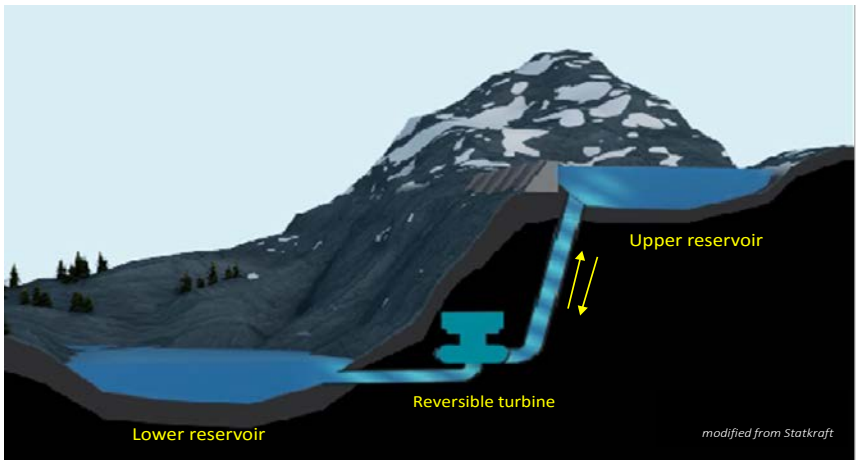
Pumped Hydro Energy Storage

Principle



Pumped Hydro Energy Storage (PHES) plants are a particular type of hydropower plants which allow not only to produce electric energy but also to store it in an upper reservoir in the form of gravitational potential energy of the water. During periods with high demand, the water, is released through the turbines to a lower reservoir in order to produce electricity. During periods with low demand, the water is pumped back from the lower reservoir and stored in the upper reservoir.

Figure 1. Principle of a pumped-storage plant

Characteristics

PHES is considered one of the most cost-efficient large-scale storage technology currently available, with a round-trip efficiency of 75-85% and competitive costs (800-1500 €/kW 2016€). The reservoirs are generally located above ground and are filled with fresh water, but some unconventional applications adopt the sea as lower reservoir (seawater pumped hydro energy storage) or underground caverns as lower, and less often, upper reservoirs (underground pumped hydro energy storage).

The typical power of PHES plants ranges approximately from 20 to 500 MW with heads ranging approximately from 50 to 1000 m. PHES plants can be equipped with binary (pump-turbine coupled to an electrical machine) or ternary units (a turbine and a pump coupled to an electrical machine). Binary units are more often used because of their compactness and cost-effectiveness, but they are slower and less flexible than ternary units due to a reduced stable operating range.

To increase the flexibility and response time, binary pump-turbines have in recent years also been operated with variable-speed motor-generator (variable-speed pump-turbines), which allows to operate over a wider range of operating conditions. While increasing the cost for both new and retrofitted power plants [1,2] the variable-speed technology has allowed to reach an operating range comparable to ternary set (from 25% to full capacity) in generating mode, whereas in pumping mode the ternary type still remains more flexible with an operating range of the variable-speed technology from 70% to full pumping capacity.

PHES plants can ramp up from 50% to full production capacity in about 15 seconds, from standstill to full production capacity within less than two minutes and from standstill to full pumping capacity within less than five minutes depending on the plant configuration [3]. PHES plants can provide both primary and secondary load-frequency control, black start capability and voltage support.

Main function

- Contingency reserve
- Regulation reserve
- Load following
- Load shifting
- Black start
- Voltgge support

General performance

- Typical Power: 200 to 350 MW
- Head range: 100 -1500m
- Cycle efficiency: 75-85%
- Energy capacity: 10 GWh
- Discharge time: > 8 hrs
- Response time: seconds to minutes
- Technical lifetime: 40-80 y

Maturity Level:

- Installed capacity worldwide: 130 GW
- Installation costs: 800 to 1500€/kW
- Operations costs (% invests): 2 %
- TRL 9

Maturity Level

Pumped hydro energy storage is undoubtedly the most mature large-scale energy storage technology. In Europe, at the time being, this technology represents 99% of the on-grid electricity

storage [4] (fig. 2). PHES plants consist of several main component and systems, most of them have already reached a TRL 9 (Actual system proven in operational investment).

Potential, barriers and challenges

Worldwide, PHES is considered to have a great development potential because of its high-efficiency, large-scale energy storage capacity, long life-time and low self-discharge. In recent years, after the liberalization of the electricity markets, the increasing interest in renewable energy sources has again turned public attention towards PHES as a mature and large scale energy storage technology well-suited to support the integration of green energy production and grid stability, with dozens of proposed projects of PHES plants which add up to more than 50 GW of new PHES power capacity.

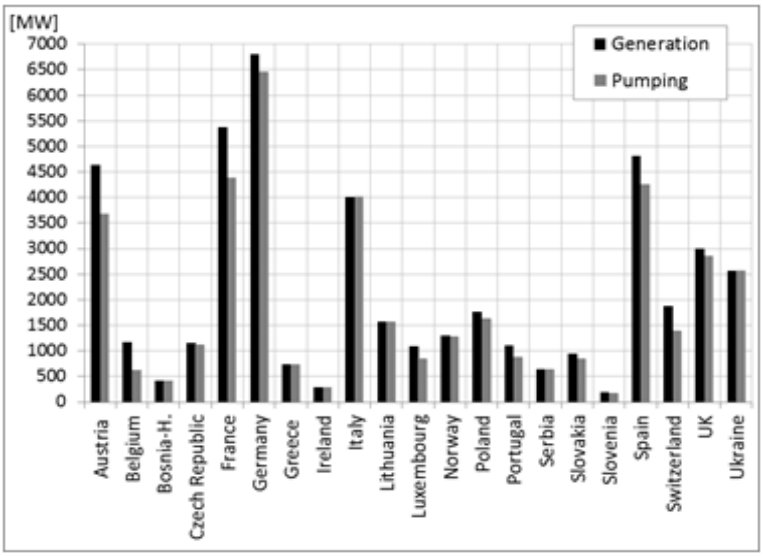


Figure 2. Installed pumped storage capacity in Europe.

Despite the above, there exist several barriers all over the world which are slowing down the development of new PHES plants. These barriers can be classified into three categories: technological, policy and environmental challenges.

The technological challenge arises from the fact that the traditional price arbitrage-based operation strategy followed in the past by most PHES plants has proved to be no longer profitable in current electricity markets [5]. PHES plants are nowadays required to provide fast and flexible response in order to help the TSO mitigate the adverse effects caused by renewable energy on the grid power quality. In this context, reducing the response time and extending the stable operating range of PHES units (especially towards low load operation) appear as the main technological challenges faced by the hydraulic machinery manufacturers.

The policy challenge is related to how PHES is allowed to operate. Even though there is a consensus on the important role PHES will play in future electric power systems, only few of the European systems (French, Belgium, British, Swiss, German and Austrian) allow PHES plants to provide both frequency containment and restoration reserves in pumping mode [6]. Furthermore, the current ancillary service markets are not well-suited to make the most of the flexibility of PHES or other storage technologies [7], and new policies are needed.

Figure 3. PSPP Dlouhé Stráně in the Czech Republic (2 x 325 MW, head 500 meters)

The environmental challenge is due to water management since PHES operation can cause an impact on river ecosystems. Upper and/or lower reservoirs of existing PHES plants are usually located in the midst of a river course, with the following three main issues: impacts on water quality, mainly due to the leakage of lubrication from the unit bearings, on the survival rate of the fishes that pass through the PHES unit runner, and on both the flora and fauna upstream or downstream the PHES plant which may experience fast water level fluctuations [8].

Potential
- Established technology
- Very long life-time
- Low self-discharge
- High efficiency
- Large Storage capability

Barriers
- High investment costs
- Long return of investment
- Difficult identification of suitable locations
- High environmental standards

Challenges
- Reduce response time
- Extend stable operating range

References

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