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HYDROELECTRIC POWER PLANTS UTILIZING RESERVOIS AND THEIR PRINCIPLES OF OPERATION

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Abstract. *This article analyzes opinions on the similarities and differences in the operating principles of hydroelectric power plants that repeatedly harness water energy, one of the key sources of renewable energy.*

Key words: *Harmful gases, power plants, upper and lower reservoirs, HPP, PSS, TPS.*

ГИДРОЭЛЕКТРОСТАНЦИИ, ИСПОЛЬЗУЮЩИЕ ВОДОХРАНИЛИЩА, И ПРИНЦИПЫ ИХ РАБОТЫ

Аннотация. *В статье анализируются мнения о сходствах и различиях в принципах работы гидроэлектростанций, многократно использующих энергию воды — один из основных источников возобновляемой энергии.*

Ключевые слова: *Вредные газы, электростанции, верхние и нижние резервуары, ГЭС, ГАЭС, ПЭС.*

It is known that electricity has become an integral part of our lives, and the demand for it is increasing year by year. Therefore, several types of power plants are used to meet the increasing demand for electricity. However, due to the harmful gases and emissions from these plants, the environment is significantly damaged. Therefore, humanity must consider building power plants that use renewable energy sources, i.e., power plants that do not rely on fuel and do not have a harmful effect on the environment. For example, let's talk about the globally significant hydropower network. Currently, there are several methods of harnessing energy from the movement of water, and all of them fall under the category of hydropower. In fact, hydropower can be divided into two types: traditional hydropower and marine hydropower. Even these two categories are further divided into subtypes. So, let's compare two hydropower stations within these two systems, i.e., PSS (Pumped Storage Power Station) and TPS (Tidal Power Station).

According to their operational principles, these two power plants are almost the same, but PSSs are built on rivers and their tributaries, while TPSs are built on the shores of seas and oceans.

PSS and HPP (Hydropower Plant) and PS (Pumping Station) are hydropower facilities with upper and lower basins. When operating in HPP mode, the accumulated water in the upper basin is transferred to the turbine in the lower basin through pressure pipes. As a result, the turbine is driven by the potential and kinetic energy of the water flow, and this rotational movement is transmitted to the generator via the shaft, which converts this mechanical energy into electricity.

When operating in PS mode, the reverse process occurs: water from the lower basin is pumped to the upper basin using pump units and pressure pipes. However, a question may arise at this point: Why should we do this?

Because the task of PSS is not only to produce electricity but also to help regulate the power in the grid, and because the installed capacity of TPS (Thermal Power Stations) producing the main electricity is quite different from the minimum power required at night, it is necessary to reduce the power of TPS by 25-50% at night. This often involves stopping some units completely.

Frequent stopping and starting, as well as changing the power of these units, can lead to equipment failure and premature wear. For example, changing the power of TPS by 20% can reduce the service life of this equipment by 15-20%. Therefore, using PSS as a consumer at night when energy consumption is low and as a producer during peak energy consumption hours during the day is very effective in adjusting the daily energy distribution. PSS units are distinguished by being cheaper, more efficient, and more promising compared to other devices performing this task, such as gas turbines or steam-gas turbines. In some cases, PSS can participate not only in daily energy distribution but also in weekly energy accumulation. In this scenario, on weekends (days with low energy consumption), water energy is collected in the upper basin, and during the remaining five days, it is used to generate electricity. The power produced by the PSS is calculated as:

$$P\ [\mathrm{kW}] = \rho \bullet g \bullet F \bullet H/\eta \quad \text{or} \quad P\ [\mathrm{kW}] = 9.81 \bullet F \bullet H/\eta$$

Here:

P – power produced by PSS;

ρ – density of water, approximately equal to 1000 kg/m^3;

g – acceleration due to gravity, equal to 9.81 m/c^2;

F - water flow rate, or the volume of water flowing per unit of time;

H – head, or the difference in height between the two water levels;

η – efficiency coefficient of the PSS.

Also, to find the amount of electricity produced, we multiply the given power by the time spent on production:

$$E\ [\mathrm{kWh}] = P \bullet t$$

It is known that various galvanic elements, such as batteries and accumulators, are used to store a portion of the electrical energy produced by ESs, but this process is not straightforward and involves several complex reactions. Electrical energy is converted into chemical energy, and when needed, it is converted back into electrical energy. However, the storage capacity of these elements decreases over time, leading to a loss in efficiency.

In fact, PSSs act as large batteries that store electrical energy and can generate it without the need for complex chemical reactions. Instead, they rely on the kinetic and potential energies of water. The water lost through evaporation and filtration in the upper and lower basins is replenished by an additional water source. Based on this principle, PSSs are classified into three types:

1. Pure PSS: This system consists of two basins, as previously described. Water from the lower basin is pumped to the upper basin using pumping units, and the water flows back to the lower basin by turning the turbines. A unique feature of this scheme is that no additional water source is supplied to the upper basin; instead, any water lost through evaporation and filtration is replenished from the lower basin.
2. HPP-PSS Scheme: In addition to the usual components of a PSS, this system includes additional power-generating turbines that operate in HPP mode. These turbines work due to the additional inflow of water into the upper basin.
3. HPP-PS Scheme: This setup involves the construction of an additional basin, higher than the upper basin. Using a PS, a certain amount of water from the upper basin is transferred to the

additional, higher basin. This creates increased pressure, which enhances the performance of the HPP turbines located in the lower basin.

PSSs are also categorized into three types based on their hydraulic booster equipment:

1. Four-Machine PSS Scheme: This system consists of two separate units: a pump-engine unit and a turbine-generator unit, each specifically designed for its respective function. In this setup, one unit does not perform the tasks of the other.
2. Three-Machine PSS Scheme: In this design, a single electric machine replaces both the engine and generator. The pump and turbine are connected to this electric machine, which functions as an engine in pump mode and as a generator in turbine mode.
3. Two-Machine PSS Scheme: This system is composed of one electric machine and one hydraulic machine, where the hydraulic machine performs both the functions of a pump and a turbine.

Examples of large PSSs around the world include: Fengning PSS (3,600 MW, China), Bath County PSS (3,003 MW, USA), Huizhou PSS (2,448 MW, China), Guangzhou PSS (2,400 MW, China), Pudong PSS (2,400 MW, China), Tianhuangping PSS (1,836 MW, China), Okutataragi PSS (1,932 MW, Japan), Castaic PSS (1,495 MW, USA), La Muela II PSS (1,800 MW, Spain), Linth-Limmern PSS (1,480 MW, Switzerland), Raccoon Mountain PSP (1,652 MW, USA), Yangyang PSS (1,000 MW, South Korea).

Just as the Earth has its own gravity, the Moon and the Sun also have gravitational effects on Earth. However, since the Moon is closer to our planet than the Sun, its influence is more significant. As a result of these gravitational forces, large masses of water in Earth's oceans and seas are moved, causing the sea level to rise and fall twice each day. This complete cycle typically takes 12 hours and 25 minutes, with a 6-hour and 12-minute difference between each high and low tide. Power generating stations that harness this rise and fall are known as Tidal Power Plants (TPP or TPS). TPPs generate electricity using the head difference created between two water basins due to the changing sea levels, and their operating principle is similar to that of HPP and PSS. These tidal power facilities are usually separated from the sea by a dam or an artificial barrier. When the sea level rises, special gates are opened, allowing seawater to flow through the turbines. This water is collected in a reservoir behind the dam, and after several hours, when the sea level falls, the gates are opened again, allowing the water to flow back into the sea, generating electricity a second time. TPPs are typically categorized into two types:

1. Tidal Barrage: located where rivers and lakes flow into the sea.
2. Tidal Lagoon: built along the seashore.

A favorable location for the construction of TPPs is in estuaries of rivers flowing into the sea and the areas near them. In this type of TPP, one side is connected to the sea, and the other side is linked to the river or lake flowing into the same sea. The flow from the river or lake is stored in the estuary for a certain period of time, and when the sea level drops, the stored water is released into the sea through turbines, generating electricity. One of the advantages of this type of hydropower facility is its role in flood prevention. If the water level in the estuary exceeds safe limits, the excess water is discharged into the sea (to a part where the water level has not risen) or to additional reservoirs through special tunnels with one-way valves. These check valves prevent seawater from flowing back into the estuary if the sea level is higher than the river's water level.

When natural drainage into the sea is not possible, one-way valves, pumping stations, or reserve basins are used to manage the flow.

The 240 MW La Rance TPS, built in 1966 in the estuary of the La Rance River in France, is the world's first and most well-known tidal barrage power plant. Another notable example is Canada's Annapolis Royal Generating Station, with a capacity of 20 MW. Currently, the world's largest tidal barrage power plant is South Korea's Sihwa Lake TPS, with a capacity of 254 MW.

South Korea also has plans for larger tidal power stations, such as Incheon TPS (1,320 MW) and Garorim Bay TPS (520 MW). Upon completion, South Korea will become the country with the largest TPPs in the world. There have also been proposals to build the Penzhin Tidal Power Plant in Penzhin Bay, the upper right arm of Shelikhov Bay in the northeastern corner of the Sea of Okhotsk, which has some of the world's strongest tidal currents. One of the proposed options has an installed capacity of 87,000 MW and an annual production of 200 TWh.

Tidal lagoon TPSs located along the seashore are separated from the sea by an artificial dam, with a basin of a specific size constructed behind the dam. These hydropower facilities operate based on hydraulic principles. When the Moon and Sun are closer to the Earth than usual, their gravitational pull causes the sea level to rise by several meters. However, the water level in the basin behind the dam remains significantly lower than the sea level. As the sea level rises, the gates of the upper basin are opened, and water is directed through turbines into the lower basin, generating electricity. Later in the day, when the sea level falls, the gates of the initially filled basin are opened, allowing the water to flow in the opposite direction, producing electricity again. This process allows the generation of electricity twice a day, harnessing the natural rise and fall of the tides.

Although tidal lagoon power plants are not yet widely used around the world, projects such as the Swansea Bay Tidal Lagoon (320 MW), Cardiff Tidal Lagoon (1,800 MW), and Colwyn Bay Tidal Lagoon (2,500 MW) planned in the UK may soon become some of the largest tidal power stations globally.

In conclusion, humanity should not rely solely on fossil fuels for electricity production. Instead, it is essential to create new methods of generating energy by making efficient use of renewable sources. The development and practical implementation of these technologies will benefit all societies. Countries with hydropower resources, in particular, should seize these opportunities and collaborate in sharing new techniques and modern technologies.

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