ISSUES OF USING LOCAL ENERGY SYSTEMS WITH HYDRAULIC ENERGY STORAGE IN THE POWER SYSTEM OF THE REPUBLIC OF UZBEKISTAN

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Abstract. The method of determining the main energy parameters of a local energy system based on renewable sources with hydraulic accumulation of part of the generated energy is considered. The example shows the economic efficiency of hydraulic energy storage in comparison with lithium-ion batteries.

1 Introduction

Modern energy system is developing in four main directions: diversification, decarbonization, decentralization and digitalization of the process of energy production and consumption. If the first two listed areas have long been in the process of implementing and achieving goals, and decentralization and digitalization of energy are relatively new areas that are getting more and more developed from year to year. In terms of diversification and decarbonization of energy processes, the achievement of goals is primarily related to natural factors, and the main goal of decentralization and digitalization of energy is to increase the energy efficiency of the process of generating and consuming energy.

All these areas, despite their independence in achieving goals, are interrelated, for example, decentralization cannot do without digitalization, and it ultimately leads to the decarbonization of the energy process, as well as diversification.

The power system of the Republic of Uzbekistan is centralized, and like all traditional similar power systems, it has significant disadvantages, such as significant energy losses due to the remoteness of some consumers, insufficient flexibility of the production process due to the low share of highly maneuverable power plants in it, lack of proper regulation of energy consumption and pricing. All these disadvantages ultimately lead to higher fuel consumption, CO_2 emissions, and the cost of energy produced.

Currently, these negative consequences of the centralized power system have created the prerequisites for a gradual transition to other, more efficient forms of production and consumption management, such as local power systems.

Local power systems (LPS) are relatively small energy supply systems that operate within well - defined boundaries for generating, storing, transmitting, and distributing energy.

Today, there are many local power systems in the world such as microgrid, smart grids, and distributed generation clusters. Such systems can help solve very important tasks, such as optimization, stabilization, flexibility of the energy system, integration of renewable energy sources (RES) and "smart" control centers in the process of energy production and distribution [1,2,3].

At the same time, Local Power plants can be connected to a centralized energy network to carry out energy transactions for its import or export, depending on the current situation.

The international energy Agency in its World Economic Access Outlook 2017 report States that the most cost-effective way to expand access to energy in remote areas of the planet is through Local power plants, and this contributes to the fact that by 2030 at least 30...40% of localities in developing countries will be connected to such systems [4].

A very important advantage of a Local power plant is the ability to manage not only the generation process, but also energy consumption based on the use of appropriate IT- technology, which allows you to optimally distribute all the generated energy between consumers, accumulate its excess part or exchange it with a centralized power system.

The accumulation of a part of the generated energy is one of the main elements of the production process of LPS, used renewable energy sources (RES) and it takes up most of the funds spent on the operation of the system. This is due to the fact that most of the operated LPS use expensive electrochemical, regenerative fuel and other energy storage systems for this purpose,

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which cannot provide large amounts of energy storage, have high costs and a relatively short life cycle [5,6].

The main indicators of energy storage systems that affect the efficiency of use in energy systems are capacity, storage time, and unit cost of energy. Among all currently operating energy storage systems, the best indicators are hydro-storage power plants (HSPS) [5,6,7].

In [8], the issues of using HSPS in the power system of the Republic of Uzbekistan were considered, which showed the economic efficiency of hydraulic energy storage by achieving the fuel effect and reliability of the system.

2 Methods and materials

Let's consider a possible scenario of using a HSPS in a proposed LPS operating on the basis of renewable energy sources. The LPS serves to supply one of the industrial zones of the Republic, whose annual electricity demand is 3.6 billion rubles. kW·hours. The main consumers of electricity are: industrial enterprises – 1.8 billion rubles. kW·hours, housing and utilities-1.2 billion kW·hours, agricultural enterprises – 0.47 billion. kW·h, reclamation pumping station – 0.07 billion kW·hours and other consumers – 0.06 billion kW·hours. The average daily electricity demand of a LPS is 10 MW·h.

In our opinion, for the above-mentioned consumers, one of the appropriate schemes may be the scheme of a RES-based LPS plant, shown in Fig. 1.

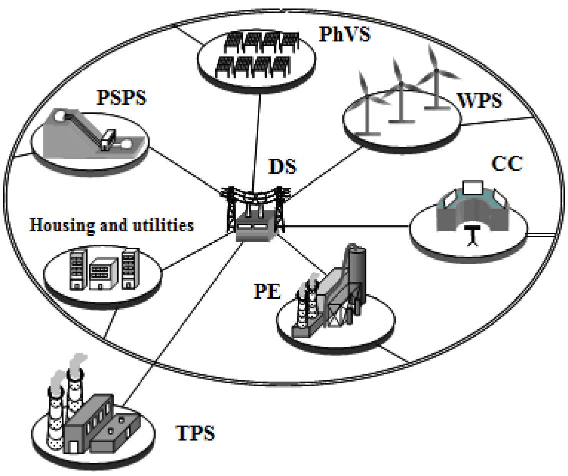

Fig.1. Scheme of the local energy system

PhVS – photovoltaic station; WPS – wind power station; PSPS – pumped-storage electric power station; DS – distribution station; PE – production enterprises; CC – control center; housing and utilities – housing and communal services; TPS – thermal power station.

This system can consume excess energy of wind and photovoltaic stations (WPS and PhVS) in the hours of minimum demand (to power the pumping units pumped storage, pumping water from the lower reservoir at the top) and give it to the grid during peak-load hours (by supplying water to the turbines from the upper reservoir). This scheme of hydro-accumulation of energy will be expedient and very effective, even at small values of the head and amount of water.

The daily schedule of the LPS operation mode is shown in Fig. 2.

The graph $(N_{WPS}+N_{PhVS})=f(t)$ is obtained by adding the values of the capacities of the PhVS and WPS vertically at times t. This graph describes the total capacity of the PhVS and WPS in the time interval from t_2 to t_5.

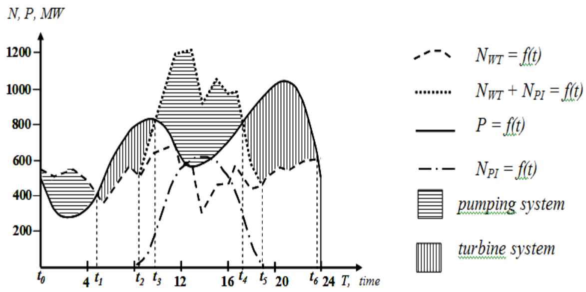

Fig.2. Schedule of daily operation of the local power plant

According to the energy balance in the considered local power plant the following condition must be met

$$E_c = E_{HPS} - E_{PS} + E_{WPS} + E_{PhVS} \qquad (1)$$

where, E_c – the amount of electricity consumed by the *LPS, WPS, PhVS, HPS* – the amount of energy produced by all power stations, PS – the amount of electricity consumed by the pumping station (PS) to lift water from the lower reservoir to the upper one.

$$E_{HPS} = \eta_{HPS}\left(\int_{t_1}^{t_2}(P - N_{WPS})(t)dt + \int_{t_2}^{t_3}\left[P - (N_{WPS} + N_{PhVS})\right](t)dt + \right. \qquad (2)$$

$$\left. + \int_{t_4}^{t_5}\left[P - (N_{WPS} + N_{PhVS})\right](t)dt + \int_{t_5}^{t_6}(P - N_{WPS})(t)dt\right)$$

where, *P(t)* is the power consumption of the local power plant according to the daily load schedule, η_{HPS} is the efficiency of the *HPS.*

The sum of the difference between the power of N_{WPS} and the daily load P in the time intervals from t_0 to t_1 and $N_{WPS} + N_{PhVS} - P$ from t_3 to t_4 is used to power the pumping unit, which provides accumulation of water volume in the upper reservoir. In this case, the consumed electricity of the PS is determined by the following equation

$$E_{PS} = \eta_{PS}^{-1}\left(E_{PS}^{t_0-t_1} + E_{PS}^{t_3-t_4}\right) =$$

$$= \eta_{PS}^{-1}\left(\int_{t_0}^{t_1}(N_{WPS} - P)(t)dt + \int_{t_3}^{t_4}(N_{WPS} + N_{PhVS} - P)(t)dt\right) \qquad (3)$$

The value of the accumulated volume of water in the upper reservoir is determined based on the electricity consumed for this purpose and the pressure of the *PS*, which varies depending on the water level in the reservoirs, i.e. on the volume of water in them.

$$V_U = 367\left(E_{PS}^{t_0-t_1}\int_{t_0}^{t_1} H_{PS}^{-1}(t)dt + E_{PS}^{t_3-t_4}\int_{t_3}^{t_4} H_{PS}^{-1}(t)dt) \right) \quad (4)$$

The actual volume of water in the upper reservoir V_U will be greater than the value calculated from (3), taking into account the loss of water and the degree of probability of solar and wind energy coming to this area.

The efficiency of the *LPS* is largely due to *PhVS* and *WPS*, so to solve the problem of choosing their power, it is necessary to consider economic aspects as the profitability of the operation depends on the selected values of N_{WPS} and N_{PhVS}, i.e. reliability and economy coverage daily load total energy of these stations.

The degree of participation of *PSPS* in covering the daily load, as a rule, should be up to 25% of the total capacity of the power system [8,9,10]. The remaining load should be distributed between the wind and power plants, taking into account the local conditions of energy arrival. To determine the optimal combination of the degree of participation of installations in covering the daily load schedule, we use the following procedure for determining their capacity, based on preliminary comparative economic estimates.

We determine the daily energy output of power plants, taking into account the degree of their participation in this process

$$E_{daily} = E_c + E_{PS} = K_{1i} \cdot E_c + (1 - K_{1i})\, E_c \quad (5)$$

where $K_{1i} \cdot E_{daily}$ – the share of *PSPS* power generation in the turbine mode, $(1 - K_{1i})$ – the share of power generation of *WPS* and *PhVS*, K_{1i} – the load factor of the *PSPS*, i = 1,2,....n – the number of compared options. For example, if we take $K_1 = 0.25$, then the share of power generation from *WPS* and *PhVS* is 75 %, which can be determined by the following formula

$$E_{daily}(1 - K_{1i}) = N_{\mathrm{WPS}i}^{\mathrm{av}} \cdot t_{WPSi}^{av} + N_{\mathrm{PhVS}i}^{\mathrm{av}} \cdot t_{PhVSi}^{av} \quad (6)$$

t_{WPSi}^{av}, $t_{\mathrm{PhVS}i}^{av}$ – the average duration of operation of the wind turbine and power plant.

The average power values can be determined as follows

$$N_{WPSi}^{av} = \frac{(1 - K_{1i}) \cdot K_{2i} \cdot E_{daily}}{t_{WPSi}^{av}}$$

$$N_{PhVSi}^{av} = \frac{(1 - K_{1i})(1 - K_{2i}) \cdot E_{daily}}{t_{PhVS}^{av}} \quad (7)$$

where, K_{2i} is the load factor of the wind farm.

The load factors of the *PSPS* (K_{1i}), *WPS* (K_{2i}), and, respectively, *PhVS* $(1 - K_{2i})$ are selected based on the analysis of hydroelectric resources (head H and water flow Q), wind energy inventory data, actinometric observations, and taking into account the accumulated energy share of the *PhVS* and *WPS*.

Similarly, it is possible to determine the capacity of a *PSPS* in the turbine mode

$$N_{PSPSi}^{\mathrm{av}} = \frac{K_{1i} \cdot E_{daily}}{t_{PSPS}^{av}} \quad (8)$$

The optimal combination of capacity utilization from the considered options *N* can be obtained on the basis of the following criterion

$$П_i = И_i + \lambda \cdot C_i \rightarrow min \quad (9)$$

$П_i$ – reduced costs, $И_i$ – annual operating costs, C_i – capital investment, λ – the size of the tax rate.

C_i and $И_i$ is determined based on the specific parameters

$$C_i = \alpha_{WPS} \cdot N_{\mathrm{WPSi}}^{\mathrm{av.}} + \alpha_{PhVS} \cdot N_{\mathrm{PhVSi}}^{\mathrm{av.}} + \alpha_{PSPS} \cdot N_{\mathrm{PSPSi}}^{\mathrm{av.}}$$

$$И_i = \beta_{WPS} \cdot C_{WPSi} + \beta_{PhVS} \cdot C_{PhVSi} + \beta_{PSPS} \cdot C_{PSPSi} \quad (10)$$

where α is the unit cost of power and β is the unit operating cost.

3 Results and discussion

Calculations to determine the optimal composition and energy parameters of local power plants, made according to the dependencies (2 – 10) revealed the following results:

The calculations considered 8 options for combining capacities and the degree of participation of stations in covering the daily load. According to condition (9), the optimal one is the variant with load coefficients $K_1 = 0.15$, $K_2 = 0.65$, which revealed the following parameters:

E_{WPS} = 6630 MW·h, E_{PhVS} = 3570 MW·h, E_{HPS} = 1800 MW·h, E_{PS} = 2000 MW·h, V_U = 18 million. m^3, N_{WPS}^{av} =276 MW; N_{PhVS}^{av} =446 MW; $N_{PSPS}^{\mathrm{av}} = N_{\mathrm{HPS}}^{\mathrm{av}} + N_{PS}^{av}$ = 180 + 210 = 390MW.

The value of the reduced costs П was 210596$, while data from the IRENA Yearbook renewable energy costs in 2019 were used to determine the values α, β [11]. For example, α_{WPS}=1473 $/kW, α_{PhVS} = 995 $/kW, α_{PSPS} = 1704 $/kW.

The main advantages of the proposed scheme of power plants and the operating mode of power plants are as follows:

- power supply to the pumping station of the PSPS using the energy produced by the *PhVS* and *WPS* in comparison with the traditional option from thermal power stations significantly reduces energy costs, since at present the specific cost of *PhVS* energy is 0.068 $/kW·h, wind turbines - 0.053 $/kW·h [11]. According to the Fraunhofer Institute for solar energy systems, the specific energy cost of combined cycle steam - gas installations is 7.78...9.96 Euro cents/kW·h, while gas installations are 11.03...21.94 euro cents/ kWh [22], moreover, the cost of renewable energy is decreasing from year to year, and the energy generated in thermal power plants is increasing;

- consumers are supplied with the cheapest and "clean" energy generated by *PhVS, WPS* and *HPS* (the unit cost of hydroelectric power stations is $0.047/kW·h [12]);

- using a *PSPS* as a storage device allows you to accumulate all the excess (unused) part of the energy of the WPS and PhVS, increase the capacity and functionality of the power system, and reduce costs during its life cycle.

Many researchers consider hydraulic storage as an effective direction for expanding the use of renewable energy sources, but they believe that the availability of sufficient water resources, conditions for the construction of reservoirs and obtaining high pressures are crucial factors for the effective operation of *PSPS* [13,14]. However, as the results of calculations show, in the considered local power plant for the effective operation of the *PSPS* at a pressure of 25 meters, the volume of water in reservoirs is 18 million m^3. This is due to the fact that the volume of accumulated energy is 15...30% of the volume produced, and the accumulation time takes 25...50 % of the daily time. For example, a power system with a capacity of 1.0 GW will require reservoirs with volumes of about 30...35 million m^3 (at 20 meters of pressure), covering an area of about 25...30 hectares each. At the same time, water consumption is necessary only to compensate for losses on evaporation and filtration, which depend on the water surface area, as well as on climatic conditions and do not exceed 2...10% of the total volume of the reservoir with proper quality of construction work [15].

Conclusion

1. The results of technical and economic calculations of the main parameters of power plants with a daily power generation of 12 MW·hours based on *FhVS, WPS* and *PSPS* showed that the use of power plants based on RES can achieve cost savings of 521.25 thousand rubles. $ per day due to the difference in the cost of electricity compared to the *TPP* (the cost of *TPP* energy is assumed to be 0.12 $/kW·h). If you take into account the environmental costs, the provision of system services, the benefits of programmed capacity management and other opportunities, the benefits will undoubtedly be even greater.
2. The cost of energy storage by lithium-ion batteries, which are one of the most popular storage devices in 2019, amounted to 275...285 $/kW·h, and for hydraulic storage-177...186 $/kW·h (costs take into account the cost of storing power in kW for a certain time (in hours), usually for lithium-ion batteries 4 hours, and for PSPS 16 hours) [16]. If we take the average values of these specific indicators, i.e. for lithium-ion batteries 280 $/kW·h, for PSPS 180 $/kW·h, the economic effect of using a hydraulic storage system in the considered local power plant is 180,000 thousand rubles. $ per day.

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