**Technical and economic substantiation of the innovative hydro-accumulation system design**

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**Abstract.** The effective utilization of renewable energy sources such as solar and wind requires reliable and efficient energy storage systems due to their irregular and intermittent supply. This paper presents a novel hydro-accumulation system that significantly reduces energy consumption by integrating hydraulic ram pumps instead of traditional electrically powered pumps. The proposed system operates in cascade mode, where the kinetic energy of water is used multiple times through a sequence of hydraulic rams to pump water from a lower reservoir back to the upper one. Each stage of the system reuses the outflow water of the previous ram, achieving up to 78% water return without electricity when three rams are applied. Additional stages can further increase efficiency up to 87%, though with increased complexity and structural requirements. The study compares the economic and operational indicators of the traditional and proposed systems under the same capacity. Results show a notable reduction in annual energy consumption and a corresponding increase in economic efficiency. The proposed system is autonomous, environmentally friendly, and cost-effective, offering a sustainable solution to energy redistribution challenges in renewable energy systems. This approach not only improves system efficiency but also contributes to the global shift toward greener energy technologies.

**INTRODUCTION**

The efficient use of renewable energy sources requires reliable energy storage and redistribution systems. Due to the intermittent nature of renewables like solar and wind, energy storage is essential for maintaining a stable power supply. Among various storage methods, hydro-accumulation systems stand out for their cost-effectiveness, reliability, and scalability. This study explores a new hydro-accumulation system designed to reduce energy consumption and improve efficiency. Unlike traditional pumped-storage systems that rely on high-power pumps, the proposed design integrates hydraulic ram technology, which uses water flow energy to lift water without external electricity. This approach significantly cuts operational costs while enhancing system sustainability [1, 2, 3, 4].

**EXPERIMENTAL RESEARCH**

For the widespread use of renewable energy sources, it is necessary to solve the issue of efficient redistribution of the energy received from them over time. It is known that the inflow of renewable energy sources is highly uneven and depends on many factors. At the same time, the consumption process or load schedule is also uneven, depending on the rhythm of human life, the nature of energy consumption, etc. To coordinate these processes, it is possible to use the following operating modes of the renewable energy plant [5, 6]:

1) operation in the power system in parallel with the network in the maximum production mode;

2) underutilization of renewable energy sources by dissipating excess energy;

3) adjusting the consumption process to align with the production process;

4) combined use of several renewable energy sources;

5) ensuring the required consumption regime;

6) accumulation of excess energy during periods of maximum renewable energy inflow and return during periods of minimum, heat accumulation.

However, it should be acknowledged that even the comprehensive use of renewable energy does not eliminate the need to accumulate a relatively small portion of energy. Therefore, the problem of energy storage is one of the key issues in the use of renewable energy. In this context, we often face the need to store mechanical, thermal, and electrical energy, and for this purpose, the following types of storage systems are used [7, 8]:

- hydraulic;

- pneumatic;

- inertial, capacitive (thermal);

- phase transition;

- capacitive (electric);

- electromagnetic;

- electrochemical;

- hydrogen.

The power range most commonly used for these systems, as well as specific indicators, are presented in the table1.

Hydraulic energy accumulation is the process of converting one type of energy into the potential energy of a liquid mass, which can be converted into the necessary type of energy at the required time intervals. Based on this definition, in principle, with the help of known technical means, it is possible to ensure the hydraulic accumulation of thermal, mechanical, electrical, and radiant energy [9].

**TABLE 1.** Specific cost of various types of storage systems.

|  |  |  |
| --- | --- | --- |
| **Type of Automatic Control** | **Power range MW** | **Specific cost,  Dollar \ kW** |
| Hydraulic | 05,-3500 | 400-1000 |
| Pneumatic | 5,0-150,0 | 500-1200 |
| Inertial | 0,5-60,0 | 400-700 |
| Capacitive | 0,01-0,2 | 400-1500 |
| Electromagnetic | 10,0-500 | 3000-100 |
| Electrochemical | 0,001-0,01 | 170-250 |
| Hydrogen | 0,001-0,1 | 450-1500 |

The unevenness of electricity consumption schedules requires the application of a more flexible energy production and distribution management system.

Achieving efficiency in the redistribution of generated energy over time is possible only through the application of accumulating systems that allow for the accumulation of excess energy during periods of minimal energy consumption and the transfer of it during peak load periods.

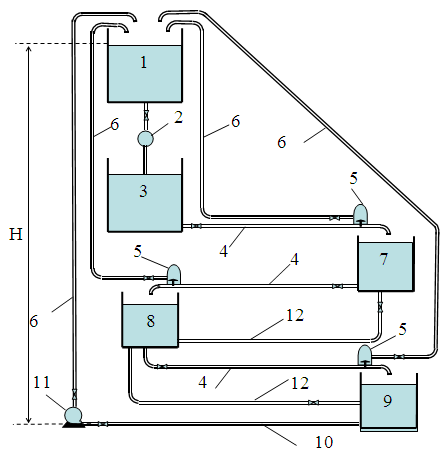
Currently, widely used methods of accumulating energy provide for the preservation of the final product, that is electrical or other energy. However, accumulating the primary energy resource is more economical, as in this case, energy is not lost on transfers and transformations. Such batteries can be tanks, tanks, pools, reservoirs, and reservoirs, and the method of energy accumulation itself is called hydraulic.

The method of hydraulic energy storage stands out due to several advantages, including the simplicity of construction and operation of the devices (structures), the capacity to accumulate large volumes of energy, relatively acceptable costs, and other benefits.

The operational indicators of Hydro-accumulating installations primarily depend on the cost of supplying the used water from the lower reservoir to the upper one. Usually, pump units are used for this purpose, in which the suction line is connected to the lower reservoir (tank), and the discharge line is connected to the upper reservoir (tank). At the same time, the pump units consume no more than 18-38% of the turbines' output. Hydro-accumulating installations of energy [10, 11]. From this, it is clear that reducing the costs of supplying water to the upper basin undoubtedly increases the efficiency of the hydro-accumulating installations.

For this purpose, in our opinion, using hydraulic ram to supply water to the upper body of water is undoubtedly a profitable method. A hydraulic ram is a water lifting device that uses the force of the hydraulic impact of the water flow moving in the pipe to lift it to a height. The ram can operate automatically without inspection and for a long time using the power of water energy. The operating principle and some designs of hydraulic rams are presented in the work [12, 13, 14, 15].

One of the main disadvantages of a hydraulic ram is that more than half of the supplied water flows out of the impact valve opening into the atmosphere. Even in the most successful designs, only about 40% of the water taken from the water source enters the upper tank. This is because the velocity of water flowing from the pipe into the atmosphere must increase to such a value that the accompanying hydrodynamic pressure, acting upwards on the impact valve, exceeds the valve’s weight, causing it to close abruptly. Until this moment, water continues to flow through the impact valve opening into the atmosphere.



**FIGURE 1.** Diagram of the hydro-accumulating installations complex with hydraulic ram. 1-upper tank; 2-turbine; 3-lower tank; 4-water pipe; 5-hydraulic rams; 6-pressure pipes; 7-supply tank second ram; 8-feeding tank third ram; 9-pump feed tank; 10-suction pipe; 11-pump; 12-emergency pipes.

To increase the efficiency of the hydraulic ram operating as part of hydraulic accumulation units, in our opinion, it is advisable to use the following system. The water jet discharged through the impulse valve should be directed to a special tank, which serves as a source for the next hydraulic ram, pumping the subsequent volume of water into the upper tank. Similarly, the water flowing out of this ram can be used for the next stage of the rams joint operation. Given that the water pressure in the lower (feed) tank can be 0.8-1.0 m and higher, and the ram can increase this pressure tenfold, the system can include several rams operating in a cascade order. The scheme of such a complex, consisting of three hydraulic rams in operation, is shown in (Figure 1) [16, 17, 18].

The proposed system operates as follows. The water flow from the upper tank 1 passes through the turbine 2, generating electrical energy, and enters the lower tank 3. From there, it is fed to the hydraulic ram 5 via the water supply pipe 4. The hydraulic ram ensures the pumping of water from tank 3 into the upper tank 1 through the pressure pipe 6 (The volume of water pumped into the upper tank is assumed to be approximately 40% of the total flow).

About 60% of the water flowing from ram 5 accumulates in tank 7, which is then fed into the next hydraulic ram, ensuring the pumping of subsequent portions of water into the upper tank 1 in a volume of 40% from tank 7.

Thus, when both hydraulic rams operate with a 40% water supply in tank 8, 36% of the water volume from tank 3 remains, which can be supplied to the next stage of the complex with the third hydraulic ram. In this case, it is again possible to gain 40% of the water volume supplied to the upper tank 1, and the remaining portion of the third ram water in tank 9 is pumped by pump units 11 to the upper tank 1. In case of temporary malfunction and repair of the rams, emergency pipes 12 are activated.

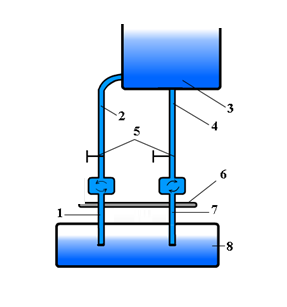
From the above, it follows that when using three hydraulic rams, approximately 78% of the water volume from the lower tank 3 is delivered to the upper tank 1 without the use of electrical energy.

In the same manner, the number of hydraulic rams can be increased, for example, to four. In this case, the volume of machine-free water supply using hydraulic rams amounts to 87%. However, as the number of rams increases, the total head pressure also rises, which leads to a decrease in the reliability of the complex, an increase in the construction costs of the structure, and higher electricity consumption by the pumping unit 11.

**RESEARCH RESULTS**

His proposed scheme allows for saving electricity consumption compared to the traditional hydro-accumulating installations scheme (Figure 2) for accumulating water in the upper tank, and is also economically efficient [19, 20, 21].

Table 2 shows comparisons of economic indicators at the same power of the traditional hydro-accumulating installations scheme with the proposed scheme at different numbers of hydraulic rams.

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**FIGURE 2.** Traditional scheme of hydro-accumulating installations. 1-suction pipe of pump unit; 2-pressure pipeline of pump unit; 3-pressure tank; 4-pressure pipeline of turbine-pump unit; 5-gate valve; 6-support frame for aggregates; 7-suction pipe of turbine-pump unit; 8-water intake tank.

**TABLE 2.** Comparisons of economic indicators at the same capacity of the traditional scheme of hydro-accumulating installations with the proposed scheme at different numbers of hydraulic tanks

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Parameters** | **Unit of measurement** | **As usual** | **According to the proposed scheme** | | |
| **first hydraulic ram** | **second hydraulic ram** | **third hydraulic ram** |
| Capasity in turbine mode | kW | 100 | 100 | 100 | 100 |
| Pressure in turbine mode | m | 5 | 5 | 5 | 5 |
| Water consumption in turbine mode | m3/sek | 2,4 | 2,4 | 2,4 | 2,4 |
| Pressure in pump mode | m | 5,5 | 8 | 11 | 15 |
| Water consumption in pump mode | m3/sek | 1,7 | 1,7 | 1,4 | 1,2 |
| Volume of the upper tank | m3 | 34 560 | 34 560 | 34560 | 34560 |
| Volume of the lower tank | m3 | 34 560 | 20750 | 12450 | 7500 |
| Daily working hours in turbine mode | hour | 4 | 4 | 4 | 4 |
| Daily working hours in pump mode | hour | 6 | 3,4 | 2,46 | 1,72 |
| Capacity in pump mode | kW | 115 | 167 | 189 | 220 |
| Annual electricity generation | kWh | 146 000 | 146 000 | 146 000 | 146 000 |
| Annual Consumed Electricity | kWh | 251 850 | 207 250 | 169 700 | 138 120 |
| Saved electricity | kWh | - | 44 600 | 82 150 | 113 730 |
| Annual income \* | dollar USA | - | 1 561 | 2 875 | 3 980 |

(\* price of 1 kWh of electricity - $ 0,035 USA)

**CONCLUSIONS**

As can be seen from Table 1, the proposed scheme of the hydraulic accumulation units, regardless of the number of hydraulic tanks used, is much more efficient than the traditional type of hydraulic accumulation power plant

Thus, when using the proposed design of hydroelectric pumped storage installations for accumulating water in the upper reservoir, compared to the traditional scheme, a hydroelectric pumped storage power plant over the course of a year:

- with first hydraulic ram, it is possible to save 44,600 kWh of electricity and generate a profit of $1,561 USA;

- with second hydraulic ram, you can save 82,150 kWh of electricity and generate a profit of $2,875 USA;

- with third hydraulic ram, it is possible to save 113,730 kWh of electricity and generate a profit of $3,980 USA.

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