Technology: Pumped Hydroelectric Energy Storage

GENERAL DESCRIPTION

Mode of energy intake and output

Power-to-power

Summary of the storage process

Pumped storage plants are a combination of energy storage and power plant. They utilise the elevation difference between an upper and a lower storage basin. Pumps driven by electric motor–generators move water from the lower to the upper basin, thereby storing potential energy. For electricity generation, the stored water flows back down through the pipes and into turbines, which drive generators that feed electricity into the power grid. Instead of elevated reservoirs, dammed up rivers can also be used for hydroelectric storage.

Figure 1: Upper reservoir of Goldisthal Pumped Storage Plant in Germany (© Vattenfall)

System Design

Since the design of individual pumped storage plants depends strongly on the given topography, the system components, most of all pumps and turbines, are always custom parts. In most plants, pipelines and turbines are installed underground. The powerhouse is then located in a shaft or cavern. It contains the generators, which are operated as motors in pumping mode, the pumps and turbines, or, optionally, pump turbines. These work as turbines in one direction of rotation, as pumps in the other. The height difference between the two reservoirs, called the head, is typically between 200 and 1,000 m. There are, however, plants with a smaller head and ones that surpass 1,000 m. If the upper reservoir has natural inflows, these may also be stored and used to generate electricity in line with demand. Most pumped hydroelectric storages are designed to deliver their maximum output over a period of 4 to 9 hours. Systems with very large reservoirs, especially ones with a natural inlet, can deliver energy over much longer periods, some more than 100 hours.

Focus on provision of power or energy

Power

Suitable fields of application

Pumped storage plants are technically suited to all existing energy markets. They balance power generation and consumption in the electricity system, provide system services and reserve capacity, are capable of black start, contribute to redispatch, and supply instantaneous reserve.

Figure 2: Ternary machine set at Kraftwerk Wehr, Germany (© Schluchseewerk AG)

State of development/commercial availability

Pumped hydroelectric storage is a fully mature technology. Plants have been in operation worldwide for several decades. The TRL for systems in the output range between 50 MW and 1 GW is 9. In 2022, the global installed capacity of pumped hydroelectric storage reached 137 GW, representing 99 % of the overall installed storage capacity.

Besides the conventional pumped storage plants described above, ideas exist for less conventional approaches, such as ring wall storages, reciprocating piston storages, and underground pumped storage plants. Some of these are the subject of current research activities, while the technical feasibility of others still needs to be demonstrated.

TECHNICAL SPECIFICATIONS

Specific energy storage density	kWh/m³	kWh/t
	Not relevant	Not relevant
Specific power density	kW/m³	kW/t
	Not relevant	Not relevant
Typical/feasible storage size	kWhout	kWout
	> 800,000	> 200,000
System efficiency	75-80 %	
Storage efficiency	75-80 %	
Storage duration	Hours-weeks	
Response time	< 5 min	
Service life (maximum)	Cycles	
	> 20,000	
Loss per time in %	0	

Notes

Storage size:
New plants are assumed to output more than 200 MW and have a storage size sufficient for at least 4 hours of full-load operation.

Storage efficiency:
Empirical value as stated by operators

Response time:
The response time varies with the current operating status. In turbine operation, it is below 1 s. Reaching maximum output from standstill generally takes about 2 minutes, from pump mode about 5 minutes, depending on the applied system concept (pump turbines or pumps and turbines).

Service life:
At one storage cycle per day and an assumed service life of 50 years, a pumped storage plant will achieve about 18,500 cycles. Many plants, however, have been in operation for much longer (over 80 years) and the end of their service life is not in sight. Even individual machine sets, which switch mode up to ten times a day or more, have been in operation for over 80 years.

Loss per time:
Losses theoretically occur through seepage and evaporation of the water. They are, however, small enough to be compensated for by precipitation, so that in practice they can be neglected.

ECONOMIC SPECIFICATIONS

Investment cost per kW: 500-1,200 € (Value as stated by operators and planners).

Notes

This investment cost can vary strongly, mainly depending on whether a storage reservoir already exists or needs to be newly built.

For further information, see

International Hydropower Association, https://www.hydropower.org/factsheets/pumped-storage