict requirements to support any technological parameters (flow or head).

2. The analysis of various methods of regulation of pump units at the operation of irrigation pumping stations has shown that according to the degree of coverage of water consumption schedule the most optimal methods are regulation of gate valve and change of impeller shaft speed. According to the criterion of "economy", speed change control and time control of the pump unit are more suitable. At pumping stations equipped with units with "excess" head, the greatest effect is given by the method of diameter change.

3. Taking into account the peculiarities of operational modes of irrigation pumping stations, the economic effect due to the use of frequency converters at irrigation pumping stations (in contrast to water supply pumping stations) at regulation is not so significant and consists mainly of water-saving and indirect effects of the above.

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