Prospects for the Development of the use of Pumped Storage Power Plants in the Energy System of the Republic of Uzbekistan

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Abstract: The article discusses the need to use pumped storage power plants (PSPP) to increase the reliability, stability, maneuverability and energy-economic efficiency of the electric power system (EPS) with power plants based on renewable energy sources (RES), which make it possible to cover the minimum and maximum daily load schedules, and also regulating the capacities of solar-wind power plants, for which the tasks of equalizing power fluctuations and energy storage are especially important. For a technical and economic assessment and determination of the optimal parameters of a PSPP, a mathematical model is proposed under the conditions of its construction with existing structures, taking into account its water-use purpose - low-pressure, daily and seasonal operating modes, with the criterion of minimum investment, payback period, annual costs for PSPP and environmental factors with the maximum generated peak power and fuel savings. On the basis of the proposed mathematical model, a methodology and program have been developed to determine the optimal energy and economic indicators of a PSPP.The schemes of using pumped storage power plants at four energy and water facilities, that is, the Tuyamuyun hydroelectric complex, Arnasai, Talimarjan and Khodjikent reservoirs, were considered, and for these facilities, on the basis of the developed methodology and program, their energy and economic parameters of the PSPP were determined.

1 INTRODUCTION

In the global energy sector, when diversifying the energy balance through the use of traditional power plants and alternative energy sources, including renewable ones, the most important aspects are increasing the reliability, stability, maneuverability and energy-economic efficiency of the electric power system (EPS) and power plants based on renewable energy sources (RES) - solar, wind, hydraulic, etc.

Large-scale work is being carried out in Uzbekistan to develop the energy industry, taking into account the best international experience and current trends in the development of the world electric power industry [1,2]

To date, the total installed capacity of Uzbekistan's power plants is about 14,140.6 MW. About 85.7 % of electricity generation is accounted for by thermal power plants (12,129 MW), mainly powered by natural gas, 13.3 % by HPP (1,878 MW) and 1 % by the station unit (132.9 MW) [1]. The operated power plants of Uzbekistan generate more than 62.9 billion tons per year. kWh of electricity, and the consumption is more than 62.0 billion rubles. kWh [1-4].

At the same time, certain work is being carried out to develop the use of renewable energy, primarily on the use of hydropower potential, solar and wind energy.

The tasks of RES development are specified in Government Resolutions and Decree No. PP-2947 "On the program of measures for the further development of hydropower for 2017-2021" 2.05.2017 [5], No. PP-3012 "On the program of measures for the further development of renewable energy, improving energy efficiency in economic and social sectors for 2017-2021" 26.05.2017 [6] and UP No. 5044 of May 18, 2017 "On the formation of the joint-stock company "Uzbekhydroenergo"" [7].

Thus, the need for a consistent increase in the use of renewable energy sources, the creation of new environmentally friendly generating capacities on their basis, the provision of technical and technological re-equipment of existing hydroelectric power plants based on the use of modern technologies was noted [5-6].

These resolutions are aimed at improving the efficiency of water resources management, taking into account international best practices, improving the balance of energy resources and ensuring, on this basis, the needs of enterprises and the population for electricity [5-7].

Among the priority issues of the development of the electric power industry of Uzbekistan in such areas as thermal power plants (TPP), nuclear power and RES [2, 3, 8]. Major investment projects are being worked out to increase the generating capacity of the energy system in the period up to 2030, including [2, 3, 8]:

1) construction of energy-efficient thermal generating capacities with a total volume of about 15 GW;
2) construction of modern CCGT units of combined cycle of electricity production with a total capacity of about 9.5 GW (at the Syrdarya, Navoi, Talimarjan, Takhiatash, Turakurgan TPP, etc.);
3) construction of regulating capacities on the basis of maneuverable gas-piston installations, aviation GTI, modern energy storage systems with a total capacity of about 3.2 GW (at the Syrdarya, Tashkent TPP, Mubarak TPP, etc.);
4) construction of new objects RES (solar, wind and hydroelectric power plants) with a total capacity of more than 8,400 MW, in order to increase the specific share of RES in the total generation volume to 25%.
5) construction of a NPP with a capacity of 2,400 MW.

However, along with the positive aspects of the development and saturation of the energy system of Uzbekistan with large power plants of huge capacity, the difficulties with covering the minimum and maximum daily loads of the EPS are compounded (Figure 1). In addition, the demand for electric energy was not fully met, the deficit was about 9.4 percent of the demand [9]. The limited range of power control of large-block units and the lack of the possibility of frequent starts and stops without a sharp decrease in the reliability and efficiency of the power equipment of power plants makes it difficult to cover the uneven part of the electrical load schedules and leads to the need to increase maneuverable capacities.

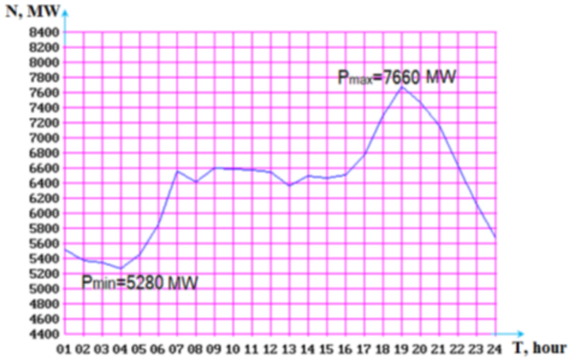

Figure 1: Schedule of daily loads of EPS of the Republic of Uzbekistan (09.10.2019).

The insufficient share of highly maneuverable power plants in the structure of generating capacities of the EPS of the Republic of Uzbekistan forces the regulation of capacities by TPP. This leads to a deterioration in energy supply indicators, in particular, voltage and frequency surges occur in the power system, since thermal power plants cannot quickly change the power. Frequent starts and stops of turbine units lead to fuel overspending, a decrease in the operational resource of heat and power equipment, an increase in repair costs, and a deterioration of the environmental situation in the areas where the TPP is located [9]. In general, according to the Ministry of Energy of the Republic of Uzbekistan, in 2018, the average specific fuel consumption was 354.6 g. t./kWh, and the EPS of countries where proper capacity regulation is carried out using PSPP, this figure does not exceed 330.0...340.0 g.t./kWh [10].

As is known, for the normal operation of the EPS, maneuverable capacities should be about 25% of its total capacity [11]. The most promising maneuverable capacities are HPP, but their share in the EPS of Uzbekistan is only about 13.3%.

The most optimal solution to this problem is the creation and use of pumped storage power plants (PSPP). The peculiarities of the creation and use of PSPP in our region are that the available hydro resources mainly have a water management purpose, and other priorities have so far been secondary, especially with regard to the tasks of improving the energy efficiency of existing reservoirs.

The most important issue in the development of water resources has always been meeting the needs of water management and drinking water supply [12]. Therefore, at the current stage of hydropower development, the development of hydropower resources should be carried out on seasonal inland watercourses, in reservoir systems, on hydraulic structures without compromising the interests of irrigation and water supply [13]. This, as calculations show, significantly reduces the capital investment for the development of hydropower resources and makes it possible to more fully use the potential of the accumulated volume of water.

In general, we can say that the hydropower complex (HPC) is the parallel operation of electric power facilities (HPP, TPP, WPP, SPP, etc.) and water management systems (PS, geoTPP pumps, HS etc.) [14].

Currently, the construction of new PSPP requires the construction of new reservoirs, which requires large capital investments [15]. It can also be noted that the issues of detailed design of reservoirs for PSPP hydroelectric power plants and their operating modes are only beginning to be developed. When designing reservoirs, it is necessary to take into account a large number of factors: terrain, soil properties, water filtration, groundwater, rocks located in this area, the possibility of using local materials for the construction of a dam, the location of settlements and farmland in the area, the availability and development of road transport capabilities and the environmental situation in this area. For the PSPP, it is necessary to additionally take into account the water management purpose of water resources and their use regimes.

To reduce capital investment in the construction of a PSPP, existing reservoirs can be used [16], but this issue has not been studied.

Another economical option for the construction of a PSPP is the construction of only one reservoir, and instead of the second one, use a large river or canal, as well as create a special pool near large PS and TPP.

As is known, agriculture plays an important role in the economy of Uzbekistan. The most important aspect of the development of agriculture in our region is the water resources necessary for irrigation of land. For this reason, most of the reservoirs in our country, including "Charvak", serve for the needs of agriculture. During the construction of any new hydropower facility, or the reconstruction of the old one, it is necessary to take into account the needs of agriculture. It is advisable, in conditions of shortage, to use water resources simultaneously for the needs of agriculture and for the needs of the country's energy system.

In this regard, improving the energy, economic and environmental efficiency of hydraulic storage systems, directly related to the development and improvement of methods and methods for determining the optimal regime and technical and economic parameters of the PSPP, and assessing their significance in ensuring the reliability, stability and maneuverability of the EPS and power plants based on RES, is relevant.

2 METHODS AND MATERIALS

For this purpose, a mathematical model is proposed for the technical and economic assessment and determination of the optimal parameters of the PSPP under the conditions of construction of additional facilities with existing structures.

Let there be a set of options with fixed values of capital investments for the construction of the HPC K_{HPC} and the annual costs of the I_{HPC}.

At the same time (1), (2)

$$K_{HPC} = \sum_{i=1}^{n} K_{E,i} \, ; \tag{1}$$

$$I_{HPC} = I_{WMEc} + \sum_{i=1}^{n} I_{E.i} \; . \tag{2}$$

where, I_{WMEc} – annual costs for water management facilities to environmental factors; K_{HPC}, I_{HPC} – capital investments and annual costs for hydropower facilities.

The task will be to distribute limited capital investments between objects $i = 1...n$ and choose the appropriate solution option $j = 1...m$.

As is known [14, 16], the criterion for such calculations is (3):

$$C_{HPC\,ij} = I_{HPC,\,ij} + \lambda K_{HPC,\,ij} + \sum U_{\,i\,j} \rightarrow min; \tag{3}$$

where, $\sum U$ is the total damage during the commissioning of hydropower facilities (for example, an increase in water loss).

Given the values of the multiplier λ for known values of I_{HPC}, K_{HPC}, and $\sum U$, after a certain number of steps, we can find a solution that satisfies the above criterion and is acceptable for the balance of investments. In this case, the multiplier λ will be the standard of efficiency for the considered set of options.

The set goal, i.e., the increase in additional capacity of ΔN_{HPC} should be provided with a minimum of annual costs with the condition (4)

$$\left(\sum_{i=1}^{n} K_i \right)_j \le K_{HPC} \, . \tag{4}$$

With the known given economic indicators of the $\gamma_{K,i}$ and $\gamma_{I,i}$, the mathematical model of such a system can be described as follows (5):

$$\left.\begin{aligned} & I_i = \left(\sum_{i=1}^{n} \gamma_{I,i} \cdot N_i \right)_j \rightarrow min \\ & \sum_{i=1}^{n} N_i \geq \Delta N_{HPC} \\ & \left(\sum_{i=1}^{n} \gamma_{K,i} \cdot N_i \right)_j \leq K_{HPC} \end{aligned}\right\} \quad (5)$$

The efficiency of the functioning of any WMC (water management complex) is associated with the balance of the volume of water in reservoirs. When it comes to the accumulation of hydraulic energy, the water balance is compiled separately for the upper and lower streams.

The structural scheme of the PSPP with two reservoirs is shown in Figure 1.

For the upstream, the following condition must be met (6):

$$V_{U.B}(t) = V_{U.B}(t_0) + \int_{t_0}^{t_l} [Q_{flow}(t) - Q_{idle}(t) + \\ + Q_{sed}(t) - Q_{loss}(t) - Q_{draw}(t) \pm Q_{PSPP}(t)]\, dt; \quad (6)$$

where, $V_{u.b}\ (t_0)$ is the initial volume of the reservoir; $Q_{flow}\ (t)$, $Q_{idle}\ (t)$, $Q_{loss}\ (t)$, $Q_{loss}(t)$, $Q_{draw}(t)$ are the flow rates, idle discharges, sediment, losses and water withdrawal for various needs at time t; $Q_{PSPP}\ (t)$ is the performance of a hydropower plant, where the sign (+) corresponds to the pumping, and the sign (–) corresponds to the turbine mode.

The volume of the lower reservoir depends on the following balance ratio (7):

$$V_{D.B}(t) = V_{D.B}(t_0) + \int_{t_0}^{t_l} [Q_{idle}(t) + Q_{sed}(t) - \\ - Q_{WMS}(t) - Q_{loss}(t) - Q_{draw}(t) \pm Q_{PSPP}(t)]\, dt; \quad (7)$$

where, Q_{WMC} (t) is the water consumption for the participants of the *WMC* at time *t*. For the lower reservoir, the sign (+) before the Q_{HP} value (t) corresponds to the turbine mode, and the sign (–) corresponds to the pumping mode. If it is impossible to catch filtration waters coming from the upper stream in the lower reservoir, then it is necessary to take this factor into account when calculating the value of the $V_{D.B}$.

This mathematical model determines the relationship between economic costs and the potential of reservoirs in the PSPP. In particular, it follows that the local conditions of the lower stream and the near-dam area can become determining factors for the value of $V_{D.B}$.

Based on the mathematical model for the technical and economic assessment and determination of the optimal parameters of the PSPP, a methodology and a program for determining the optimal energy and economic indicators of the PSPP were developed, which allows us to solve the above problem and makes it possible to determine capital investments in the PSPP (K_{PSPP}), as well as electricity generation in the turbine mode (TR) (E_{TR}), electricity consumption in the pumping

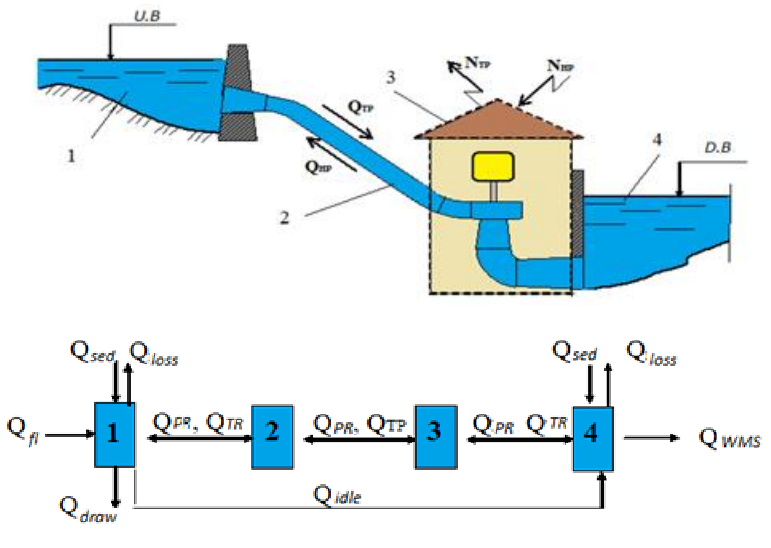

Figure 1: Structural diagram of the PSPP: 1 - upper reservoir; 2 - pressure pipe; 3 - the building of the PSPP; 4 - lower reservoir.

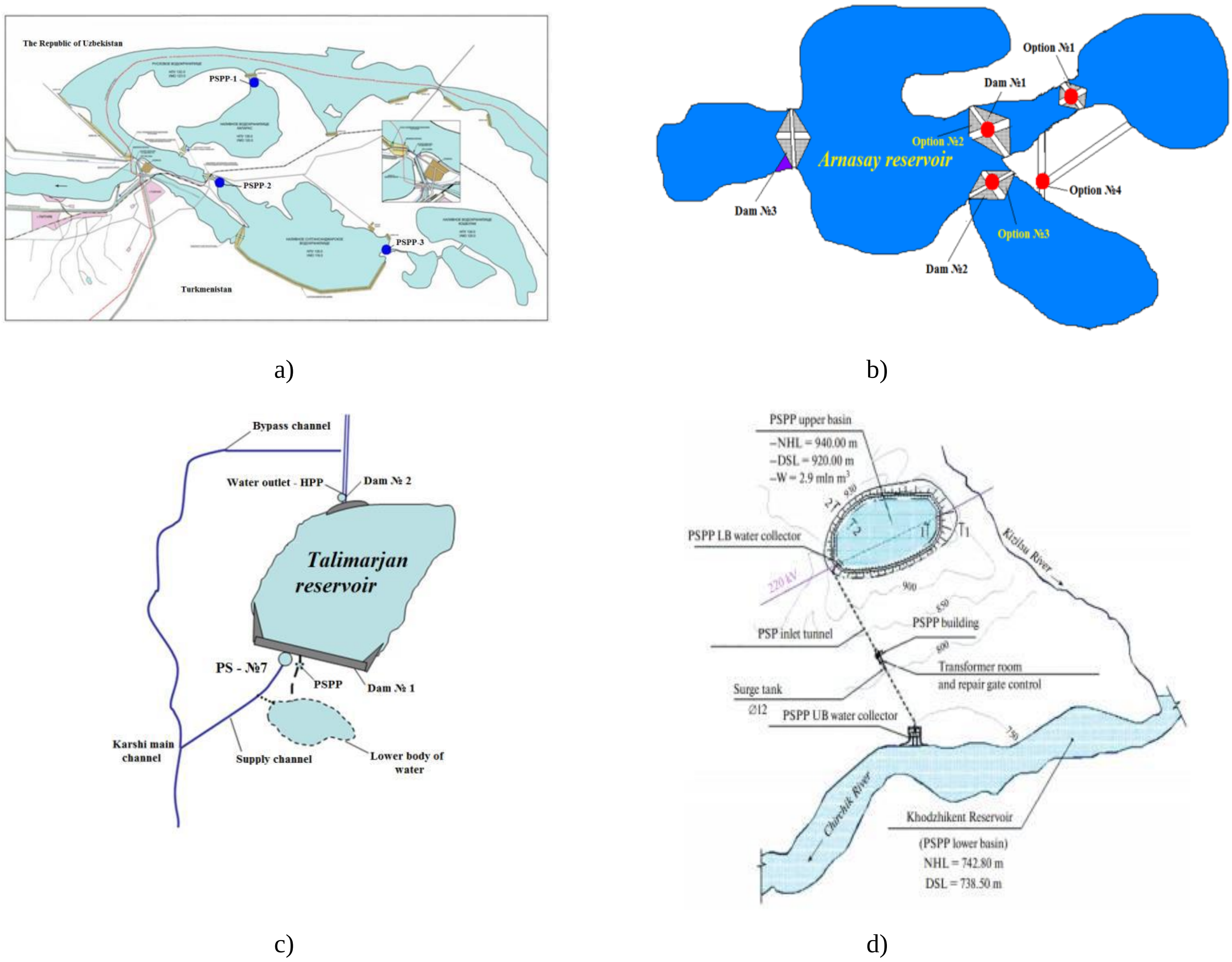

Figure 2: Schemes of energy and water facilities using the PSPP: a) the scheme of the Tuyamuyun hydroelectric complex; b) the scheme of the Arnasay reservoir; c) the scheme of the Talimarjan reservoir; d) the scheme of the Khodjikent reservoir.

mode (PS) (E_{PS}), annual fuel economy (D_{fuel}), fuel economy (E_{fuel}), annual costs of the PSPP (I_{PSPP}), economic efficiency per year (E_{PSPP}), the payback period of capital investments ($T_{payback}$) (5-6 years) and the profitability of capital investments R [17].

3 RESULTS AND DISCUSSION

Based on the developed methodology and program, the energy and economic indicators of the PSPP were studied when they were used by energy and water management facilities [18] at the Tuyamuyun hydroelectric complex, Arnasay, Talimarjan and Khodjikent reservoirs (Figure 2) and the following results were obtained:

- The construction of a PSPP with a total capacity of 39.4 MW in the Tuyamuyun hydroelectric complex will make it possible to receive at least 86.5 million kWh of electricity per year, with an annual economic efficiency of 24.3 billion. sum, and also save 12,950. 0 tons of organic fuels.
- The construction of a PSPP with a total capacity of 159.8 MW at the Arnasay reservoir will make it possible to receive at least 350.0 million kWh of electricity per year, with an annual economic efficiency of 109.5 billion. sum, as well as save 52,508. 3 tons of organic fuels [24,25].
- The use of a PSPP with a capacity of 18.473 MW at the Talimarjan reservoir makes

it possible to obtain 40.456 million kWh of electricity per year, with an annual economic efficiency of 5.440 billion. sum, as well as savings of 6 068.45 t. u. t. of organic fuels.

- Construction of the Khodjikent PSPP with a capacity of 200 MW with an annual economic efficiency of 564.55 billion rubles . sum, makes it possible to generate 452.600 million kWh of electricity per year, save 67.90 thousand tons of organic fuels.

4 CONCLUSION

The use of the PSPP increases the reliability, stability, maneuverability and energy-economic efficiency of the EPS and RES-based power plants; makes it possible to cover the minimum and maximum daily loads of the EPS, regulate the capacities of solar and wind power stations, equalize power fluctuations by accumulating energy.

Currently, the existing reservoirs of the republic are mainly used for irrigation purposes, partly for drinking water supply. For a more complete use of the potential of water resources in the operated reservoirs, it is necessary to create hydropower complexes with PSPPs that can solve issues of electricity production during the mutual operation of reservoirs.

A mathematical model is proposed for the technical and economic assessment and the choice of determining the parameters, a methodology and a program for determining the energy and economic indicators of the PSPP for the energy and water facilities of Uzbekistan are developed. They can be used in the design, development, feasibility study and determination of optimal options for complexes.

The potential and technical possibilities of creating a PSPP at four energy and water management facilities-Tuyamuyun, Arnasay, Talimarjan and Khodjikent facilities allows to obtain a total peak capacity of about 418 MW and additionally generate more than 930.0 million kWh/year of electricity, as well as save fuel resources up to 139 thousand tons of u.t./year. At the same time, it becomes possible to reduce the annual emission of CO_2 emissions to 213 thousand tons / year and achieve environmental efficiency of 32.11 billion rubles. sum/year (or $ 3,195 million / year) and as a result, the economic efficiency of the PSPP will be about 700 billion sums/year.

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