ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 10, Issue 5, May 2023

Selection of parameters of hydroaccumulation power plant operating in autonomous mode and determination of economic efficiency

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ABSTRACT: Accumulation of energy for renewable energy sources is one of the necessary activities, which significantly increases the efficiency and continuity of energy supply due to the more complete use of renewable energy sources. In our country, a lot of attention is paid to the development of the energy sector. A lot of work is underway to modernize existing capacities and commission new capacities. At the same time, the unit capacities of units and power plants also increase, which ensures faster commissioning of capacities in the power system and an increase in the efficiency of power plants. Attention is also paid to the development of power plants based on renewable energy sources (hydraulic, solar, wind, etc.). One of the most important tasks in the power industry is to cover peak minimum and maximum loads, which is becoming increasingly important in connection with the growth of the power system's capacity. As is known, according to world indicators, the maneuverable capacities should be about 25% of the total power of the EPS. The most promising maneuverable capacities are hydroelectric power plants. However, in our country, hydroelectric power plants account for about 14.3%. This task will become more complicated with the introduction of capacities based on solar and wind energy and the commissioning of new hydroelectric and thermal power plants in the Republic. This is because RES capacities have a significant discontinuity even during the day, and the water resources in the Republic are primarily for irrigation and drainage purposes and are significantly variable during the season. One way to solve these problems in the world is the creation and use of pumped storage power plants (PSPP).

KEY WORDS: renewable energy sources, turbine, pump, hydroaccumulation power plant, electricity, water reservoirs.

I. INTRODUCTION

Worldwide, the use of energy-efficient technologies in renewable energy sources (RES) is growing rapidly. Currently, the European Union aims to reduce greenhouse gas emissions by 80-95% by 2050 compared to the 1990 years for this purpose, a long-term energy saving strategy "Energy Strategy 2050" has been developed. Currently, due to the presence of many instruments that allow RES to take a strong place in the country’s energy balance, the policies to support their development are different, for example, in many cases, favorable tariffs, preferential taxes and loans are used, and in less cases, grants, subsidizing the value of debt capital are used [1,2,3,4].

II. THE DEGREE OF STUDY OF THE PROBLEM

Scientific research aimed at accumulating the energy of energy devices with the help of a hydroaccumulation power plant (PSPP) is carried out in many leading scientific research centers and universities of the world, in particular: International Renewable Energy Agency (IRENA) (UAE), National Laboratory of Renewable Energy Sources (USA), Rural Electrification Alliance (Belgium), Portuguese Renewable Energy Association (Portugal), China Renewable Energy Association (China), and others are being implemented [5,6,7,8].
Development of generally accepted methods for determining the energy and technical-economic parameters of energy devices based on RES and PSPP, calculation methods for optimizing their operating modes and parameters, and

determining and justifying the optimal operating modes and parameters of combined power plant based on RES, for their energy systems and small consumers a number of well-known foreign scientists have made a significant contribution to solving issues such as determining the importance of the product, including: Hu Lin, Ruan Xinbo, Hocine Belmili., Vasilev Yu. S., Elistratov V.V., Velkin V.I., Lukutin B.V., Zai Yar Lin, Telegin V.V and others.

III. RESEARCH RESULTS

When determining the economic efficiency of PSPP, it is necessary to take into account the factor that it is directly related to the nature of the energy consumption graph [5,6]. For example, typical energy consumers with private production may have their daily load graph as shown in Figure 1.

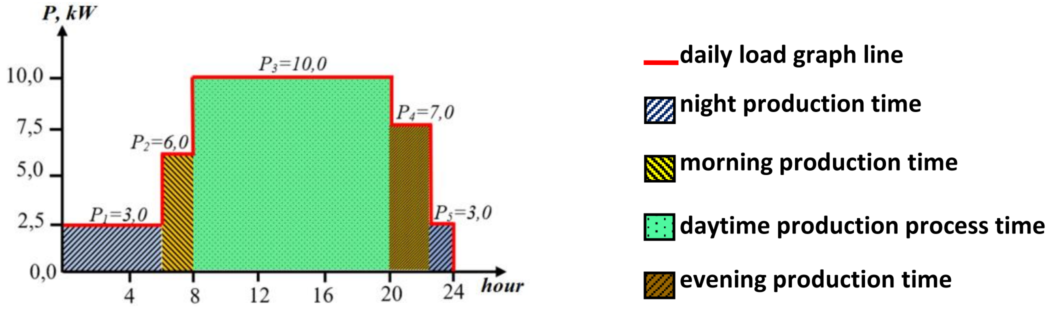

Figure 1. Daily load graph of energy consumers with individual production

This graph shows the average values of the required power, because the loads of individual generators vary between hours and although their values appear to fluctuate dramatically, the range of changes between them can be small.

To determine the main parameters of PSPP and evaluate its economic efficiency, the daily load graph of a self-produced energy consumer with a capacity of 10 kW and a maximum daily electricity consumption of 170 kW·h, presented in Figure 1, was used as an example. That is,

$$\sum E = \sum_{i=1}^{5} P_i \cdot t_i = P_1 \cdot t_1 + P_2 \cdot t_2 + P_3 \cdot t_3 + P_4 \cdot t_4 + P_5 \cdot t_5 = 18 + 12 + 120 + 14 + 6 = 170\ \mathrm{kW} \times \mathrm{h}$$

here	P_1=3 kW;	t_1=6 hour;	E_1=$P_1 \cdot t_1$=3·6=18 kW·h.
	P_2=6 kW;	t_2=2 hour;	E_2=$P_2 \cdot t_2$=6·2=12 kW·h.
	P_3=10 kW;	t_3=12 hour;	E_3=$P_3 \cdot t_3$=10·12=120 kW·h.
	P_4=7 kW;	t_4=2 hour;	E_4=$P_4 \cdot t_4$=7·2=14 kW·h.
	P_5=3 kW;	t_5=2 hour;	E_5=$P_5 \cdot t_5$=3·2=6 kW·h.

If there is enough water resources to cover the loading schedule shown in Figure 2, there is no need to collect them and you can use the hydro turbine directly. In practice, such conditions do not always exist. In this regard, one of the main goals of the dissertation work is to prove that the amount of electricity needed to meet the needs of private energy consumers can be realized by moving water between two basins (transferring the amount of water from pump and turbine devices) using a small amount of water [9,10,11,12,13,14].

Two options for PSPP modes of operation were investigated in the course of the thesis.

1. Using the PSPP pump mode only during the minimum load period of the daily load graph.

In this option, at the time when the lowest energy consumption is observed, that is, from 22^{00} at night to 6^{00} in the morning, the required amount of water is collected in the upper reservoir using a pumping device (Fig. 2).

2. Using a small power PSPP in continuous pump mode.

This option envisages the parallel use of pumping and hydroturbine devices during the day, that is, continuous movement between water reservoirs is ensured, which in turn leads to a significant reduction in the volume of the upper and lower water reservoirs.

During the studies, the indicators of the use of PSPP in these two options were considered.

1. Determination of PSPP indicators using the PSPP pump mode only during the minimum load period of the daily load graph (option 1)

The maximum water volume transferred for the turbine mode was determined based on the formula (2.38), taking the coefficients of useful work of the turbine $\eta_{tur}=0.84$ and the pump $\eta_{pump}=0.80$, which are somewhat characteristic for low-power PSPP and the head $H=7.0\ m$:

$$V_{tur}=\frac{367{,}0}{\eta_{tur}}\sum_{i=1}^{n}\frac{P_i\cdot t_i}{H_{tur\ i}}=\frac{367{,}0\cdot 170}{0{,}84\cdot 7{,}0}=10611\,\text{m}^3$$

At the same time, V_{tur} corresponds to the amount of water needed to produce 170 kW·h of electricity consumed per day. The maximum volume of the upper water basin is determined as follows

$$V_{\max}=V_{tur}-V_T^{`}=10611-1498=9113\,\text{m}^3$$

where $V_T^{`}$ - the volume of water delivered to the turbines during the operation of the pumping device

$$V_{tur}'=\frac{367{,}0\cdot P\cdot t}{\eta_{tur}\cdot H_{tur}}=\frac{367{,}0\cdot 3{,}0\cdot 8{,}0}{0{,}84\cdot 7{,}0}=1498\,\text{m}^3$$

In pumping mode, the power consumed by the pumping device to transfer the volume of water required to be transferred V_{max} is determined as follows

$$N_{pump}=\frac{V_{tur}\cdot H_{pump}}{367{,}0\cdot t_{pump}\cdot \eta_{pump}}=\frac{10611\cdot 7{,}0}{367{,}0\cdot 8{,}0\cdot 0{,}8}=31{,}6\,\text{kW}$$

where t_{pump} is the working time according to the daily loading schedule of the pumping device, according to Figure 1, it is 8.0 hours.

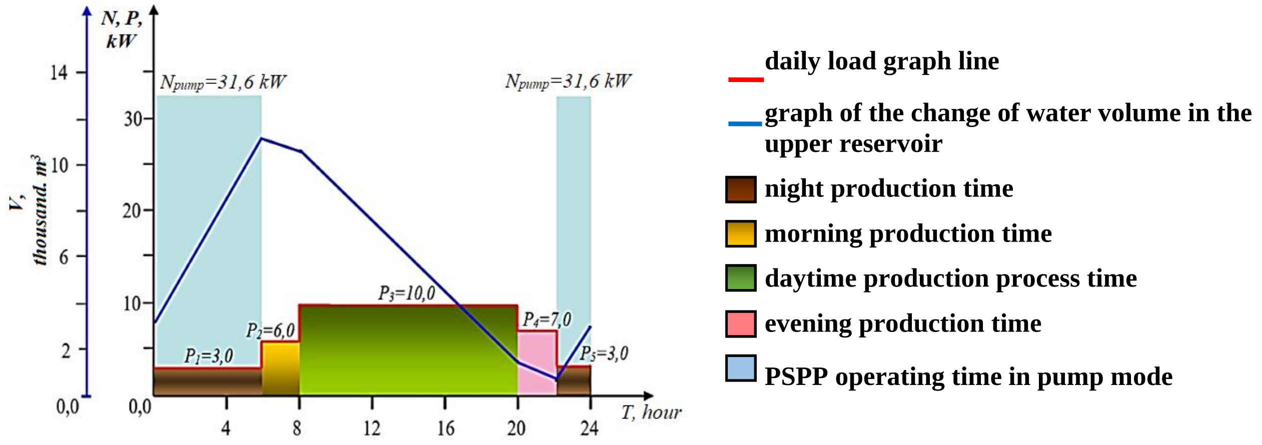

Figure 2. Diurnal operating modes of small power PSPP operating in pump mode during the minimum load period of the daily load graph.

From 0^{00} to 6^{00} and from 22^{00} to 24^{00} hours of the day, the volume of water delivered by the pump to the upper reservoir was determined as follows

$$V_{pump}^{0-6}=\frac{367\cdot N_{pump}\cdot t_{pump}\cdot \eta_{pump}}{H_{pump}}=\frac{367\cdot 31{,}6\cdot 6{,}0\cdot 0{,}8}{7{,}0}=7952\,\text{m}^3$$

$$V_{pump}^{22-24} = \frac{367 \cdot N_{pump} \cdot t_{pump} \cdot \eta_{pump}}{H_{pump}} = \frac{367 \cdot 31{,}6 \cdot 2{,}0 \cdot 0{,}8}{7{,}0} = 2650\,\mathrm{m}^3$$

The calculation results are presented in Table 1.

Table 1. Results of PSPP upper watershed size and capacity determinations for option 1

Hours in a day	Consumer power P, kW	The volume of water used in turbine mode, V^T, m^3	The volume of water transferred in pump mode, V^H, m^3	The volume of the upper reservoir, V, m^3	PSPP power in turbine mode, N_{tur}, kW	PSPP power in pump mode, N_{pump}, kW
0 – 6	189,6	1124	7952,0	9113,0	3,0	31,6
6 –8	-	749	-	8364,0	6,0	-
8 – 20	-	7490,0	-	874,0	10,0	-
20 - 22	-	874,0	-	0,0	7,0	-
22 – 24	63,2	371,0	2650,0	2279,0	3,0	31,6

The volume of the upper reservoir is determined as follows, depending on the volume of water arrival and consumption during the period of energy consumption

$$V_{upper}^{0-6} = V_{\max};\ V_{upper}^{6-8} = V_{\max} - V_{\mathrm{tur}}^{6\text{-}8} \ \text{ and } \ V_{upper}^{8-20} = V_{upper}^{6-8} - V_{\mathrm{tur}}^{8\text{-}20};\ V_{upper}^{22-24} = V_{pump}^{22-24} - V_{tur}^{22\text{-}24}$$

The amount of electricity consumed by the pumping device

$$E_{pump} = N_{pump} \cdot t_{pump} = 31{,}6 \cdot 8{,}0 = 252{,}8\ \mathrm{kW{\cdot}h}$$

The power of the PSPP in the turbine mode should be equal to the load value in the daily load graph of the consumer (Fig. 2).

2. Determination of PSPP indicators when using low-power PSPP in continuous pumping mode (option 2)

In the second option, the working time of the pumping device is 24 hours and its capacity is determined as follows

$$N_{pump} = \frac{V_{max} \cdot H_{pump}}{367{,}0 \cdot t_{pump} \cdot \eta_{pump}} = \frac{10611 \cdot 7{,}0}{367{,}0 \cdot 24{,}0 \cdot 0{,}8} = 10{,}6\ kW\,.$$

The amount of electrical energy consumed by the pumping device will be equal to the following

$$E_{pump} = N_{pump} \cdot t_{pump} = 10{,}6 \cdot 24{,}0 = 254{,}4\ \mathrm{kW{\cdot}h}.$$

At the end of the working day, that is, at 20^{00} hours, the volume of water in the upper reservoir is assumed to be equal to zero value and then, taking into account the arrival and consumption of water volume in the upper reservoir based on the time intervals of electricity consumption, changes in water volumes are determined. The calculation results are presented in table 2.

Table 2. PSPP upper watershed size and capacity determination results for option 2

Hours in a day	Consumer power P, kW	The volume of water used in turbine mode, V^T, m^3	The volume of water transferred in pump mode, V^H, m^3	The volume of the upper reservoir, V, m^3	PSPP power in turbine mode, N_{tur}, kW	PSPP power in pump mode, N_{pump}, kW
0 – 6	*3,0*	*1123,5*	*2667,5*	*2073,5*	*3,0*	*10,6*
6 –8	*6,0*	*749,0*	*889,0*	*2213,5*	*6,0*	*10,6*
8 – 20	*10,0*	*7490,0*	*5335,0*	*0,0*	*10,0*	*10,6*
20 -22	*7,0*	*874,0*	*889,0*	*15,0*	*7,0*	*10,6*
22 -24	*3,0*	*374,5*	*889,0*	*529,5*	*3,0*	*10,6*

Based on the results of Table 2, a graph of changes in PSPP parameters was constructed and the provision of the required load to the energy consumer by continuously transferring water volume to the upper water basin is presented in Figure 3.

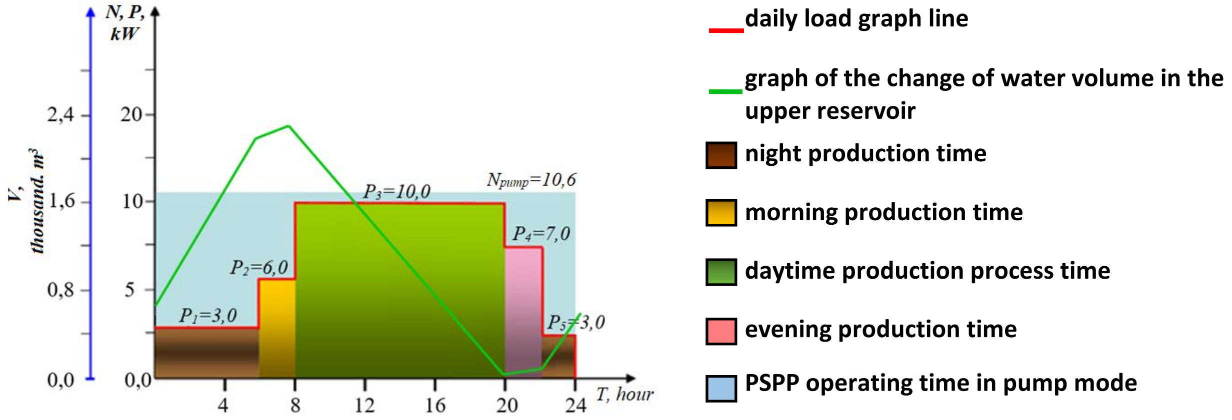

Figure 3. Small power PSPP diurnal modes operating in continuous pump mode.

It can be seen from Table 2 that the volume of the reservoir in the second option is equal to 2213.5 m^3, which is 4 times less than the first option (9113.0 m^3). It can be seen that when comparing the costs of construction of water reservoirs according to two options at the same energy costs, the second option is considered to be significantly more economically efficient [13, 14].

In order for PSPPs operating in autonomous mode to be economically efficient, it is necessary to reduce the energy consumption of the pumping device or to implement their use in combination with devices based on renewable energy sources.

IV. CONCLUSION

1. The state and modes of operation of the EPS of the Republic of Uzbekistan show that to improve the functioning of the EPS, maneuverable capacities are needed, in particular, it indicates that this requires the creation of pumped storage power plants operating in the daily, weekly and seasonal mode of energy storage.
2. At present, the existing reservoirs of the Republic are mainly used for irrigation purposes, partly for drinking water supply. For complete use of the potential of water resources in the operated reservoirs, it is necessary to create hydropower complexes that, in their essence, are capable of solving the issues of electricity production during the depletion of reservoirs.
3. Terrain relief is of great importance in designing a PSPP - desirable to use local reservoirs and elevation differences to increase the pressure and thus improve its economic performance. In our region, it is necessary to take into account

the new conditions for the creation of pumped storage power plants - low-pressure, at the same time high capacities, as well as the maximum use of existing reservoirs and watercourses, which are mainly of water economic importance.

4. The developed methodology for substantiating the technical and economic indicators of PSPP in Uzbekistan's energy and water systems and its software implementation can be used in the design and development of a feasibility study at PSPP and determining its optimal options.

5. The technical and economic indicators of the PSPP according to the developed methodology are preliminary; that is, the capacity of the projected PSPP will depend on the possibility of creating sufficient capacities of the upper and lower basins and the injection and operation modes will be determined by the results of optimization technical and economic calculations for the requirements of the power system, taking into account the long-term strategy its development.

REFERENCES

[1] The concept of providing the Republic of Uzbekistan with electric energy for (2020-2030).

[2] Mukhammadiev M.M., Dzhuraev K.S Justification of the energy and economic parameters of pumped storage power plants in Uzbekistan. International journal "Applied Solar Energy", Vol. 56, №3, pp.227-232. (2020).

[3] Mukhammadiev M and Klichev Sh Use of Pumped Storage Hydroelectric Power Plants in Uzbekistan. International journal "Applied Solar Energy", Vol. 54, №6, pp.468-471. (2018).

[4] Mukhammadiev M, Urishev B Use and accumulation of renewable energy in the energy system of the Republic of Uzbekistan. Monograph, Tashkent, NURFAYZ, p. 252. (2020).

[5] Mukhammadiev M, Urishev B, Mamadiyorov E and Dzuraev K Low-power power plants based on renewable energy sources. Monograph, Tashkent TDTU, p. 162. (2015).

[6] Muhammadiev M and Urishev B. Hydroaccumulative power plants. Monograph. Publishing house "Fan va texnologiya", Tashkent, p. 212. (2018)

[7] Mukhammadiev M, Dzhuraev K and Klychev Sh Capabilities of Hydroelectric Pumped-Storage Stand-Alone Power Plants. International journal "Applied Solar Energy", Vol. 49, №4, pp. 267–271. (2013).

[8] Klychev I. Sh., Mukhammadiev M. M., Nizamov O.Kh., Mamadierov E.K., Dzhuraev K.S., Saifiev A.U Method for calculating the power of combined autonomous electric power plants. International journal "Applied Solar Energy", Vol. 50, №3, pp.196-201. (2014).

[9] Dzhuraev K., Nasrulin A., Shadibekova F., Kurbonov Sh Geoinformation systems at the selection of engineering infrastructure of pumped storage hydropower for the Tuyamuyun complex. IOP Conference Series: Materials Science and Engineering, Volume 869, Number 4, Engineering Infrastructure, IOP Publishing, pp.1-10

[10] Muhammadiev M., Urishev B., Juraev S. and Boliev A 2020 Detritus removal from a pumping-plant intake chamber with hydrajet pumps. IOP Conference Series: Materials Science and Engineering, Volume 883, IOP Publishing, pp.1-8. (2020)

[11] Mukhammadiev M, Nasrulin, A Mukolyants A and Ergasheva D A complexly method of GIS technologies and optimization models used in the development of environmentally acceptable modes of operation of hydraulic and hydropower facilities in Uzbekistan. Journal of Physics: Conference Series, Vol.1425. (2020).

[12] Barbour E, Wilson I A G, Radcliffe J, Ding Y L and Li Y L A review of pumped hydroenergy storage development in significant international electricity markets Renew Sust Energ Rev, 61, pp. 421-432. (2016).

[13] M Mukhammadiev, O Glovatskiy, N Nasyrova, N Karimova, A Abduaziz uulu and A Boliev. Assessment of investment technologies for use of hydro – accumulating stations on intermediate channels of irrigation systems and water reservoirs. IOP Conf. Series: Earth and Environmental Science 614 (2020) 012088 doi:10.1088/1755-1315/614/1/012088

[14] Mukhammadiev M.M, Urishev B. U., Abduaziz uulu A, Gadaev S. K, Zhankabylov S.U. Issues of using local energy systems with hydraulic energy storage in the power system of the Republic of Uzbekistan. ICECAE 2020, Tashkent. E3S Web of Conferences 216, 01138 (2020) https://doi.org/10.1051/e3sconf/202021601138