Pumped Storage Systems

RELIABLE & ECONOMICAL
AFRY enjoys in the energy sector a unique reputation and is proud of the track record with over 60 pumped storage schemes boosting the renewable energy sector.

Leading the way in pumped storage

**PUMP STORAGE HISTORY**

The technological invention and development of reversible pump turbines in the 1930s led to significant growth in pumped storage plants, although they had been in existence from the beginning of the 20th Century. More recent innovations, including variable speed units that allow capacity to be adjusted during the pumping mode, have further improved efficiencies and, today, installed capacity amounts to around 140 GW.

**THE LEADING EDGE**

AFRY have been involved at the forefront in the design of pumped storage plants since the 1960s with in Switzerland — the 240 MW Hongrin-Léman PSP, completed in 1971 — and in Austria — the 231 MW Rosshag PSP, completed in 1972.

Since then AFRY has proven its competence as one of the sector leaders, having applied its engineering expertise to more than 60 PSP projects worldwide. We pride ourselves on being at the forefront of all new developments in pumped storage technology.

With profound experience in site evaluation, concept and feasibility studies, design, construction management of PSPP, clients can rely on our expert services. We support IPPs, investors and utilities alike in all phases of a PSPP project. We act as lender and owner’s engineer to ensure on time, on budget and quality project deliveries to minimize risks and increase profitability.

**OUTLOOK**

Pumped storage is currently the only energy technology capable of storing electricity on a large scale and in a cost effective and sustainable way, whilst also providing flexible supply to grids with a high share of variable renewables. Thus, global pumped-storage capacities are expected to grow substantially to about 200 GW in 2030, and about 300 GW in 2015. This will lead to significant increases in its share of national grids.

### Pumped-storage Grid Share

<table>
<thead>
<tr>
<th>Region</th>
<th>2018</th>
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<tbody>
<tr>
<td>United States</td>
<td>2%</td>
</tr>
<tr>
<td>Europe</td>
<td>5%</td>
</tr>
<tr>
<td>Japan</td>
<td>10%</td>
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The current share of PSP in national grids is about 2% for the United States, 5% in Europe and 10% in Japan. With the increased shares of intermittent renewable energy sources, it is expected that the shares of storage capacities needs to increase to about 8% to 10%.
PRINCIPLES OF PUMPED STORAGE

Pumped storage schemes store electric energy by pumping water from a lower reservoir into an upper reservoir when there is a surplus of electrical energy in a power grid. During periods of high energy demand the water is released back through the turbines and electricity is generated and fed into the grid.

They play an important role as they absorb energy from the system in periods with excess energy, and generate electricity when energy demand is high or a generator fails in the system. Their ability to react quickly to grid load changes means they also provide a valuable service for the stability of electricity grids and reserve capacities.
Pumped-storage in electricity grids

As the market share of renewable energies increases, the necessity of large scale potential energy storage and increased regulating capacity becomes imperative. Pumped storage is currently the only solution.

- The only available technology to store electricity on a large scale
- Highly responsive, in seconds, to sudden changes in demand
- Helps control transmission system frequency
- Provides reserve energy (capacity reserve; reactive power; black start capability; spinning reserve)
- Economically viable, by generating power in peak power / value times

With its ability to absorb excess energy when demand is low, and generate energy when demand is high, pumped storage technology has been used for decades in combination with large base load power plants.

However, it is the increased demand in renewable energy sources, leading to new challenges for grid stability, that has seen pumped storage usage expand rapidly. Its regulating capabilities and ability to provide the large storage capacities essential to provide a stable system makes it indispensable, particularly in grids reliant on a greater share of wind and solar power.
BASE LOAD POWER PLANTS

Nuclear and coal-fired plants are slow to react to load changes and are best operated at a constant output at peak efficiency, which, with coal-fired plants, results in higher efficiencies, lower thermal stresses and reduced maintenance costs.

Pumped storage works well in tandem, by balancing the load in the system, absorbing energy during off-peak hours and meeting demand in peak times without producing additional CO₂ emissions.

RENEWABLE ENERGY SOURCES

Most countries have renewable energy targets in place resulting in the construction of wind and solar plants at an ever increasing pace. However they are volatile sources of power, dependent on the vagaries of weather, with the attendant uncertainties of availability.

Pumped storage plants provide an excellent and secure energy supply. Through the use of modern variable speed units, pumped storage schemes are highly flexible and fast in reacting to load changes, and can help act as a supply/demand regulator.
Technical innovations have been key to the flexibility and short changeover times that make pumped storage a valuable component for economically viable grid stability.

The technology behind pumped storage

Ternary pump turbine units comprise three main parts; a motor-generator, a turbine (often a Pelton turbine), and a single stage or multi-stage pump. The latter two are connected to the motor-generator on the same shaft. With two separated hydraulic machines, the direction of the motor-generator is the same for both generation and pumping modes. To switch between the two, a clutch, starting turbine or torque converter is used. The torque converter is particularly effective in separating or connecting the pump and turbine within seconds, resulting in very short changeover times.

The downside of ternary pump turbine units is the higher investment costs, caused by the separated turbine and pump, and by higher costs for civil works (larger powerhouse) and additional hydro mechanical equipment.

Reversible pump turbines are usually operated at a fixed speed, and in pumping mode can only be switched on and off. Pumping at part-load is not possible. Nevertheless, reversible pump turbines are more cost effective than ternary units and allow for a compact design of the powerhouse. They have been installed for heads of 50 m up to 800 m.

Francis turbines and radial pumps are very similar in their hydraulic design and by changing the direction of rotation, a pump will operate as a turbine. The pumping operation is the more critical, and therefore a pump turbine is usually designed as a pump. But even in turbine mode the efficiency of pump turbines is only around 2% less than modern Francis turbines.

Three-Stage Pump (Voith)

Reversible pump-turbine (Andritz)

TERNARY PUMP TURBINE UNITS

REVERSIBLE PUMP-TURBINES
VARIABLE SPEED UNITS

By adding an asynchronous (induction) motor-generator or a frequency converter with a synchronous motor-generator, the rotational speed of a pump turbine can be varied. The capacity in pumping mode can then be adjusted, allowing for frequency control and grid stabilization services. This allows operations outside of the usual 70-100% capacity range.

Variable speed asynchronous motor-generator (GE)

CYCLE EFFICIENCY

Unlike conventional hydro power plants, pumped storage plants are net consumers of energy due to the electric and hydraulic losses incurred by pumping water to the upper reservoir. The cycle, or round-trip, efficiency of a pumped storage plant is typically between 70% and 80%.
Both conventional hydropower and pumped storage plants require similar structures; pumped storage schemes, however, have some specific aspects in their design.

**AFRY’s leading role in pumped storage**

As a leading hydropower consultant, AFRY has the experience and technical knowledge to meet all the requirements for pumped storage projects.

**LIFE CYCLE SERVICES**

With an outstanding track record in hydro power, we can provide the full range of services from the initial concept design, feasibility study, basic design and tender documents to detailed design, site supervision and commissioning of the plant.
CONCEPTUAL DESIGN

Two aspects are particularly important for the conceptual layout and design of a pumped storage plant:

— The role of the pumped storage plant in the grid
— The remuneration scheme for the provided services

A conventional pumped storage plant will absorb over capacities during low demand periods, and generate power during peaking hours, with the economics based on the spread between peak and off-peak electricity prices. Thus, flexibility in pumping mode and short changeover times will become important design criteria, and the need for advanced technical solutions (variable speed units, ternary unit sets, hydraulic short circuit for full flexibility) must be assessed.

HYDRAULIC SYSTEM STABILITY

Storage capability and short start-up / shutdown times make pumped storage plants extremely flexible and valuable for grid stability.

Modern pumped storage plants might have up to 20 mode changes per day and require minimized changeover times that are governed by the technology and characteristics of the units and the hydraulic system.

We are extremely adept at carrying out the highly detailed investigations of hydraulic transients in the water conduits and in the turbo machinery water passages that must be undertaken to optimize performance.

ENERGY PRICE FORECASTS AND SIMULATIONS

We have developed, and continuously update, energy market models for numerous countries and regions across the globe. Our electricity price forecasts (for up to 20 years) take into account actual and planned generation mix as well as demand and fuel price forecasts.

With many years of expertise in the industry, we have successfully carried out extensive optimization efforts in recently constructed pumped storage plants leading to significant reductions of up to 40% in both construction costs and time.

OPTIMIZATION OF UNDERGROUND WORKS

Many pumped storage plants require the construction of large underground structures, including water tunnels, underground powerhouses and access tunnels. These are usually both costly and on the critical path during construction.

IMPACT ON EXISTING RESERVOIRS

Many pumped storage plants are developed using existing reservoirs, where it is essential that the impact on the existing operation is minimized. We always ensure that we have a full understanding of the operator’s requirements and that the construction of the intake / outfall structures is carefully planned.
Case Studies

Limberg II pumped storage power plant
Kaprun, Salzburg, Austria

Austria’s entry into the European Electricity Market in 2001, together with an increase in share of intermittent renewable energy sources (mainly wind and photovoltaic / solar) in the European electricity grid led to the need for additional electricity storage capacity in the region.

Located in an environmentally sensitive area in the high Alps, the 480 MW Limberg II PSPP uses two existing reservoirs, connected by a 5.4 km underground water conveying system. Virtually all new components of the project have been constructed underground, leading to minimal impact on the environment – a major factor in ensuring the project did not face difficulties during the permitting process.

The project commenced in 2006 and was completed, one year ahead of schedule, in 2011, in the main due to an acceleration program initiated by the owner, contractor, equipment supplier and designer.
The 900 MW Nant de Drance PSP is designed to provide storage capacity and ancillary services for the European power grid. The pumped-storage plant connects the existing reservoirs Lac d’Emosson and Lac du Vieux Emosson.

When developing a new pumped-storage plant by using existing hydropower schemes and reservoirs the potential outage times of the existing plants during construction often have a considerable impact on the overall economic evaluation of potential alternatives. For the construction of the lower inlet/outlet structure, AFRY developed an innovative solution by floating in and lowering a pre-cast first-stage concrete intake structure at the Emosson reservoir, minimizing the outage time of the plant required for construction of the inlet/outlet structure.

The existing double-curvature arch dam forming the upper reservoir was heightened by 21.5 m to about 76.5 m in order to increase the storage capacity. The waterway is designed as a twin tunnel system, each with a 240 m long headrace tunnel, a 450 m deep vertical shaft and a 1,250 m long tailrace tunnel.

The six variable-speed reversible pump-turbines (with asynchronous motor-generator) with an installed capacity of 150 MW each are installed in an underground powerhouse. The powerhouse complex is situated 600 m below ground, and comprises the machine cavern and the transformer cavern as well as connecting tunnels, the 5.5 km long main access tunnel and a 2 km long ventilation tunnel.
Case Studies

Pyhäsalmi pumped storage power plant

Finland

Currently in the study phase, this pumped storage project is very special and uniquely complex, as it will use the infrastructure of the existing Pyhäsalmi mine, at 1,400 m the deepest in Europe, for access to construct the high-head pumped storage scheme. The project plans to connect an existing open pit as the upper reservoir with the lower reservoir, a newly constructed 1.6 km long tunnel system including aeration system, by a 1.1 km long headrace tunnel and a 1,340 m deep vertical shaft. The underground powerhouse will be 1,400 m below the surface.

The extremely high developed head of 1,400 m will require Ternary units, a multi-stage pump and a Pelton runner on one shaft, connected to the motor-generator.

The study in all disciplines from geology, civils and geotechnics to electromechanics, included the concepts of safety, function, design, construction, transportation, erection, operation and maintenance. The results of this study demonstrate that the energy storage plant has performance characteristics that are well suited to the expected market conditions.
Avče pumped storage power plant
Slovenia

Due to absence of storage power plants in the national grid, Slovenia had experienced shortage of energy to meet peak demand and a lack of grid regulation capacities.

The role of the 185 MW Avče PSP in the Slovenian electricity grid is to address the above shortages, making it a central piece in the national electricity system.

The Avče PSP is located on the Soča River in the western part of the country and develops about 520 m gross head between the existing Plave HPP reservoir and an artificial pond as the upper reservoir. The single variable speed pump-turbine unit (with asynchronous motor-generator) is located in a shaft powerhouse (80 m deep, inner diameter of 18 m) next to the Plave reservoir. The two reservoirs are connected by a 1,500 m long steel penstock and a 700 m long headrace tunnel. The upper reservoir with a capacity of 2.2 million m³ is formed by an asphalt lined pond located in a natural depression capable for a weekly operating cycle.

The Avče PSP provides valuable peak load energy and frequency control services to support the grid stability. By the installation of a variable speed unit, primary and secondary frequency control can be provided during turbine and pumping mode operation. By providing peak load energy and frequency control services for the grid, the Avče PSP plays a central role.

As the Owners Engineer, AFRY was responsible for the Feasibility Study, Tender Design and Tender Documents, Detailed Design, Site Supervision and Support during Commissioning.
The planned role of a pumped storage plant in the electricity grid defines the underlaying business case for the project, and has significant impact on the selection of suitable equipment. The planned Aya PSP in Luzon intends to provide Ancillary Services to support the stability of the electricity grid. To maximize operational flexibility two reversible 50 MW pump-turbines, coupled with full-size frequency converters, will be installed.

The Aya PSP uses two existing reservoirs – Pantabangan / Aya Reservoir as the upper reservoir, and Masiway Reservoir, located just downstream of the Pantabangan / Aya Dam, as the lower reservoir. This arrangement allows for the development of approximately 90 m head with a short underground waterway of around 700 m length connecting the two reservoirs.
The increased shares of intermittent renewable energy sources in the Australian grid led to shortages in energy storage capacities and stability issues in the electricity grid.

The Snowy 2.0 PSP, a 2000 MW PSP project located in the Kosciuszko National Park, aims to develop a gross head of almost 700 m by connecting two existing reservoirs, the Talbingo and Tantangara reservoirs. The two reservoirs are connected by a 26 km long waterway system, the six reversible pump-turbine units (three fixed speed units, three variable speed units with asynchronous motor-generators) are located in an underground cavern.

To support the grid stability by providing ancillary services, short time periods for units start-up, reaction on load changes and switch-over times between operating modes are required by the Owner. These system requirements together with the long waterways leads to a challenging hydraulic and transient design of the water conveyance system, comprising headrace and tailrace tunnel and the u/s and d/s surge tanks. Constructability in challenging geological conditions, overall construction time and construction costs had to taken into account during the preparation of the Basic Design.

AFRY was part of the design team for an EPC Contractor, and was responsible for the hydraulic design, transient analysis and optimization of the entire water conveyance system as well as the optimization and Basic Design of the underground powerhouse complex (main powerhouse, transformer and GUS cavern,ing tunnels).

The project is highly challenging, due to the proposed large 26 km long pressure tunnels that will add enormously to the cost. AFRY is part of the design team for an EPC contractor, with a goal of reducing the costs and construction time by introducing alternative concepts and design.

Once ratified, we will then be responsible for detailed design and site services in what will be one of the world’s largest PSP projects.
AFRY is an international engineering, design and advisory company. We support our clients to progress in sustainability and digitalisation.

We are 17,000 devoted experts within the fields of infrastructure, industry and energy, operating across the world to create sustainable solutions for future generations.

Making Future