Technology unveiled

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Revin PHES plant

Energy storage plants pump up the power

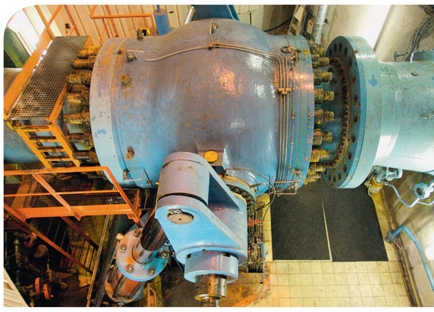
The use of pumped energy storage throughout the world is now more relevant than ever. This is the most economical way to store electricity, provided that an elevated reservoir is available that can be connected via pipes and galleries to another body of water at a lower level. The key components are the turbines and the pumps, or the dual-function pump-turbines, which need to operate in an extremely flexible way. Pumped storage is now the most commonly used power storage method in the world, with plants across the globe achieving an installed capacity of around 140,000 MW by 2010. EDF has built six pumped hydro-electric energy storage (PHES) plants in France, which it is now renovating and extending.

PHES plants

(pumped hydro-electric energy storage)

PHES PLANTS ARE A PARTICULAR TYPE OF HYDRO-ELECTRIC POWER STATION, HAVING TWO RESERVOIRS AT DIFFERENT LEVELS. DURING OFF-PEAK PERIODS, THE WATER IS PUMPED INTO THE UPPER RESERVOIR, WHEREAS AT PEAK USAGE TIMES, IT IS DIRECTED TO THE TURBINES TO GENERATE ELECTRICITY.

The key role of PHES plants is to transfer energy production from low-demand periods to higher-demand periods. Pumped energy storage was developed on a broad scale between the 1970s and the 1990s to optimise the operation of large thermal and nuclear power plants, to cope with high fluctuations in electricity demand over time. Large plants, with a unit power output of up to 3,000 MW, were built for this purpose in Europe, the United States, Japan and, a little later, in China. In addition to this primary use, pumped energy storage contributes to various power network and system services, such as voltage and frequency control, the provision of a guaranteed power supply during peak periods and a backup supply if problems arise on the network. It also prevents large power plants from having to shut down or slow their production. The development of pumped storage is needed on an international scale to support advances in renewable, intermittent, solar and wind energy sources. This second activity model is stimulating a vital new wave of development in this technology, not only in Europe but also in countries such as China and the United States



Plant B3, ball valve seen from above, Super Bissorte PHES plant

Pierre-Louis Viollet, Chairman of the Scientific and Technical Advisory Committee at Société Hydrotechnique de France

OPERATING PRINCIPLE FOR PHES PLANTS

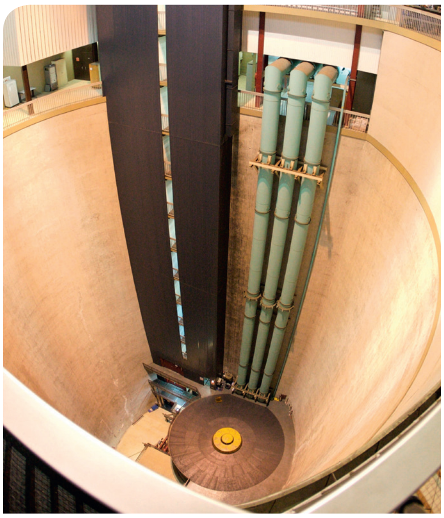
Spare energy capacity

BY ALLOWING ENERGY TO BE STORED, PHES PLANTS ARE KEY TO THE DEVELOPMENT OF RENEWABLE ENERGIES

Pumped storage plants are characterised by five parameters. **The maximum amount of energy,** stored in the form of potential gravity energy, is over 10 GWh for the largest installations and can be as much as several hundred GWh. **The nameplate capacity** in turbine mode or pump mode (generally at around the same level) is the second parameter: in 2000, around 30 power plants worldwide had a unit power output of 1,000 MW. In 2020, this figure will have more than doubled. Currently, most of the 170 PHES plants in Europe have a power output of a few hundred MW. **The time constant** is the ratio of storable energy to power. The vast majority of PHES plants are based on a daily operating principle, with a time constant of around eight hours. However, EDF's Grand'Maison plant operates on a weekly basis (30 hours). Certain Norwegian projects, on very large lakes, could function as seasonal plants. The overall **efficiency** across a full cycle is the ratio between the turbine-generated power and the power consumed by the pumps; this is around 80% for the more recent installations, which is a little less than the pump's and the turbine's yield, due to hydraulic head losses in the circuits. **The degree of flexibility** depends on the dynamic characteristics of the pumps and the turbines. This requirement is linked to the supply of system services and is becoming increasingly important. The most recent installations use variable-speed pump-turbines to provide fast power adjustment services in both pump mode and turbine mode. The British PHES plant in Dinorwig (1,700 MW), built in 1984 to support the development of nuclear energy in the United Kingdom, is now essentially used for providing system services to the National Grid.

Different types of PHES plant

Pumped storage plants can be either **pure** or **mixed**. Mixed plants have an upper reservoir that receives a natural water supply. EDF's Grand'Maison is an example of this type. Plants can also be distinguished by the nature of their lower reservoir. **On-shore PHES plants**, the most common type, consist of two reservoirs with volumes of around 10 to 100 million m^3. **Lake-based PHES plants** use a large lake



Unit 1 well at the Cheylas PHES plant

as their lower reservoir: the Hongrin-Léman plant in Switzerland uses Lake Geneva and the large Ludington plant in the United States relies on Lake Michigan. **Off-shore PHES plants**, following the same model, use the sea as their lower reservoir. This technology, which shows promise in its early stages of development, remains a challenge. Other technological variants may also emerge, such as a small reservoir with a high head.

KEY FACTS

Grand'Maison (France, EDF)
1987, mixed PHES plant with eight pump-turbines and Pelton wheels providing a total of 1,790 MW of pump power and 1,160 MW of turbine power.
Useful volume of upper and lower reservoirs (106 m^3): 14 and 132.
Head height: ranging between 822 and 955 metres.

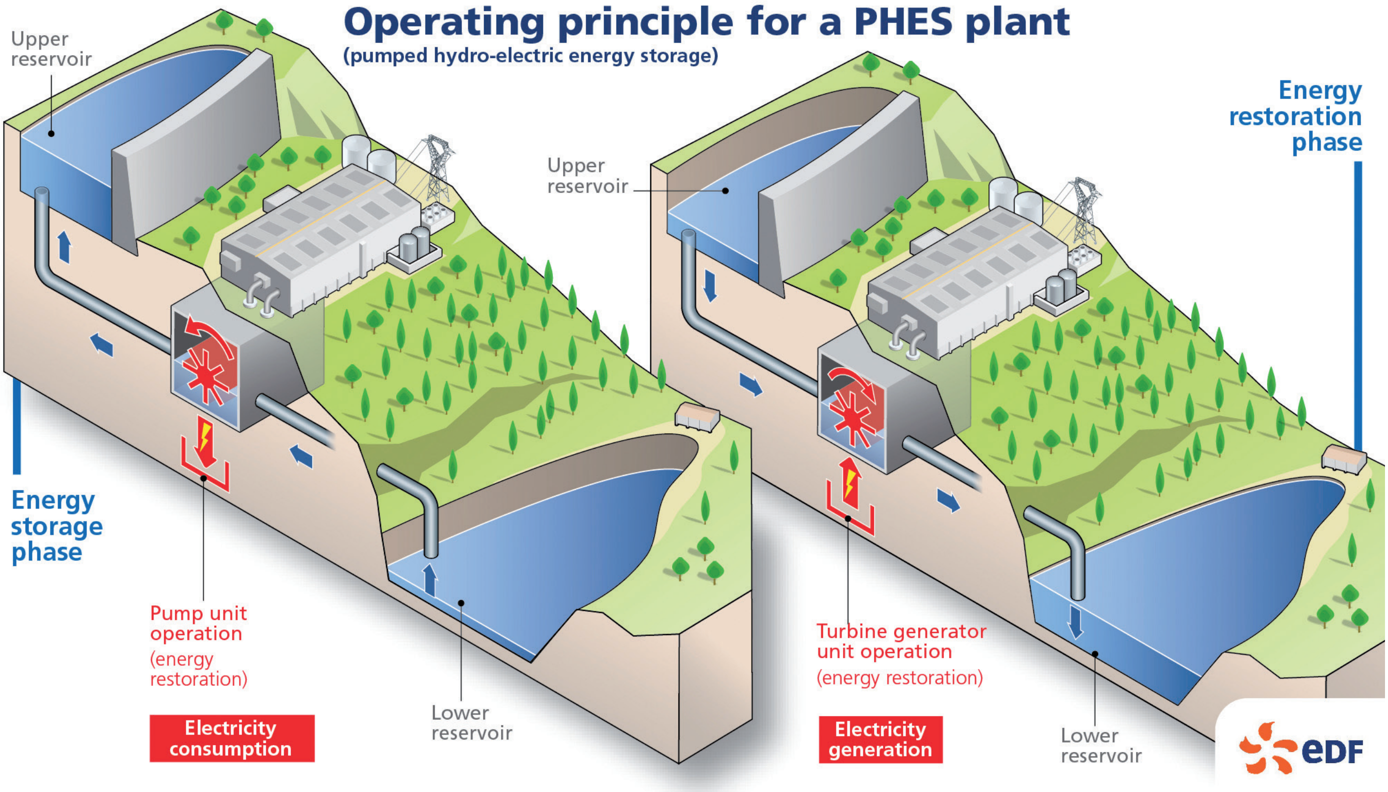
Vianden (Luxembourg, SEO, operated for RWE)
1964, 1976, undergoing Extension.
10 pump-turbines totalling 850 MW of pump power and 1,096 MW of turbine power; 11th pump undergoing installation (+190 MW).
Useful volume of upper and lower reservoirs (106 m^3): 7.
Head height between 266 and 291 metres.

Goldisthal (Germany, Vattenfall) 2003
Four variable-speed pump-turbines totalling 1,060 MW.
Useful volume of upper and lower reservoirs (106 m^3): 19 and 12.
Head height: approx. 302 metres.
Nant de Drance (Switzerland, ALPIQ) Planned for 2017.
Six variable-speed pump-turbines, totalling 900 MW.
Useful volumes of Vieil Emosson and Emosson reservoirs (106 m^3): 210 and 11.
Head height between 250 and 390 metres.

Hohhot (China, Inner Mongolia, China Three Gorges Corp) Planned for 2014.
Four variable-speed pump-turbines totalling 1,224 MW.
Useful volume of reservoirs (106 m^3): 6.
Head height: approx. 520 metres.

Operating principle for a PHES plant

(pumped hydro-electric energy storage)



DID YOU KNOW?

- **The world record for turbine power is held by the American Bath County power plant, renovated in 2009, with a capacity of 3,000 MW.**
- **The Kannagawa plant in Japan, currently being built by TEPCO, has a potential capacity of 2,800 MW.**
- **The Guangzhou and Huizou plants in Guangdong, China, commissioned in 2000 and 2011, each have a turbine power of 2,400 MW.**
- **The European record is held by EDF's Grand'Maison PHES plant with a capacity of 1,790 MW.**
- **The largest PHES plant in Germany is Goldisthal (1,060 MW), which is owned by Vattenfall.**

Social and environmental acceptability

One of the conditions for developing PHES plants is social and environmental acceptability. Although energy storage generally has a positive impact on the environment (optimal operation of large coal power plants, reduced need for state-of-the-art gas methods, integration of renewable energies, etc.), the development of PHES plants relies on the acceptance of these schemes at local level. For example, the new 1,400 MW power plant in Atdorf, Germany, is currently facing strong local opposition, and some of the large-scale PHES schemes in India and China are also seeing the displacement of populations. The local impact on biodiversity and fish must also be taken into account.

Economic aspects

LThe economic equation is also a delicate issue, as new PHES projects will have direct competition from other flexible generation methods, such as combustion turbine plants. The construction cost depends largely on the extent of the civil engineering works, particularly if dams or dikes need to be built. The overall investment cost ranges between €0.5 and €2 million per MW of nameplate capacity so it is often more economically viable to increase the capacity of an existing plant rather than build a new one. Overheads include the cost of the energy used for running the pumps, everyday maintenance and operating costs and taxes, including network access tax. In some countries, the network access cost is only applied to the difference between the energy consumed by the pumps and the energy produced by the turbines. In France, it is applied to both of these, so this type of technology is at a disadvantage. The sale of turbine-generated electricity can only return a gross profit if the ratio between the electricity prices during off-peak / peak periods is lower than the overall efficiency of the PHES plant. Operating revenues derive not only from the sale of turbine-generated electricity but also from payments for the various services provided to the power system, the cost of which must be appropriately quantified.

Outlook

Transmission networks enable the power storage needs of renewable energy plant pools to be combined by developing pumped energy storage schemes. In Europe, all countries developing wind energy on a large scale have considerable storage requirements: ten days without wind in Germany in 2050 might require a storage capacity of around 5 TWh. In 2012, Switzerland, Germany and Austria announced a joint initiative to develop energy storage through pump-turbine technology. Germany's goals are ambitious but they could be difficult to achieve due to local opposition. As a result, the country may need to rely on its neighbours for this supply. Switzerland is pursuing a programme to increase its PHES nameplate capacity from 1,400 to 5,000 MW between 2012 and 2030, which includes, for example, Nant de Drance, a new scheme in which ALPIQ holds a 39% share. Norway has considerable resources at its disposal thanks to its large number of lakes; this country has launched a 'green energy initiative', which includes plans to build new pumped storage plants (with a capacity of up to 10,000 MW) by installing underground galleries and stations between existing lakes, and aspires to become Europe's 'green battery'. Spain and Portugal also have ambitious plans for pumped storage plant development, with their La Muela II (852 MW), Frades II (760 MW) and Alto Tamega (900 MW) schemes. In France, plans are currently under way to renovate and extend the Revin pumped storage plant, while also under examination is the recommissioning of the old Lacs Blanc et Noir PHES plant following its renovation. However, China is setting the example as the main driving force. In 2009, it had 22 plants with a combined nameplate capacity of 11 GW. In 2015, this figure should reach 30 GW and, by 2020, between 50 and 60 GW. This development is evidenced by major new building projects in regions where consumption is high (including a third PHES plant with a capacity of 2,400 MW), and the recent emergence of schemes supporting advances in wind energy. The main motivation behind the PHES plant at Hohhot, planned for 2014 in Inner Mongolia, is to complement a wind farm developed by the same investor.

List of terms

Watt (W): international unit of power. This corresponds to the amount of energy consumed or generated over a given unit of time (one joule per second). The power corresponds to a flow of energy.

kWh: one kWh (kilowatt hour) equates to 3.6 MJ (megajoules) and is equivalent to the power used by a 1,000-watt electrical device over a one-hour period.

Hydraulic head losses:
loss of energy during the flow of a fluid, caused by viscosity, turbulence and friction against the walls of the pipes.

Power system: assembly consisting of electrical power generation machinery and usage points, connected by a meshed network.

System service: a package of services provided by power plants to guarantee the safety of the networks, particularly including voltage and frequency control and the supply of spare capacity, both upwards and downward.

> for further information

- Klaus Engels, Michaela Harasta, Werner Braitsch, Albert Moser, Andreas Schafer, Machine concept optimization for pumped-storage plants through combined dispatch simulation for wholesale and reserve marketss, La Houille Blanche, no. 3, 2012, pp. 37-43.
- François Lempérière, Stockage d'énergie par pompage d'eau de mer, article on pumped seawater energy storage to appear in Les Techniques de l'Ingénieur, 2013.
- Xavier Ursat, Henri Jacquet-Francillon, Isabelle Rafai, Expérience d'EDF dans l'exploitation des STEP françaises (EDF's experience in operating French PHES plants), La Houille Blanche, no. 3, 2012, pp. 32-36.
- Peter Vennemann, Karl Heinz Gruber, Jan Ulrik Haaheim, Andreas Kunsch, Hans-Peter Sistenich, Hans-Rudolf Thoni, Pumped storage plants – Status and perspectives. VGB Powertech Report, 4/2011.
- Pierre-Louis Viollet, Stockage d'énergie par pompage hydraulique, article on pumped hydro-electric energy storage to appear in Les Techniques de l'Ingénieur, 2013.
- Pierre-Louis Viollet, Histoire de l'Energie Hydraulique, article on the history of hydro-electric power, Presses de l'Ecole des Ponts et Chaussées, 2005.

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