

PUMPED STORAGE PLANTS

Shaping our world



Why Pumped Storage?

With the Paris agreement in effect, the global aim is to reduce the emission of greenhouse gas in order to “hold the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels”.

At present, the commercially harnessed sources of renewable energy mainly comprise hydropower, wind, photovoltaics, biomass and geothermal power. Also referred to as “the renewables”, they provide more than 20 % of the world’s total energy consumption in the year 2017.

To meet the global climate objectives will require substitution of fossil fuels by renewables.

While combustion of fossil fuels generally produces reliable base load, most of the renewables, in particular wind and photovoltaics, share one key feature; they are intermittent and volatile. Their availability is independent of the energy demand.

Since the renewables are a volatile source of energy an increased share of renewables will dramatically increase the requirement for additional storage capacity as well as increased load stabilizing capacities of the world’s electric grids.

Benefits and Advantages

The most mature and efficient technology to store energy in a large scale are pumped storage plants, also referred to as “PSPs”. For almost 100 years pumped storage technology has been successfully implemented and the technology has been continuously improved.

Typical up-to-date pumped storage plants have enough potential to balance demand and supply of up to 12 hours with high capacities. In addition, PSPs can be used for grid stabilization due to their rapid reactivity.

Decentralized and small-scale energy storages (such as power-to-gas [P2G], batteries, smart grids and the like) are still in their early stages of technological and economic development. Moreover, grids, in which there are large producers and consumers, require large backup facilities for stabilization. These facilities must be capable of responding to instantaneous load variations of individual large producers and consumers by providing high capacities rapidly.



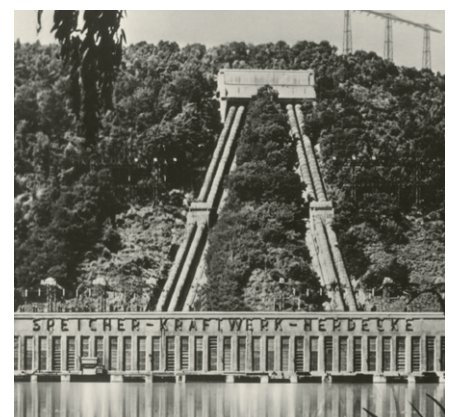
PSPs will be increasingly needed for an efficient, stable and secure energy supply.



In the long term, PSPs will remain the most economic and most flexible technology available for grid energy storage. The overall “round trip” (wire to wire) efficiency of modern projects with economic layouts is in the range of 80 %.



PSPs reduce the required back-up capacity and part-load operation provided by conventional power plants and thus decrease emission of greenhouse gases.



*Herdecke PSP, Germany,
Koepchenwerk, 140 MW (1924–1930)*

Ensuring a Reliable and Stable Energy Supply

The traditional purpose of a PSP is to store surplus energy when the demand is low and to return electricity to the grid when it is needed during peak-load times. In addition, PSPs can assume a variety of ancillary functions:

- PSPs provide “regulating reserve capacity” with high flexibility and extremely short response times (primary, secondary and tertiary grid control functions). In pump mode it can absorb surplus energy from the grid and generate electricity at any time required. Such load balancing stabilises the grid’s 50 or 60 Hz frequency and hence enhances the reliability of the system.
- PSPs are suitable for voltage control by providing or absorbing reactive power at all active power levels, even when idling without load in phase-shift mode.
- PSPs can be assigned to provide black start capacities in the event of a wide-area grid outage. PSPs are especially reliable and effective for this purpose as they can be regulated over a wide range of performance.

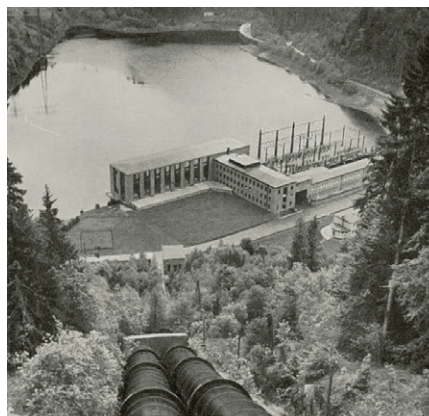
Experience in Planning, Construction and Operation

For nearly 100 years, Tractebel has been closely connected with the planning and construction of PSPs. Over many decades, Tractebel has pioneered technical innovations

- The Koepchen Scheme in Germany, which was erected between 1927 and 1930 with four ternary 35 MW sets, was one of the very first PSPs. In 1994 – after 64 years of successful operation – the old plant was decommissioned. It was replaced by a single pump-turbine of 153 MW installed in a new shaft-type powerhouse. Tractebel provided engineering services for both the original plant and the replacement plant.
- When constructed in 1964, the Vianden PSP in Luxembourg with 9 ternary sets, each with a turbine capacity of 100 MW, was the largest scheme of its kind worldwide. Tractebel’s engineers took over the planning, tendering and supervision of the construction and commissioning. Plant extensions with the 10th Unit (+200 MW, 1970 to 1976) and an 11th Unit (+200 MW, 2006 to 2016) were again carried out with full engineering services by Tractebel.
- The 1,060 MW Goldisthal PSP in Thuringia, Germany was commissioned in 2004. It was the first plant in Europe with large adjustable speed pump-turbines. Two of the plant’s 4 units were equipped with double-fed, asynchronous motor-generators. Starting with conceptual planning in 1991, Lahmeyer provided all essential engineering services, including supervision of construction, commissioning and assistance during the guarantee period.



*Vorarlberg Illwerke, Austria,
172 MW (1927-1948)*



*Schluchseewerk, Germany, 3 Phases,
470 MW (1927-1953)*



*Waldshut PSP, Germany,
168 MW (1940-1953)*

State of the Art Technology included in the Tractebel Designs

For many decades Tractebel has been at the leading edge of key innovations in pumped storage technology. The following illustrates the state of the art of PSP technologies and naturally Tractebel will adapt these innovative technologies to fit the client's requirements best.

Ternary Sets and Pump-Turbine Technology

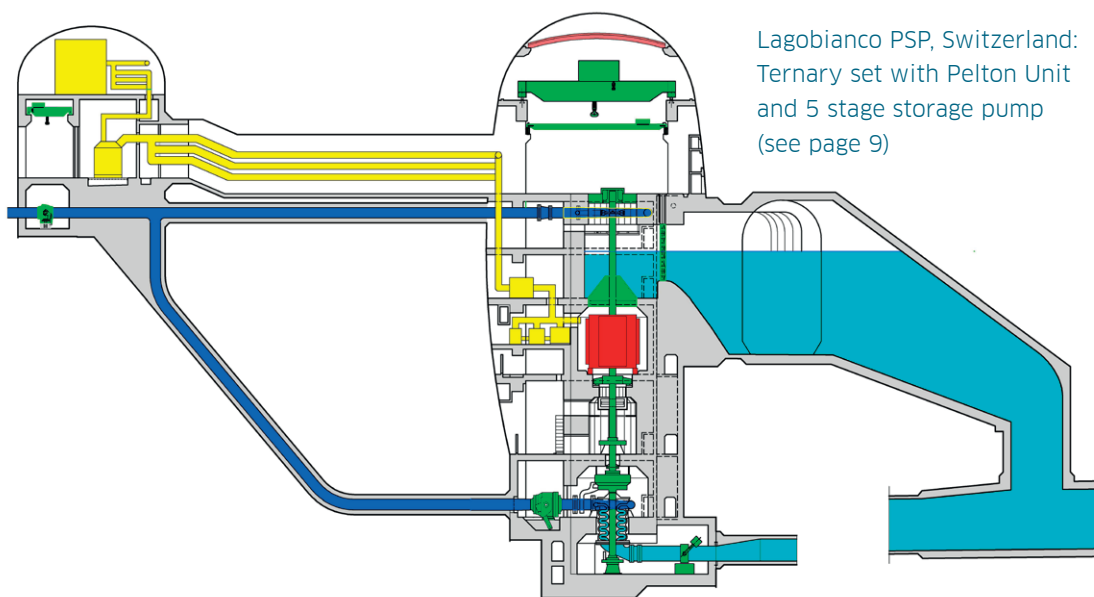
In principle, there are two different types of generating equipment in pumped storage systems:

- **Ternary set units** comprise the following five main components: (a) a turbine (Francis or Pelton Type), (b) the clutch, (c) the motor-generator, (d) the hydraulic torque converter, and (e) the pump. The main benefits

of a “ternary set” is a very rapid change from turbine to pump mode and vice versa and quick start-up times in both modes.

- **Reversible pump turbines**, as their name suggests, can reverse their rotational direction. Their runners are specifically designed to serve as a pump, and, with a change in the direction of rotation, as a turbine. The motor-generator and the pump turbine are directly connected.

Both technologies are wide spread with the latter having slightly lower efficiencies but advantages in reduced investment, and operating costs. While the ternary set has five main components, the pump turbine has only two components.



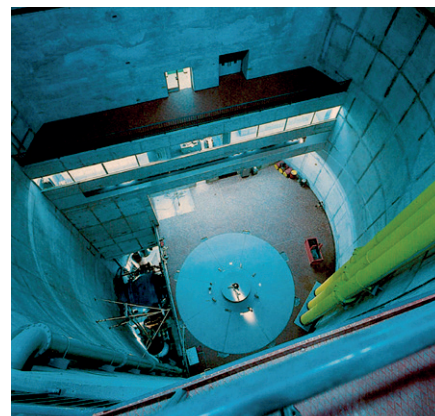
Lagobianco PSP, Switzerland:
Ternary set with Pelton Unit
and 5 stage storage pump
(see page 9)



Vianden PSP, Luxembourg, Units 1-9,
900 MW (1956-1965)



Säckingen PSP, Germany
360 MW (1960-1967)



Vianden PSP, Luxembourg, Unit 10,
900 MW (1964-1974)

Variable Speed Technology versus Hydraulic Short Circuit

To control the output of a PSP, there are essentially two different layouts:

- A feature of synchronous motor-generators is that their rotational speed is synchronized with the grid's frequency and cannot be varied in steady state operation. This implies that the range of performance variation is small. In order to control the performance of a synchronous motor-generator (in turbine as well as in pump operation), the "hydraulic short circuit" mode is applied. This mode is only possible with a ternary set unit, because pump and turbine are operated simultaneously. In the hydraulic short circuit mode water from the turbine is fed directly to the pump and vice versa. Obviously, the hydraulic short circuit mode decreases the efficiency.
- A variable speed motor-generator (double fed asynchronous motor-generator or synchronous motor-generator with full-sized converter) can be used in conjunction with pump-turbines as well as with ternary sets. Since it can control its rotational speed, it can, therefore, function over a wide performance range.

Double Fed Asynchronous unit with AC Excitation (VSC = Voltage Source Converter)

Variable voltage and frequency is fed by converter directly into the rotor windings. This solution is best suited for large scale installations since the converter must be rated for the slip power of the rotor only.

Synchronous Motor-Generator with Full-Sized Converter (VSC = Voltage Source Converter)

In this arrangement the converter is connected to the stator windings and must be designed to carry the full output of the motor-generator continuously (=full-sized), therefore, the rating of such units is limited to the size of converters available on the market.

Benefits of Variable Speed Units

A higher overall efficiency in turbine operation (especially in part load operation) can be achieved with variable speed units. In pump operation, the power can be varied according to the actual hydraulic and grid conditions. Moreover, the units can participate in frequency and power control of the electrical grid (primary regulation/control) using the fast regulation capabilities of the converters.



*Turlough Hill PSP, Ireland
290 MW (1967-1973)*



*Wehr PSP, Germany, Hornbergstufe
1,000 MW (1970-1976)*



*Goldisthal PSP, Germany,
1,060 MW (1991-2004)*

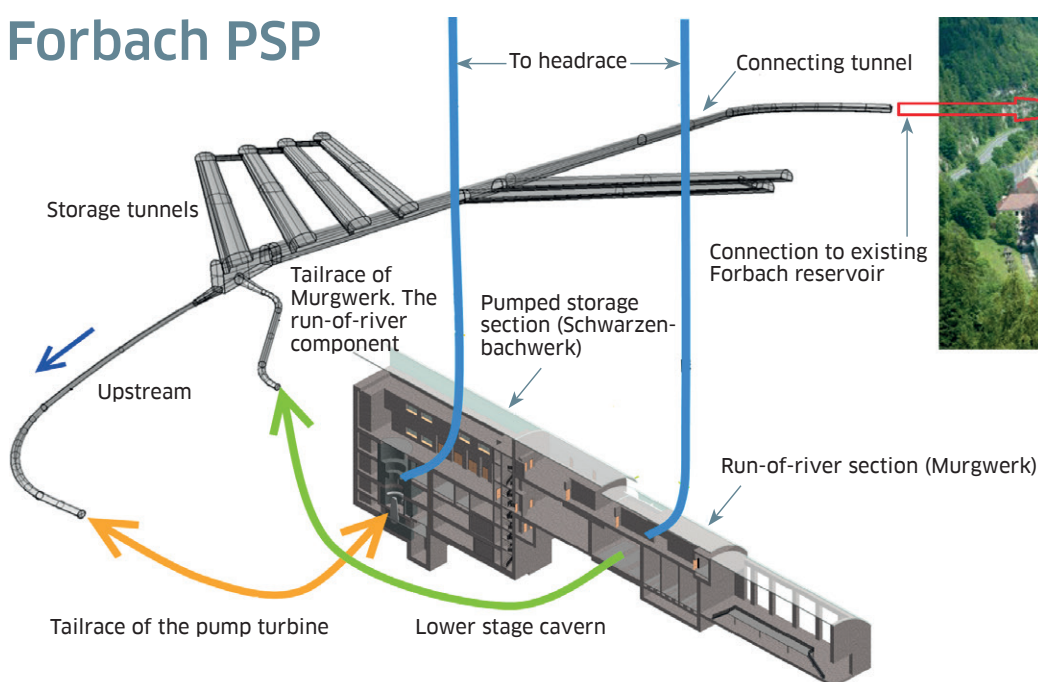
Innovative Technology in Today's Design

Underground Storage

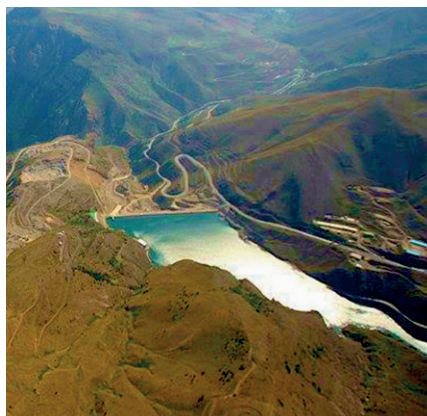
In order to preserve the pristine nature underground storage caverns have increasingly become an option to create lower reservoir storage capacity. Tractebel Hydroprojekt GmbH and Tractebel Engineering GmbH have designed an underground storage cavern for the Forbach Extension (see page 9) and Rehabilitation Project (see figure) in Germany.

The storage cavern has four fingers, also referred to as the “storage tunnels”, with a length of 340 metres and two with a length of 210 metres. In the centre of the layout a connecting tunnel, with a length of about 1,000 metres, links the tailrace tunnels of the power cavern with the existing open-surface reservoir and the storage tunnels.

Forbach PSP



Guangzhou PSP, China, Phase II,
1,224 MW (1994-2000)



Siah Bishe PSP, Iran, Phase 2, 1,000 MW
(2003-2011)



Waldeck 1 PSP, Germany, 70 MW
(2004-2009)

Identification Tool for Suitable Sites

Tractebel developed a proprietary geographic information system (GIS) based tool which allows evaluating large areas for suitable PSP sites. The areas covered by the investigation can vary in size from countries, states, counties or other territories over many thousands of square kilometres.

An outstanding feature of our tool is that it can be customized to consider specific criteria desired by the client such as: installed capacity, cost limitations, geologic constraints, maximum distance to nearest grid connection, environmental and social constraints, etc.

The procedure for the search comprises three steps:

1. Terrain analysis
2. Site analysis
3. Ranking of sites and sensitivity analysis

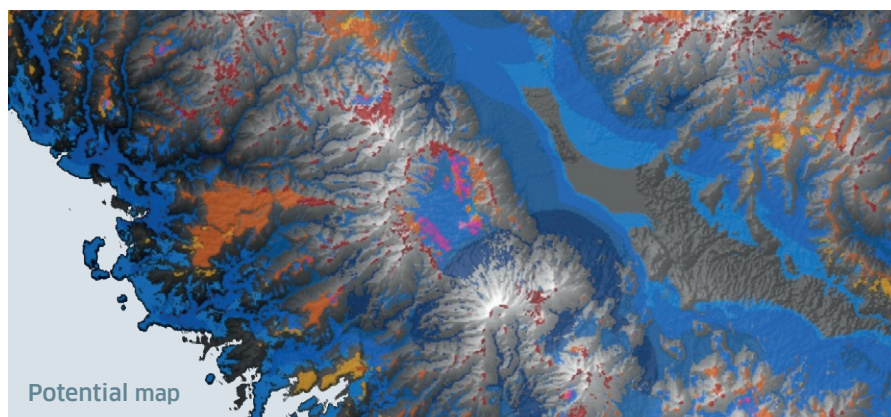
In the first step, the **terrain analysis**, predetermined areas are screened to identify sites which allow the construction of head ponds and tail ponds within a predefined maximum horizontal distance (e.g. 5,000 m), and simultaneously have a minimum predefined difference in elevation (e.g. 300 m). As an additional feature our tool has the capability to check whether the terrain is suitable for the construction of ponds and dams. For man-made reservoirs the objective is construction in

“mass balance” where the quantity of excavation roughly equals the quantity of fill; whereas for dams a maximum height can be set which allows accommodating a desired storage volume for the prevailing terrain.

The second step is the **site analysis** where the results of the previous step are further refined. The objective of this analysis is to exclude sites which do not meet a predefined set of criteria such as presence of settlements, significant infrastructure, and protected areas. Other constraints specific to the site, project and client can also be added to the analysis.

Taking the remaining sites into consideration, this step defines possible combinations of head and tail ponds, also referred to as “pairs”. Comprising only major plant components, a standardized plant layout is applied to all identified pairs in order to estimate the installed capacity. So as to make the pairs comparable in terms of cost and CAPEX, indicators such as „Dollar per KW“ are worked-out.

In the last step a **ranking** of the identified pairs is produced which is based on three criteria: technical, socio-economic and environmental. Supplementary criteria such as hydrology, road access, and distance to grid connecting points can also be integrated into the ranking. To confirm the ranking and complete the analysis, a **sensitivity analysis** is carried out.



upper basins  lower basins  both types 
 increasing potential   



Vianden PSP, Luxembourg, Unit 11
(2006-2016)

New Technologies in the Pumped Storage Market

The market for storing electricity in a large scale is currently highly innovative and dynamic. The following two innovative layouts shall serve as examples for the latest applications:

Green Energy Storage Gaildorf

Developed by the Naturstrom GmbH of Germany, the new concept of combining of generation and storage of green electricity in one geographical location increases the overall efficiency. A new and innovative layout was proposed to combine both features.

Given the condition of an elevation differential of between 150 and 350 metres, a wind farm can be supplemented with a small-scale pumped storage unit. With an installed capacity in the range of 16 to 24 MW, the plant features man-made circular headponds arranged around the windmill's towers. A tail pond and the powerhouse accommodating a pump-turbine are situated at the bottom of the valley. Given the small dimensions of the individual components the scheme can be harmoniously integrated into the landscape.

A prototype is currently under construction near the town of Gaildorf, Germany. With an installed capacity of 16 MW and a water storage capacity of 160,000 m³, the plant is capable of storing 70 MWh.



Green Energy Storage of Gaildorf, Germany

Offshore Pumped Storage Donut, Belgium

Another innovative approach is to locate the pumped storage facility offshore. This layout combines several benefits: (a) it would be out of sight, and secondly (b) the storage is located closer to the fluctuating electricity generation by the offshore wind farms. While an offshore layout is entirely new, the technology behind it is well proven. A circular embankment creates a reservoir which is filled and drained by lowhead pump-turbines driven by the surplus energy produced by the wind farm or available from the onshore grid.

A necessary precondition for such a project is shallow waters. Similar to the Green Energy Storage Project of Gaildorf, a location in close proximity of a wind farm helps limit the transmission losses, and increases its overall efficiency of the entire generation and storage cycle.



Photographer: Tim Siegert; © Max Bögl Wind AG

© Max Bögl Wind AG

Studied Projects

Basis for the successful implementation and operation of a pumped storage plant is a sound planning. Tractebel has participated in the following notable projects, which have not yet reached the phase of implementation.

Lagobianco PSP, Switzerland

The project will use the existing Lago Bianco (white lake) located near Bernina pass as upper reservoir. The power waterways comprise an about 18 km long headrace tunnel and a 2.5 km long pressure shaft. The generating sets feature Pelton turbines and five stage storage pumps in a vertical arrangement. With a discharge of some 95 m³/s and a head of 1,270 metres, an installed capacity of 1,050 MW results (see page 4).

Services:

- Conceptual design, design for governmental approval
- Tender design & documents

Client: Repower AG, Poschiavo, Switzerland



Atdorf PSP, Germany

Although the history of the project dates back to the 1970s, no steps for implementing the plant have been taken to-date. The waterways consist of a 700 m vertical pressure shaft from the upper reservoir down to the powerhouse cavern (pump-turbines, total capacity max. 1,400 MW) and from there, an inclined pressure tunnel of 8 km length to the lower reservoir.

Services:

- Alternative studies (2007-2008)
- Supervision and evaluation of geotechnical investigations (2008-2009)
- Detailed design (2010)

Client: Schluchseewerk AG, Laufenburg, Germany



Forbach PSP, Germany

The Forbach PSP is one of the oldest combined pumped storage and run-of-river schemes throughout Europe. Constructed in the first two decades of the previous century, the scheme has been continuously under operation for nearly 100 years. The overall new layout of the entire scheme foresees the following new features:

- Upper Stage 225 MW pump-turbine accommodated by a new cavern with a new upper reservoir;
- Lower Stage 50 MW pump-turbine;
- Lower Stage run-of-river (daily peaking capacity) 19 MW.

The cutting-edge innovation (see page 6) of the project is to move the storage capacity to be implemented underground and to connect the storage cavern with the existing open surface reservoir.

Services:

- Pre-feasibility studies for extension and rehabilitation
- Conceptual design, design for governmental approval
- Planning for regional planning process and permitting

Client: EnBW Energie Baden-Württemberg AG, Karlsruhe, Germany



We are Tractebel

Tractebel provides a full range of engineering and advisory services throughout the life cycle of its clients' projects, including design and project management. As one of the world's leading engineering and advisory companies and with more than 150 years of experience, it's our mission to actively shape the world of tomorrow. With about 5,000 experts and presence in more than 70 countries, we are able to offer our customers multidisciplinary solutions in energy, water and urban.

Since December 2014, Tractebel Engineering GmbH (former Lahmeyer International) belongs to Tractebel and thus is part of the international ENGIE group headquartered in Paris. Tractebel (Brussels, Belgium) and Tractebel Engineering GmbH (Bad Vilbel near Frankfurt, Germany) cooperate on numerous international projects as one company.

Tractebel Engineering GmbH

Friedberger Str. 173
61118 Bad Vilbel, Germany

Phone: +49 6101 55-0
Fax: +49 6101 55-2222
info-de@tractebel.engie.com
www.tractebel-engie.com
blog-tractebel.lahmeyer.de

