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ENVIRONMENTAL ASPECTS OF ENERGY SAVING MODES OF HYDROPOWER FACILITIES

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Abstract

The article substantiates the need to develop energy-saving regimes for hydropower facilities, including the construction of large hydroelectric power plants and irrigation pumping stations. The aim of the research is to improve the operational characteristics of hydropower installations of large hydroelectric power plants and pumping stations. The substantiation of technological, ecological factors is given. Given that large pumping stations are very energy-intensive facilities, recommendations are given for the modernization of water supply facilities, in particular, suction pipes and the flow part of pumps. Energy-saving modes are based on reducing hydraulic losses in the hydraulic unit and increasing the efficiency of the units. In order to increase the efficiency of pumps and reduce operating costs, it is necessary to ensure the introduction of hydraulic process control methods at pumping stations, primarily large ones, to establish reasonable volumes of water supply, provided by the technical condition of the equipment, taking into account the optimal level of its efficiency, and to carry out controlled operation.

The article presents the results of a study of renewable energy installations and the determination of combination conditions and the choice of power for each type of power plant.

Keywords: combined installations of renewable energy sources, operation, pumping units, hydro turbines, wind turbines, reliability, energy saving.

Introduction

Hydroelectric power engineering is a branch of technology and an applied science that combines elements of hydraulic engineering and energy. It studies both methods for generating electrical energy and hydraulic structures necessary for generating electrical energy based on the use of water energy. Improving the performance of hydropower plants is especially effective for large hydropower plants. Central Asia is characterized by a large use of hydropower resources for mechanical irrigation based on pumping stations (PS). The development of energy-saving modes of large irrigation pumping stations and installations is one of the most urgent tasks.

A feature of agriculture in Uzbekistan and other Republics of Central Asia is the widespread development of pumped irrigation. By 2022, the capacity of the main pumping and power equipment that has worked out its park (factory) resource amounted to more than 50% of the installed capacity for large pump stations in the Republics of Central Asia.

Under the conditions of urgent renovation, an operation strategy is determined, aimed at maintaining the necessary environmental, reliability and economic parameters of the main elements of the hydraulic unit of the PS. The definition of "limiting" elements in the changed operating conditions is an extremely urgent task at the beginning of the 21st century.

The scale of investment policy renewal requires both new environmental thinking and tougher requirements for resource-intensive projects. Reconstruction of machine water lifting systems (MSW) can give the greatest economic and environmental benefits.

Annually, up to 7-8 billion kWh is spent on the PS of the irrigation systems of the Republics of Central Asia, not counting diesel fuel. Reducing the power consumption at the PS up to approximately 10-15% is possible, mainly due to energy-saving modes and optimization of the MSW control. In connection with the sharp rise in prices and the growing shortage of energy resources, the problem of reducing their consumption by large PS comes to the fore (Fig. 1).

Fig.1 - Unique PS of the Amubukhara and Karshi cascades

The lack of priority work on this problem makes it impossible to optimize the PS modes at the current level of operation. According to Research Institute of Irrigation and Water Problems, the operational efficiency is lower than the calculated values by 5-7%, environmental requirements are met by 25-30% [1,2].

Materials and Methods

In the process of research, the collection of existing information, generally accepted standard methods of mathematical and hydraulic modeling and their numerical solution were used. Cases of failure of the working parts of hydropower plants, uniform flow in the flow part of the pump, anti-cavitation reliability of the pump, and an increase in the service life are analyzed. In the process of performing research, the main provisions of theoretical mechanics, hydraulics, the theory of vane pumps, processing the results of field and laboratory experiments, graphical and analytical methods were used.

Results and Discussions

The safety of PS operation can be achieved by fulfilling a set of conditions that ensure minimal external impacts on the PS associated with the state of water resources, as well as the impact of the PS itself on environmental objects.

During the operation of the PS, water sources are supplied, as is commonly believed, with normatively clean water, with an increased temperature regime. However, water can be contaminated with oils, fin, dust, mineral products. Even if their content in the water does not exceed the normative indicators, the environmental conditions of the operation of the main structures and equipment may be damaged. Elevated temperature causes direct damage to the state of the hydraulic unit and equipment.

Minimization of the risk of PS impact during operation on environmental objects. Among the risks that impact on the natural environment and entail negative social and environmental consequences are: the failure of lands suitable for various types of activities, depending on the priorities in the area (growing agricultural products, various types of crafts), the impact on the traditional way of life life, the emergence of conflict situations related to the use of water and energy resources.

Modern irrigation PS work with electricity consumption. Electricity generation has a harmful effect on the environment.

With an annual increase in electricity generation of 3-4%, the commissioning of new energy capacities as a result of energy-saving regimes at the PS 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 [3,4]. Thus, a significant environmental effect will be obtained by reducing harmful emissions into air and water. In addition, these systems reduce the likelihood of water hammer, prevent the destruction of pipelines and, as a result, the outflow of water onto the surface of the earth and into water bodies.

It is necessary to create conditions for the constant determination of the actual characteristics of the operation of the PS, including during transients in the operating conditions, to eliminate the identified causes of energy losses due to the deviation of the actual regimes from the design ones.

First of all, it is necessary to solve the problems of proper operation in operating modes that ensure the uninterrupted operation of the PS, reliable operation of equipment, the supply or pumping of water in accordance with the planned schedule, the prevention and immediate elimination of accidents, measures to eliminate accidents or their threat and restore the normal operation of the facility PS.

In the reconstruction of highly economical pumps, hydraulic turbines PS and hydroelectric power plants, the correct choice of the size and shape of the suction and exhaust pipes is of great importance [5,6]. This is especially important when mastering medium and low pressures, at which the energy characteristics of the pump and turbine are largely determined by the properties of the suction and suction pipes. The average kinetic energy of the flow behind the impeller at high flow rates is about 30-60% of the total available energy. The useful use of this energy depends on the quality of the suction and suction pipe. The most perfect from the point of view of converting the kinetic energy of axial and slightly swirling flows into potential energy are straight-axial diffusers with a small taper angle. However, the use of a pipe in the form of a straight-axis diffuser requires large depths and investments in the construction of small HPPs and PSs [7,8].

The main difficulty in planning energy-saving modes is to build an adequate mathematical model of the operating system. The identification of the model is carried out by the method of successive approximations using the results of field measurements of resource consumption on the network, and the determination of the installation locations of portable instrumentation is carried out at the stage of preliminary calculations. All control units of the PS according to the project are equipped with stationary flow meters and counters. Ultrasonic flowmeters are currently used for operational measurements of flow rates in pipelines of pumping stations.

In the practice of PS operation, 30-40% of the total number of parameters to be controlled is controlled, which certainly worsens the reliability of the units, since the PS operation mode changes in accordance with the water consumption schedule and due to other factors. Using on-site instruments, operating personnel need to quickly determine the optimal hydraulic modes and operating points of pumps on their characteristics and compare them with the corresponding recommendations.

The software currently developed with the participation of the authors makes it possible to calculate complex water supply systems in real time using design station instruments on the PS control panels (Fig. 2).

Fig.2 - Measuring systems on the PS

In general, the quality of pumped water is characterized by a set of n - parameters; concentration of suspended particles, floating bodies, chemical properties, density, temperature, etc.

Recently, there has been a growing interest in the world in the use of small hydropower plants, the so-called micro HPPs, used to supply power to the PS. This is due to the fact that they are characterized by such significant factors as the possibility of unification and full automation of equipment, ease of installation, mobility and maintainability of the installation.

A large number of designs of micro HPPs are diversion and dam pressure plants, for which the dominant factor in generating power is potential energy. For the operation of these micro HPPs, it is necessary to create at least 1 meter of head or a slope of the watercourse channel of at least 4°. This condition makes it rather difficult to use such micro HPPs on flat rivers and canals due to a significant increase in capital costs for the construction of a dam or a diversion pipeline. In this regard, the so-called free-flow micro hydroelectric power plants, which operate exclusively on the use of the kinetic energy of a free flow, are of great interest. Usually these micro HPPs are located on pontoons or rafts with impellers lowered into the water [9,10].

For example, the Brazilian micro HPP "Fortune", mounted on a pontoon together with a four-pole generator, developed a power of 1 kW at a flow velocity of 1.1 m/s and had an efficiency of 12% [11,12]. However, due to low technical and economic indicators and the high cost of equipment, work on the design was stopped.

The free-flow microhydroelectric power station of British specialists had an efficiency of 30% with a power of about 2 kW and a flow velocity of 1-2 m. The installation is equipped with a carousel-type turbine with four blades. The turbine diameter is 2 meters [13,14].

The increase in the cost of equipment with increasing power was mainly caused by an excessive increase in the diameter of the turbine wheel. This is due to the fact that in order to increase the power of a micro hydroelectric power station, it is necessary to increase either the speed of the water flow or the diameter of the impeller. The speed of water flow in lowland rivers and canals averages 1-1.5 m/s. Calculations show that at a speed of 1 m/s, to obtain a power of 10 kW, the diameter of the impeller must be 10 meters, or 10 turbines with impeller diameters of 0.1 m each must be installed at a microhydroelectric power station [5]. Thus, to obtain a power of 5–10 kW, which is considered more in demand for an isolated consumer (entrepreneur, farmer, and others), it is necessary to have large sizes or a number of hydraulic machines, which is practically and economically difficult to implement. However, even a small increase in pressure, i.e. the organization of water supply to turbines with a slight pressure can lead to a significant reduction in the diameter of the impeller.

In the practice of building PS and HPP with a vertical shaft arrangement, curved suction pipes are used. This type of pipes is characterized by lower hydraulic qualities compared to straight pipes. Studies show that turning the flow from a vertical to a horizontal direction is accompanied by significant energy losses, especially at high flow velocities in the elbow. Moreover, the dimensions of the pipe and the nature of the change in the equivalent expansion angle of the pipe along its length have a decisive influence on the magnitude of these losses.

Hydraulic calculations and studies of hydraulic phenomena in the path leading to the pump were carried out, which made it possible to obtain velocity fields in sections before the flow enters the pump impeller. On the experimental setup, the methodology for conducting research, measurements and processing of experimental data using a computer has been debugged. Experimental studies carried out on this issue made it possible to substantiate several new technical solutions [11,15].

For a hydraulically favorable mode of pumps, the authors proposed new designs of pumps and motors that improve the operating conditions of the main hydraulic elements and equipment wear [15,16]. The PS operating modes are determined by the authors algorithmically using a mathematical model [17,18]. The characteristics of the pumps are presented in the form of functional curves depending on the flow and lift height:

$$\Omega_T^i = \begin{Bmatrix} Q_j^i & j=\overline{1,\ K};\quad \left(i=\overline{1,N}\right), \\ H_T^j & j=\overline{1,K} \end{Bmatrix} \qquad (1)$$

where Q_j^i - pressure characteristic argument, flow rate of the i-th pump, m³/s;
K- is the number of points in the pressure characteristic;
j- numbering of curves in the pressure characteristic;
i- numbering of installed pumps;
N- is the power of operating pumps, kW;
$H_T^j = H + \nabla H_j$ -head characteristic function at geometric head H, m;
∇H_j - head loss, m.

The suction pipes of the water intakes of high-capacity pumping units were considered as an integral part of the pump and hydraulic losses were taken into account through η_p, the efficiency of the supply - η_s.

$$\eta_p^{'} = \eta_p \cdot \eta_s \tag{2}$$

where: $\eta_p^{'}$ - Pump efficiency taking into account losses in the suction pipe;
η_p - Pump efficiency without taking into account losses in the suction pipe;

From a comparison of the specific energies before entering the pipe and in the suction and pressure pipes, it follows that

$$\eta_s = \frac{H_p - h_h}{H_p} = \frac{H_p}{H_p} \tag{3}$$

where: h_h - hydraulic losses in the suction pipe;
H_p - pump head determined from the indication of one pressure gauge on the discharge pipe.

Let us introduce the efficiency of the pipe - $\eta_p^{'}$, which we represent as the ratio of the kinetic energy in the suction pipe of the pump with its uniform distribution over the free section to the sum of the kinetic energy with its actual distribution over the section, taken into account by the coefficient, and the hydraulic losses in the pipe - h_p, i.e.

$$\eta_{sp} = \frac{\frac{\vartheta_{suc}^2}{2g}}{\alpha \vartheta_{suc}^2 / 2g + h_p} \tag{4}$$

where the coefficient α - can be taken equal to unity, which closely corresponds to the experimental data.

The environmental conditions of the PS are improved by "green energy" with the combined use of renewable energy sources (RES) installations, taking into account the variability in the supply of RES and the inconsistency of energy generation and consumption schedules. In this regard, the problem arises of determining the conditions for combining and choosing the power of each type of power plant based on solar photovoltaic N_{ph} and wind N_w power plants.

For each recurring period of time or load cycle, the energy balance equation must be satisfied

$$\sum_{i=1}^{i=n}\left(N_{ph}+N_w-N\right)\Delta t_{Ni}=0 \tag{5}$$

where N_{ph}, N_w – load power over time Δt_{Ni},

n -number of time periods with different loads.

The general mathematical model for optimizing parameters includes an optimization criterion, which is taken as a minimum of the reduced costs for the construction and operation of RES [6,19].

In the general case, the technical and economic models of renewable energy are stochastic due to the random nature of the wind and sun. However, from the analysis of general models, the authors conclude that at the first stage of calculation and analysis of RES, it is advisable to consider simplified models.

Currently, there are two principal ways of reliable use of energy in the joint operation of wind pump installations:

1. Wind energy is captured by a wind wheel, which converts the kinetic energy of the wind into mechanical energy. The latter is used directly to drive water-lifting units.
2. Wind energy is converted into mechanical energy, and then into electrical energy, which can be used to drive electrified pumps.

The authors obtained the following results: at the rated power developed by the wind turbine, the mechanical system ensures the transfer of 92% of the energy, and the electrical system - 80%. The main advantages of the units are a simplified design and increased drive efficiency. The use of high-pressure pumps makes it possible to draw water from great depths. The disadvantages include the dependence of the water supply on the parameters of the watercourse and wind (its speed and availability), which leads to uneven operation of the pumps and the need to install the unit near the water source.

The main requirements for installations are formulated as follows: the smallest number of transformations of one type of motion or energy into another; small initial moment of resistance of the water lift; flat external characteristic Q-H of the pump in the specified speed range with a sufficiently high efficiency.

Optimization of parameters is considered as one of the main tasks, the solution of which increases the efficiency of the plant. The general task is divided into private ones with fewer variables. The developed methods made it possible, using the methods of directed multivariate enumeration, in relation to low-power installations, to determine their parameters for different zonal conditions.

The criterion for the ecological optimality of any technological process in accordance with the requirement of a limited impact of production on the environment is the gradual minimization of this impact:

$$O_f - O_e \to \min; \quad \Delta t_e - \Delta t_{Ni} \to \min, \tag{6}$$

where: O_f - actual irrigation rate of agricultural irrigated lands, m3/ha;

O_e - ecological norm of water demand, m3/ha, which is determined on the basis of the principle of energy balance of heat and moisture in the natural system [20,21].

The degree of isolation of technological processes in irrigated fields (K_{ir}) is defined as the ratio of the ecological norm of water demand for agricultural land (O_e) and the water demand of agricultural crops to the actual irrigation norm of agricultural irrigated lands ($K_{ir} = O_e / O_{act}$).

Вводится понятие безопасности технологических процессов на орошаемых полях по отношению к окружающей среде и коэффициент экологичности:

The concept of safety of technological processes in irrigated fields in relation to the environment and the coefficient of environmental friendliness are introduced:

$$K_{cl} = 1 - K_{ir} \tag{7}$$

The coefficient of closure of technological processes at all hierarchical levels of the irrigation system characterizes the efficiency of the irrigation system (η).

Conclusions

1. On machine water lifting systems and other hydropower facilities, in order to assess and improve the quality of pumped water under energy-saving modes, it is recommended to use the developed dependencies that are based on reducing hydraulic losses in the hydraulic unit and increasing the efficiency of the units. In technical terms, it is necessary to develop the scientific foundations of energy-saving regimes, their regional features (especially in the context of reconstruction and renovation of large facilities).

2. Planning of energy-saving modes of hydropower facilities is to build an adequate mathematical model of the operating system. The model is identified by the method of successive approximations using the results of field measurements of resource consumption. Further work continues in the areas of expanding and identifying the design scheme of the water supply structures of the PS and HPP units, developing options for their control with the introduction of new means of regulation and optimization of the elements into the scheme.

3. To improve the safety and sustainable operation of hydropower facilities, it is recommended to develop regulatory documents that define the properties of water that do not lead to equipment wear and material destruction; a methodology for a comprehensive assessment of the degree of risk from the impact of unsuitable quality of operation, to establish reasonable volumes of water supply to the PS, provided by the technical condition of the equipment, taking into account the optimal level of redundancy determined by modern reliability theory, adjusting and merging the observation network as part of the environmental monitoring of irrigation and energy systems, taking into account world experience.

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