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Considerations regarding the future of pumped-storage hydroelectric power plants in Romania

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Abstract. Wind turbines and solar photovoltaic (PV) collectors dominate new electricity capacity additions. Wind and solar PV are variable generators requiring storage to support large fractions of total generation. Pumped hydro energy storage is the largest, lowest cost, and most technically mature electrical storage technology. Closed-loop pumped hydro storage located away from rivers ("off-river") overcomes the problem of finding suitable sites. An analysis at the at the global level has identify 616,000 active systems. This immense pumped hydro resource demonstrates that low-cost energy storage is not a constraint to wind and PV deployment for most of the world. In Romania, in the last decade the eolian and solar have registered a significant development jeopardizing the stability of the power system. Despite an imperious need for energy storage during the excess production in the wind and solar sources the pumped storage is in incipient stage. The paper presents a review of the present stage of the pumped storage hydropower in Romania.

Keywords: Hydropower, pumped storage, efficiency.

1. History and current status at the global level

Pumped hydroelectric energy storage was originally developed to manage the difference between the daily cycle of electricity demand and the base load requirements of coal and nuclear generators. The energy was used to pump water when electricity demand was low at night, and the water was then released to generate electricity during peak consumption periods during the day. The first use of pumped storage dates to the 1890s in Switzerland and Italy [1]. In the 1930s, reversible units became available – operating both as a turbine with generation and as a pump with the generator becoming a motor. The most advanced are turbo – pumps with variable speed to increase efficiency. As a generator it operates synchronously with the system frequency but pumps asynchronously, the speed

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change being given by the change in frequency. A turning point is the unprecedented development of climate- and diurnal-dependent renewable energy sources, which changes the original role of pumped-storage hydroelectric plants from a compensator between base and peak power to a reservoir of energy produced more than system demand [2]. Figure 1 shows the 2030 outlook for energy resources. At the 2024 meeting in Dubai, world governments committed to "tripling" global renewable energy generation capacity from 3.8 TW in 2022 to 11.2 TW in 2030. Much of this growth will come from the rapidly growing wind and solar fleet, the latter of which needs to increase fivefold from over 1 TW to almost 5.5 TW in eight years if the target is to be met.

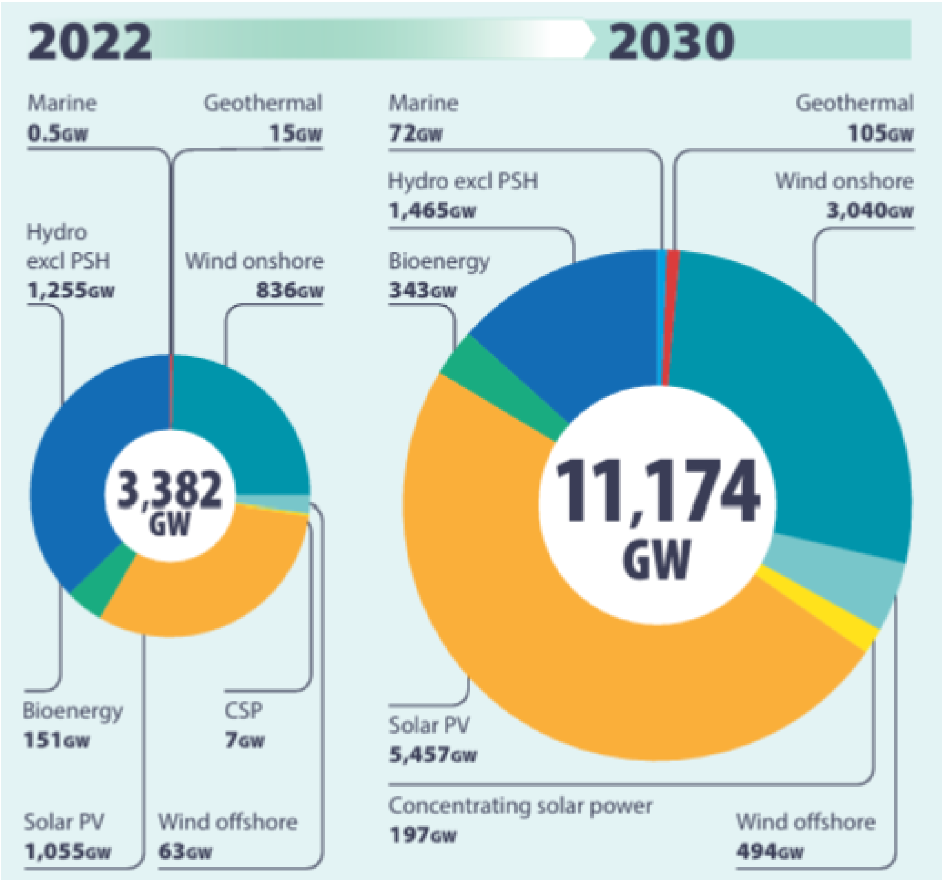

Fig. 1. Rapid growth of wind and solar energy.

Wind and solar energy with high variability in energy input threaten the stability of the energy system. Pumped-storage hydroelectric power plants store energy from intermittent sources (such as solar, wind) and other renewable energy sources that constitute a surplus especially during off-peak periods. The energy is stored in the form of gravitational potential energy of water, pumped from a reservoir located at a lower elevation to a higher elevation. The surplus electricity at low cost during off-peak periods is usually used to operate the pumps. During periods of high power demand in the system, the stored water is released through turbines to produce electricity.

Pumped-storage hydroelectric power plants are currently the largest source of electricity storage, with over 95% of the world's electricity storage capacity (GW) and 99% of the stored energy (GWh) [3].

Despite this, many studies that consider the rapid development of renewable energy sources in future electricity systems ignore pumped hydroelectric storage. Others assume that there is no growth in pumped hydroelectric storage or limit the growth of pumped hydroelectric to the scale of conventional hydroelectric resources. The advantages of pumped storage are ignored. In these arrangements, water consumption is only needed to replace the difference between evaporation and infiltration and precipitation. Reservoirs (upper basins) are usually small, on the order of tens to hundreds of hectares. Their location away from rivers and their small surface area considerably reduces the impact on the environment. In addition to balancing the system affected by the inherent variability of wind and photovoltaic energy, pumped hydroelectric storage (PSH) plants provide auxiliary services, such as: frequency control, primary energy and voltage to the electrical grid. To achieve energy system control, PSH can switch to different operating modes in a few seconds [3], [4].

Globally, there are over 170 GW of pumped storage capacity. Europe is the second largest region with 57 GW, representing around 33% of the market. Opportunities are mainly concentrated in the mountainous regions of Switzerland, Austria, Germany, Spain and Portugal. With a common target of 20% renewable energy use by 2020, and 40% by 2030, many EU Member States have introduced extensive economic support programmed for renewable energy generation, such as feed-in tariffs. In the International Energy Agency's lowest-case scenario, PSH capacity is expected to reach 91 GW in 2050, while the highest estimate proposes a capacity of 188 GW [4]. This means an average growth of 1.2 to 3.6 GW/year. Taking an average value of €1,000/kW, this corresponds to a market of €1.2 to €3.6 billion/year on average. Europe currently has 913 energy storage facilities in operation, with a combined capacity of 67 GW. The predominant technology is pumped storage (54.6 GW) [5].

2. Efficiency of the pumping-turbine cycles

2.1. Technical efficiency

The efficiency of the pumping-turbine cycle is given by the ratio between the energy ET produced by turbines using a volume of water V from the upper basin and the energy EP consumed for pumping the same volume of water across the level difference between the lower basin and the upper basin:

$$\eta_C = \frac{E_T}{E_P}.$$

The energy produced by turbines is:

$$E_T = \frac{1}{3600} \cdot 9{,}81V(H_{br} - \Delta h_T)\eta_t \cdot \eta_g \text{ [kWh]},$$

where the units of measurement are in SI and the notations are:

H_{br} – geodetic level difference between the water level in the upper and lower basins;

Δh_T – pressure loss when water passes through the hydraulic circuit during turbine operation;

η_t – turbine efficiency.

η_g –electrical machine efficiency when working as a generator.

The energy consumed for pumping is given by the relationship:

$$E_P = \frac{1}{3600} \cdot \frac{9{,}81V(H_{br} - \Delta h_P)}{\eta_t \cdot \eta_m}\eta_t \cdot \eta_g \text{ [kWh]},$$

where the following additional notations are used:

Δh_P – pressure loss when water passes through the hydraulic circuit at the pump;

η_g – the efficiency of the electric machine when working as a pump motor.

If the hydraulic efficiencies are introduced:

For turbines:

$$\eta_{H,t} = \frac{H_{br} - \Delta h_T}{H_{br}};$$

For pumping:

$$\eta_{H,p} = \frac{H_{br}}{H_{br} + \Delta h_P};$$

where $\eta_{H,p}$ is the total efficiency for turbine and $\eta_{P,t}$ is the total efficiency for pumping. The efficiency of total cycle is:

$$\eta_c = \frac{E_T}{E_P} = \eta_{H,t} \cdot \eta_{H,p}.$$

2.2. Energy efficiency

The efficiency of the pumping-turbine cycle refers only to the quantitative aspects of the production and consumption of electricity, without taking into account the quality of the electricity involved. Typically, pumped storage plants produce peak energy at the turbine and consume energy generated by climate-dependent sources for pumping water. In order to highlight the energy efficiency of the arrangement, the two energies must be brought to equivalence. The basic equivalent of the energy produced at the turbine is calculated according to the prices of the delivered energy p_v and the consumed energy pb, which is the market price of energy at the excess of production over consumption:

$$E_{T,eb} = p_v / p_B \, E_T.$$

In the above relationship it was considered that all the energy produced is peak energy. Energy efficiency results as the ratio between equivalent energies:

$$\eta'_c = \frac{E_{T,eb}}{E_P} = \frac{p_v}{p_B}\eta_{T,t} \cdot \eta_{P,t},$$

whereη'_c is the efficiency of the pumping-turbine cycle. This time we can no longer speak of an efficiency, which is sub-unitary, but of efficiency. Thus, at a technical efficiency of $\eta_c = 0.78$ and a price ratio $\frac{p_v}{p_B} = 3$, the energy efficiency is $\eta_c' = 2.34$. Of course, this simple assessment only justifies the opportunity to include pumped storage plants in the system. Real energy efficiency must also include the decrease in energy loss during transportation in the case of turbines and, respectively, the increase in energy loss during transportation in the case of pumping. Corrections also occur from the inclusion in the analysis of the financial recognition of the system services that the plant provides.

3. The stage In Romania

The first and only one pumped storage hydropower development in Romania comprises a cascade of hydropower plants on the Olt River at Ipotești, Drăgănești, Frunzaru, Rusănești and Izbiceni (Fig. 2). The development was achieved by re-furbishment the cascade of hydropower plants on the Lower Olt, which can currently operate in a dual, reversible, turbine-pump mode. They provide an available power of 285 MW in turbine mode and 200 MW in pumping mode. The installed flow rate is 240 m3/s. The cascade could provide energy storage and necessary system services in the event that the energy produced in photovoltaic systems and wind power plants cannot be consumed in the SEN.

Unfortunately, the development does not have a lower basin that would allow operation in a pumped storage mode. To connect the Ipotești - Izbiceni sector to the Danube, the initial project was based on the reservoir created by Turnu Măgurele - Nicopole development on Danube. jointly with Bulgaria. This Danube reservoir is no longer viable now due to the impossibility of reaching an agreement with the Bulgarian side. As a backup option, the possibility of building a new stage, the Islaz hydroelectric power plant, with a power of 30 MW, equipped with reversible bulb turbines, a dam and a lock identical to the 5 in the Ipotești - Izbiceni sector, was considered. The promotion of this investment is constantly being postponed (for financial and environmental reasons), which makes the investment in reversible, with pumped storage compromised.

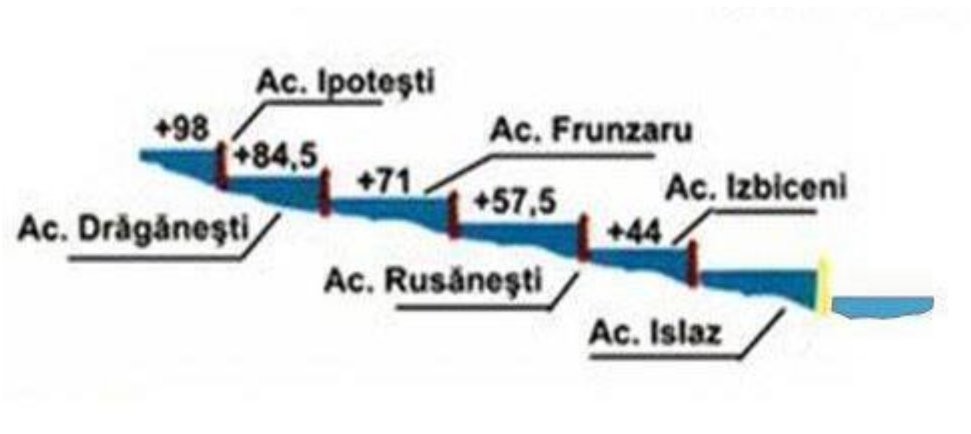

Fig. 2. The Cascade on Olt river equipped with turbo – pumps.

The promotion of this investment is constantly being postponed (for financial and environmental reasons), which makes the investment in reversible, with pumped storage compromised.

The five hydropower plants on the Lower Olt are identical from a construction point of view, each equipped with four 13.25 MW reversible Bulb hydropower units. For illustration, figure 3 shows the power plant at CHE Frunzaru.

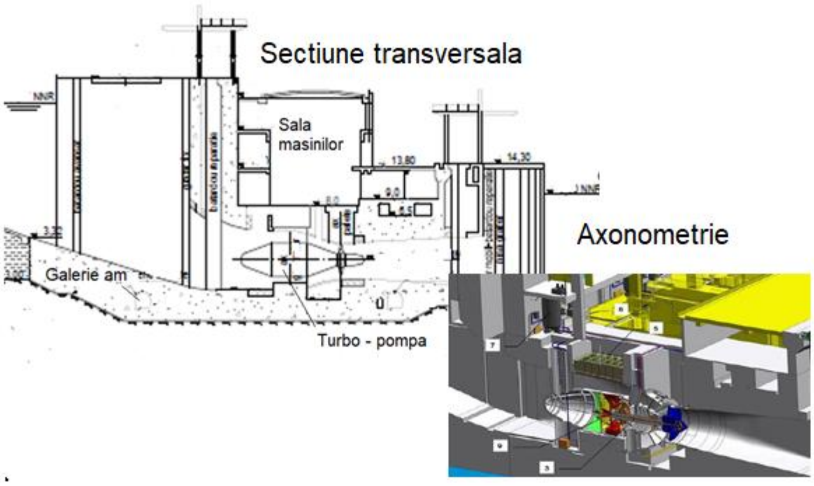

Fig.3. The hydroplant on Olt river equipped with reversible bulb turbines.

4. PSH intended projects in Romania

The oldest project for a pumped storage hydroelectric power plant in Romania dates back 50 years. The construction of the Tarniţa-Lăpuşteşti pumped storage hydroelectric power plant is being rolled over from one government to another.

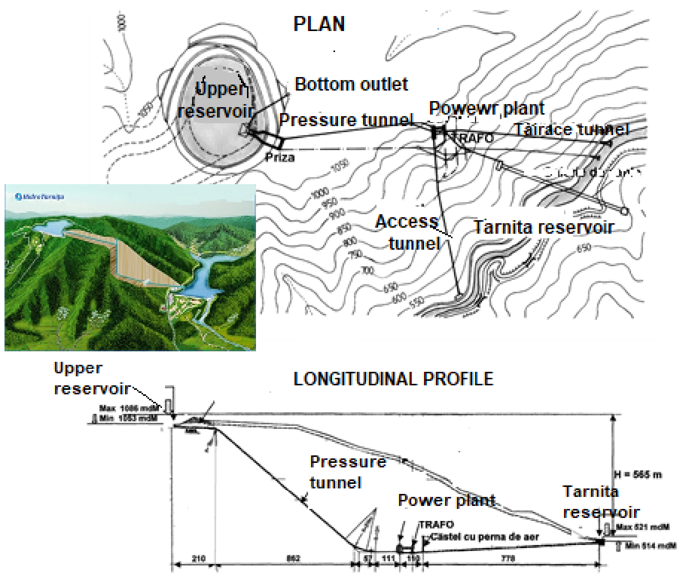

Fig. 4. Tarnița – Lăpuștești PSH.

The development scheme consists of an upper reservoir – Lăpuștești reservoir – the diversion, the underground power plant and the lower reservoir – Tarnița reservoir [7]. The useful volume for pumping is about 10 million m^3 compared to the 74 million m^3 of the lower reservoir. The power plant has the following parameters: QP = 152 m^3/s (4x38), QT = 212 m^3/s (4x53); reversible groups - P/T machines of 250 MW. The upper reservoir (Polder type with V = 10 million.m^3) is built on the Lăpuștești plateau at an altitude of 1070 m above sea level, with dams up to 35 m high and a length of about 2600 m. The intake gallery has a diameter of 6 m and a length of L=1,096 m, and serves the 4 groups. The underground power plant consists of 2 caverns, the power plant cavern and the transformer cavern and several galleries, connecting the 2 caverns.

According to SAPE, the construction and operation of the power plant improve the operating regime of the Cernavoda nuclear power plant, especially in view of the construction of units 3 and 4, but also of the closure of fossil fuel-fired thermoelectric power plants, by transferring electrical energy from empty to peak load.

The Frasin - Pângărați pumped storage power plant has the Izvorul Muntelui reservoir as its lower basin. The site is located on the left bank of the lake, about 2 km upstream of the Bicaz - Izvorul Muntelui dam (figure 5) [8]. It is a classic medium-sized pumped storage power plant, with an installed capacity of about 300 MW.

PSH characteristics are:

Head: turbine 535 m, pumping 550 m;

Installed flow: turbine 70 m3/s, pumping 50 m3/s;

Operating time: turbine 12 hours, pumping 16. 5 hours.

Installed power: turbine 307 MW, pumping 276 MW

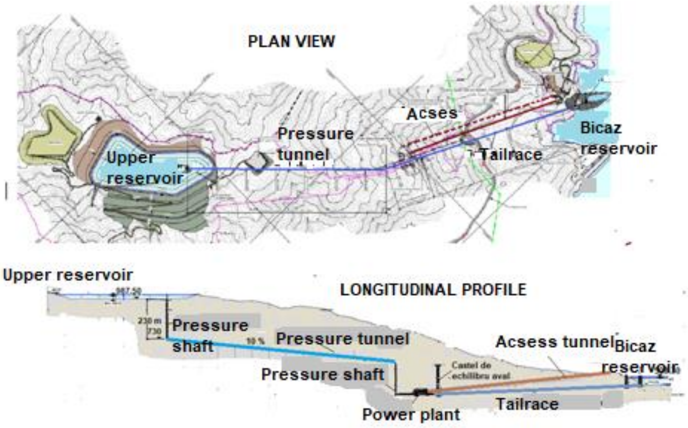

Fig. 5.
Frasin – Pângărați
PSH.

5. Concluding remark

Pumped-storage hydropower is a form of clean energy storage that is ideal for power system reliability and stability. It absorbs excess energy during periods of low demand and releases it when demand is high. Pumped-storage hydropower plants complement wind and solar power by storing the excess electricity they create and providing electricity when the wind is not blowing and the sun is not shining.

Pumped-storage hydropower is the most developed energy storage technology in the world, with a global installed capacity of nearly 200 GW, representing over 94% of the world's long-term energy storage capacity, far ahead of lithium-ion batteries and other types of batteries. The World Hydropower Outlook 2025 report highlighted that 600 GW of pumped storage hydropower projects are currently in various stages of development. The water in a pumped hydropower system can be reused multiple times, making it a rechargeable water battery.

In Romania, several sites fitted for the construction of pumped storage hydroelectric power plants were studied starting in the 1970s. At that time, the need to cover peak load, the continuous increase in energy demand and the entry into operation of units 1-5 at the Cernavoda NPP, which did not have optimal consumption coverage for the entire 24-hour operating period, were considered.

The development of pumped storage hydroelectric power plants is imperative in the context of the existence of a continuously growing portfolio with uncontrollable production, which requires the installation of additional balancing capacities, which will be remunerated on the technological system services markets, capacity markets, but also on the balancing market. These developments will be a strategic provider of energy services/system services.

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