Hydropower

SUPPORTING A POWER SYSTEM IN TRANSITION

A EURELECTRIC report

June 2015

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Hydropower - supporting a power system in transition

A EURELECTRIC paper *June 2015*

KEY MESSAGES

- **Hydropower is crucial for system stability and security of power supply**.

By providing the necessary flexibility and storage capacity to help **ensure stability of a transmission system and security of supply**, hydropower supports the integration of increasing amounts of wind and solar energy. This will become even more important in the future as the share of variable generation from renewable energy sources, such as wind and solar, increases. Due to their flexible nature, hydropower plants with reservoirs have the ability to **respond to short-term changes in the power system**, and can ramp-up and ramp-down instantaneously in order to provide energy to the system when needed.

- **Hydropower plays a central role among the renewable energy technologies: it is reliable, efficient, climate-friendly and contributes to security of supply.**

As the largest renewable generation technology, hydropower amounts to around 50% of the total renewable electricity generation in Europe today, representing approximately 200 GW of installed capacity. It offers very **high efficiency rates** (between 85% to 95%), as well as providing a **variety of services** to the power system. Hydropower also makes a major **contribution to climate change mitigation**, since it has one of the **lowest carbon footprints**. It forms a part of Europe`s domestic resources and therefore helps to diversify the electricity mix and **decrease dependency** on fossil fuel imports. In addition, hydropower plants with reservoirs provide a **wide range of other water related services** such as flood control, irrigation, drinking water, recreational activities, etc.

- **Hydropower provides the most efficient energy storage technology, and the only existing large-scale storage technology**.

The total installed energy storage capacity in Europe amounts to more than 180 TWh **delivering short, medium and long-term storage capacity**, depending on the size of the reservoirs. This means that, despite developments in energy storage, hydropower is still the only technology which currently offers mature large-scale storage.

- **In view of these benefits, policies must help to preserve and improve the competitiveness of hydropower.**

The internal electricity market should be fully implemented and improved in order to value energy, flexibility and capacity. Environmental regulation should be coherent with other policy objectives and must also take into account the full range of services which are provided by hydropower. **Pumped storage** must be considered as a **generation asset** and must therefore **not be burdened by double grid fees**. Innovation needs in hydropower should be reflected in the **EU's Energy Research and Development programmes.**

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1. Changes in the European Power Sector

Europe's electricity landscape is undergoing **profound changes.** The EU has set ambitious goals to cut its greenhouse gas emissions by 80% below 1990 levels by 2050. The 2030 climate and energy framework sets a number of targets for 2030 including, among others, a 27% EU wide target for RES energy consumption and a EU target of 40% GHG reduction compared to 1990 levels. The power sector is expected to contribute to this energy revolution and the path to the decarbonisation. In order to achieve these targets, a share of around 45% of RES in the power sector is expected. Even though the relatively large amounts of existing and new RES (such as hydro and biomass generation) provide an important contribution towards achieving the 2020 targets, the main share is expected to be made up through investments in variable generation (wind and solar generation) in the largest EU Member States. **By 2020, wind and solar generation are likely to make up 50% of RES power generation in Europe.** This figure is expected to rise further in the near future.

Increasing levels of wind and solar penetration in the generation mix will create **more variability**. Although the forecast methods are improving, it is unlikely that these will ever be entirely accurate. This will therefore require the electricity system to become more flexible, which represents a significant **challenge for the respective TSOs and DSOs.** Consequently, in order to keep the electricity system in balance, TSOs and DSOs may need to adopt different approaches to ensure that sufficient reserve capacity is available.

The development of variable RES such as wind and solar requires **increasing flexibility solutions** from other generation technologies, as well as the ability to deal efficiently with excess power supply at some times as well as shortage situations at others.

The variability of RES creates challenges for power markets in terms of **supply adequacy** since additional standby capacity, in one form or another (physical capacity, interconnections, demand response or storage), becomes necessary to be able to cover peak demand when the RES output is low. Since the availability of variable RES cannot always be guaranteed, they need to be backed up by other types of power generation.

The question therefore arises:
How can hydropower help the power system to cope with these challenges?

2. The Role of Hydropower as Provider of System Stability and Security of Supply

2.1 Hydropower – a flexibility solution today and tomorrow

The importance of energy generation technology for the overall power system stability depends mainly on its capability to stabilise fluctuations between demand and supply. This encompasses, for example, short-term reserves (generation, storage, demand response) to cover potential incidents, which decrease power supply to the system, or to respond to short-term variations in demand and generation. **Hydropower therefore provides an ideal solution for the challenges of a transitioning power system.**

Hydropower brings a strong contribution to flexibility in the power system today, together with other flexible technologies that are competing in the energy market. These fill the gap between supply and demand that has been induced by the non-dispatchable variability of RES. **The storage capabilities of many hydropower plants make them a perfect instrument for optimising the use of variable RES over shorter and longer periods.** Hydropower also provides a number of **ancillary services** which are needed in order to manage a transmission system in a way that secures system stability and security of supply. Moreover, during power system restoration, such as in the case of an extreme event (e.g. blackout), auxiliary loads of conventional thermal and nuclear power plants need external power source, which can be provided quickly by hydropower.

Hydropower plants with reservoirs reduce the dependency on the variability of the natural inflow and enable adjustments of power generation to the variability in demand. These plants are operated on a scheduled basis taking into account data regarding water flow forecast, market price and consumption patterns. They are commonly used for intense load following and to meet peak demand. The generation of peak-load energy from reservoir type hydropower plants allows the optimisation of base-load power generation from other less flexible electricity sources, such as nuclear and thermal power plants. Besides contributing to water management activities (flood control, irrigation, drinking water, etc.), hydropower plants with reservoirs also introduce unique benefits to the electricity system. There are different types of hydropower plants with reservoirs.

Storage hydro (or conventional reservoir-type hydropower plant) takes advantage of large reservoirs with natural inflow of water and the possibility to reduce or increase the water outflow instantaneously. The water is stored in the reservoir and no pumps are needed.

Pumped storage power plants store energy by pumping water from a lower to a higher reservoir and converting the potential energy back into electricity. These reservoirs can be natural or artificial. Both types of plants enable the power system to receive and store energy in periods of low demand or excessive generation, and generate electricity in times of higher demand. The role of pumped storage hydropower plants is twofold: they balance the grid for demand-driven fluctuations, and they balance generation-driven fluctuations. **Storage possibilities combined with the instant start and stop of generation makes hydropower very flexible. Pumped storage plants, such as the Grand'Maison power station in France, can ramp-up up to 1.800 MW in only three minutes.** A recent macroeconomic study[1] on hydropower shows the ability of pumped storage plants to help mitigate the effect of a solar eclipse (extreme event) on a sunny day in Germany.

[1] Macroeconomic study on Hydropower, DNV GL Energy, 2015.

The table below shows some of the characteristics of a flexible power generation technology, such as pumped storage, in responding to short-term changes in the power system.

	Start-up time cold	**Start-up time warm**	**Load gradient increase nominal output**	**Load gradient decrease nominal output**
Pumped Storage power plants	**~ 0,1 hours**	**~ 0,1 hours**	**> 40% per minute**	**> 40% per minute**

Table 1: Flexibility characteristics
Source: EURELECTRIC/VGB

The flexibility of conventional power generation technologies varies. However, **pumped storage and storage hydro** have very **quick ramp possibilities**, are able to start-up and shut-down in only few minutes, and have a relatively large energy volume capacity. Table 1 demonstrates that pumped storage power plants have a fast load gradient (i.e. the rate of change of nominal output in a given timeframe) as they can ramp up and down by more than 40% of the nominal output per minute. Pumped storage and storage hydro with peak generation are able to cope with high generation-driven fluctuations and can provide active power within a short period of time.

From day-ahead market closure to electricity dispatch, there is still a significant deviation between the contracted variable generation and the actual generation due to the forecasting challenges in RES production. These deviations need to be corrected through trading on an intraday market, when forecasts are corrected in a time perspective of less than a day, or afterwards, when TSOs have used their tools to keep the system in balance. Not all electricity generating technologies have the same technical flexibility when it comes to balancing demand fluctuations or providing back-up capacity for variable RES. Even though all generation technologies can participate in balancing, **hydropower stands out in view of its significant and important benefits. Hydropower participates on the balancing market for upwards or downwards regulation,** which means that the price for balancing relates to the spot price. Hydropower plants with reservoirs are responsive to variations in the spot prices and thus provide a contribution to the balancing market. The typical storage time (i.e. the number of hours a plant can continue to generate electricity before running out of water) for a pumped storage plant is between 4 to 10 hours, or even larger, notably in the Alpine region. Cascaded rivers system with hydro storage (generally in the upper part of a river stretch) may also act on the balancing market in the same way and with even longer endurance.[2]

Products that are traded in the electricity markets are defined according to **specific system needs**. It is crucial to ensure a level playing field for all technologies and products which provide services that meet the system’s needs and requirements. Like conventional reservoir-type hydropower plants, pumped storage power plants can provide the full range of grid-stabilising services in view of their ability to follow demand or generation fluctuations within only a few minutes. There are several different **ancillary services or grid-stabilising services** of hydropower, thus facilitating the integration of variable RES into the power system and providing a key tool for TSOs to maintain a stable and balanced grid:

- **Back-up and reserve:** hydropower plants have the ability to enter load into an electrical system from a **source that is not on-line**. Hydropower can provide this service while not consuming additional fuel, thereby ensuring minimal emissions.
- **Quick-start capability**: hydropower`s quick-start capability takes just a **few minutes.**
- **Black start capability:** hydropower plants have the capability to **run at a zero load**. When loads increase, additional power can be delivered rapidly to the system in order to meet demand.
- **Regulation and frequency response:** hydropower contributes to maintaining the frequency within the given margins through continuous modulation of active power and to **address moment-to-moment fluctuations** in system power requirements. Hydropower`s fast response ability makes it especially valuable in covering steep load gradients (ramp rates) through its fast load-following.

[2] The Limberg II hydropower plant in Austria can operate for 165 hours in pump or turbine mode

- **Voltage support:** hydropower plants have the ability to **control reactive power**, thereby ensuring that power will flow from generation to load. They also contribute to maintaining voltage by injecting or absorbing reactive power by means of synchronous or static compensation.
- **Spinning reserve:** hydropower supports the dynamic behaviour of the grid operation. Hydropower plants can provide spinning reserve – additional power supply that can be made available to the transmission system **within a few seconds** in case of **unexpected load changes** in the grid. Hydropower units have a broad band of operations and normally operate at 60-80% of maximum power. This results in a spinning reserve of up to 100%.

In the Nordic energy market for example, hydropower participates in most of the services such as inertia (together with thermal generation), frequency controlled reserves (including back-up reserve together with gas), voltage control, balancing – short-term and intraday, black start. In France almost one third of the balancing services are provided by hydropower.

Hydropower plants with a small reservoir are sometimes also called **pondage plants**. These are designed to modulate generation on a daily or maximum weekly, basis. Pondage plants can provide flexibility services mainly through balancing power. They also provide frequency and voltage control as ancillary services.

Run-of-river hydro plants have little or no storage capacity. They therefore offer short-term storage possibilities (few minutes dynamic cycle), thus allowing for some adaptation to demand, especially for ancillary services, such as frequency and voltage control. Case Study 1 shows that in a **cascaded river system in Scandinavia**, run-of-river plants are a part of the system and contribute with flexible generation to matching the demand.

To sum up, **flexibility solutions of hydropower** include:

- accommodating large variations in residual demand (since the sun does not always shine and wind does not blow constantly),
- providing increasing ramp rates in real time, caused by sudden changes of production,
- offsetting unexpected variations in production due to forecast errors in the intra-day markets or in the form of balancing power or ancillary services.

2.2. Hydropower – supporting long-term supply adequacy

Hydropower plants contribute to long-term reliability and security of supply by **providing energy and capacity when this is required by the system**. Although hydropower plants are also exposed to variable natural inflows, they are able to provide firm capacity to the power system when needed. Plants with reservoirs in particular provide firm capacity, but run-off river plants can also guarantee a certain level on a statistical basis. Whilst the level of firm capacity may vary depending on hydrological conditions, such as the relative size of the reservoir and the time horizon under consideration, they provide significant benefits to the power system. Pumped storage hydropower plants generally have a short to medium-term storage capacity, depending on the size of their reservoirs. Hydropower plants with larger conventional reservoirs make it possible to store energy efficiently also on longer time scales (i.e. for weeks, months or even on a seasonal scale). Case study 4, carried out in the context of a macroeconomic study on hydropower, shows that **Alpine** pumped storage plants are able to **contribute to the reduction of the expected 6,000 MW deficit** of generation adequacy in Southern Germany.

3. A Challenging Business Environment

Due to severe changes in the business environment for the energy sector today, which are highlighted in a recent EURELERCTRIC report[3], hydropower deployment in Europe also faces several challenges concerning competitiveness.

The electricity sector faced an overall **stagnation, and even decline, of electricity demand** during the economic crisis. At the same time the **RES boom** has led to a major overhaul of the energy system. Variable renewable capacity, which has increased significantly largely as a result of subsidies, has low variable costs, which has contributed to the **drop in wholesale price across wholesale markets.** While at first sight this is understood to be positive for customers, it also works as a disincentive for power generation.

Capital costs are high, while the start of payback is often delayed due to **long permit granting procedures and construction times**. Such long permit granting procedures, coupled with the uncertainty about the future regulatory framework, represent a high risk at the time of the investment or reinvestment decision. Moreover, **administrative barriers and regulatory changes during operation** pose additional challenges. Operation and maintenance costs for hydropower are generally lower compared to other power generation technologies. However these have been increasing due to changing power system characteristics, which require the turbines to adapt to new requirements for flexibility (e.g. pumped storage power plants need to start/stop several times per day). As demonstrated in Case Study 5, experiences with hydropower plant Kops II turbines show that each unit is in operation for over 8000 hours a year, with 10 to 20 mode changes a day. Due to a high number of load changes, there are impacts on the lifecycle of the plant and on the operation and maintenance costs.

Furthermore, **additional investments due to environmental legislation** requirements bring additional commitments. Constant innovation is required in order to maintain global leadership and to deal with the challenges of variable RES integration.

The daily market price profile has changed in recent years and has resulted in a decrease in the price difference between peak and off-peak. This has led to **reduced revenue possibilities of storage and pumped storage plants** on the electricity market. Further uncertainties also arise from the development of **levies and fees for network use**, which represent an increasing burden for the pumped storage. In several EU Member States, existing regulations treat pumped storage both as a generation asset (it is hence required to pay a grid fee for transmission grid access) as well as a final consumer (requiring it to pay the grid access fee a second time). Moreover, the long established principle according to which the storage assets are considered as generation assets and hence are a part of the competitive services of the energy sector is being called into question in some Member States. **Pumped storage ownership claims** by TSOs could potentially have negative effects on the investment framework and could cause conflicts of interest.

There is still **significant hydropower potential** to be optimised at the existing sites and to be further developed at new sites **in Europe** (in energy **over 650 TWh a year**). In order to make the best use of this potential, since further development of hydropower will play a major role to secure system stability in the future, several policy measures need to be taken into consideration by policymakers. These are elaborated in the next chapter.

[3] A Sector in Transformation: Electricity Industry trends and figures, January 2015.

4. Key Policy Measures to improve the Competitiveness of Hydropower

1. Move towards an internal electricity market that properly values energy and flexibility

- Fully implement the European energy market through **integrated forward, intraday, day-ahead, balancing and ancillary services markets** that ensure incentives for flexibility. The design of the current balancing and intraday markets must be improved, for instance by introducing possibilities to trade balancing forward and more **sophisticated and short-term products**, as well as timeframes that better fit the flexibility requirements (ramp-up, ramp-down rates).

2. Ensure that all technologies, sizes, existing and new plants can participate in properly valued capacity markets

- When discussing the introduction of capacity mechanisms aspects related to **cost efficiency** and **compatibility** with the European electricity market as well as **technology openness** need to be taken into account. With the possible introduction of a capacity mechanism, it must be ensured that **hydropower** can participate in relevant procedures without discrimination. This applies both for new as well as for existing installations.

3. Remove double grid fees for pumped storage power plants and ensure a level playing field between storage technologies

- Pumped storage **does not constitute final electricity consumption** and it should therefore not be treated as such when setting grid fees.
- Policymakers should refrain from introducing discriminatory taxes, fees or regulated costs on pumped storage which distort the level playing field and result in a suboptimal use of, and underinvestment in, pumped storage. The basket of **services** offered by pumped storage should be **remunerated** under well-functioning market conditions.
- Create a level playing field in Europe for power generation from domestic water resources, compared with other electricity production and storage technologies, with a special focus on the **value of providing flexibility** to the electricity system.
- Since hydropower and pumped storage are scarce and constitute highly valuable resources, their **potential has to be used** to its optimum on a European or even pan-European scale.

4. Reaffirm that pumped storage is a competitive and not a regulated business

- **Pumped storage plants are electricity generation assets,** and should therefore operate in a competitive and unbundled market environment. While EURELECTRIC recognises TSOs' increasing needs for balancing and system services to maintain grid stability, these services must be provided through market mechanisms and should be remunerated on the basis of market dynamics.

5. Address conflicts between the low-carbon and the environmental agenda

- EURELECTRIC acknowledges the important achievements of environmental legislation, from Natura 2000 to the Water Framework Directive (WFD). In order to ensure a sustainable perspective on water use management, the **WFD should be applied based on a thorough socio-economic cost-benefit analysis** that also considers the full range of water services provided by hydropower. Since hydropower is a site-specific technology, a **case-by-case approach** should be adopted.
- Better **equilibrium** should be established between, on the one hand, the objectives of local **biodiversity,** and on the other, the need to **increase capacity** of existing hydropower plants and the construction of new ones. Hydropower plays an important role in accommodating short term

variations in the power system. Greater attention should therefore be paid to barriers that currently hinder its growth potential.

6. **Incentivise investments in R&D**
   - Investments must be directed towards research, development and deployment programmes that allow equipment manufacturers and operators to improve power plant design and operation, making units more flexible and responsive. For example, activities within the **EU Energy R&D programmes** (including Horizon 2020) should **address hydro future solutions** more frequently, since there is a constant need for optimisation.

Case study 1: Flexibility of Cascaded river systems in Scandinavia

All upstream storage and their hydropower plants' operation affect generation planning in downstream plants. A river stretch is therefore usually planned as a cascaded system in order to achieve overall efficiency and flexibility in the overall operation. A common strategy in hydro development is to build a large storage in the upper catchment area to be able to "tap" flow to the rest of the river at high demand. This creates flexibility not only in the upper hydropower plant but also in the rest of the generation facilities.

L**ong time scale flexibility (from week to season)**: the flexible power is proportional to each plant's head. This includes low head run-of-river plants that use the flow from upstream plants without any substantial intermediate storage.

Peaking flexibility, typically time scale is around a day: there may be intermediate storages built downstream high head plants. In this way a part of the river stretch may contribute with both up and down regulation capacity (from mean flow) and give the same type of service as pumped storage plants.

Ancillary services, reserves in short time scales: all hydropower plants may contribute due to their quick response characteristic. This short time results in less need for reservoir volume. It is important to note that this means that low head run-of-river plants may also contribute to services such as frequency regulation, and this contribution may be especially important in low total demand (e.g. summer nights) when other plants are pausing.

Figure 1 shows an example with generation diagrams from a cascade of six power plants during a week (blue diagrams). The summed generation (brown diagram) matches the load demand. Note that plants D and F, which are run-of-river plants, contribute clearly with flexible generation matching the demand.

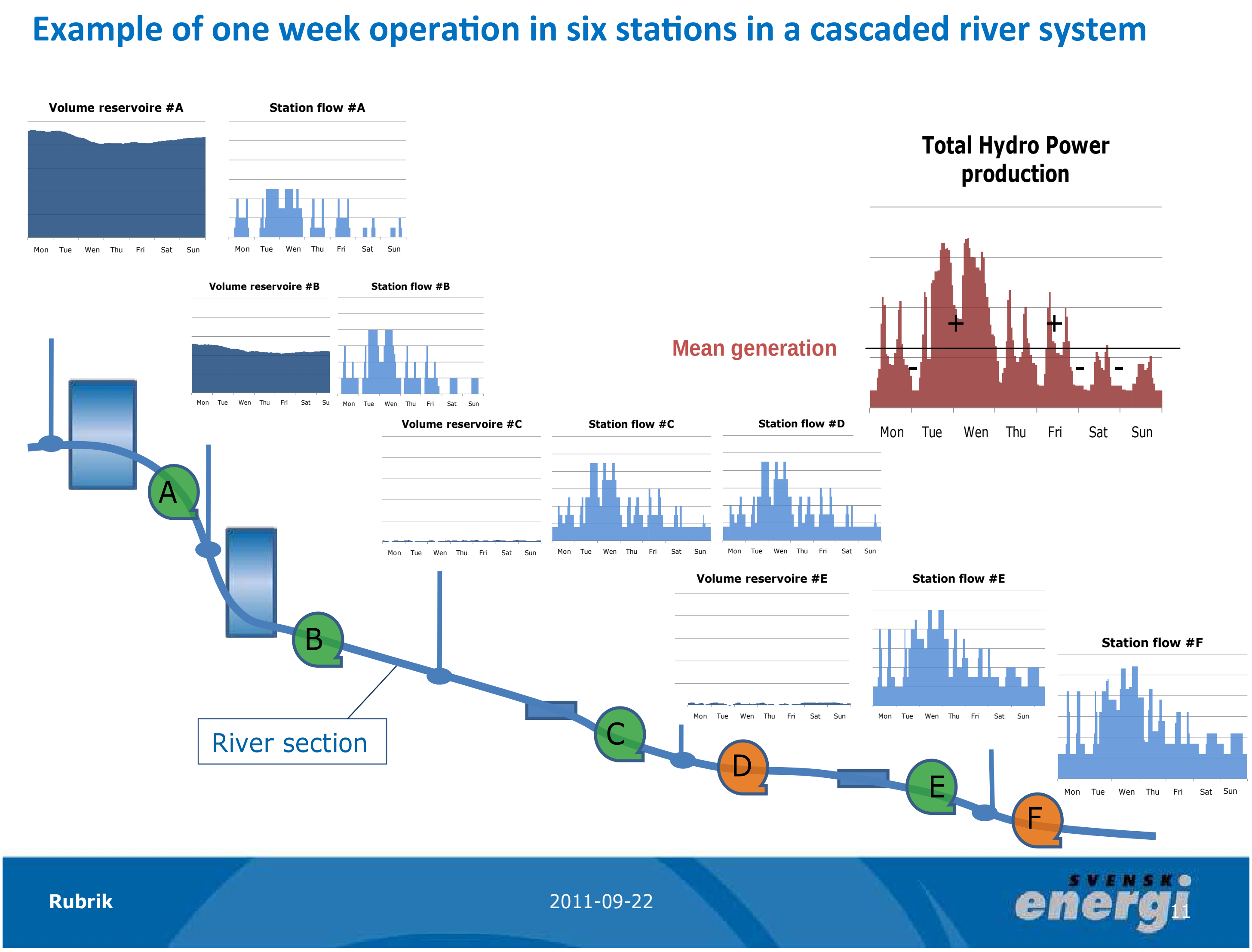


Figure 1: Nordic cascade river system

Case Studies 2, 3 and 4 (Macroeconomic Study on Hydropower)

Flexibility

Figure 2 shows the ability of pumped storage plants to mitigate the effect of a solar eclipse on a sunny day in Germany. Although the installed capacity of pumped storage plants (6.5 GW) is less than 20% that of solar power in Germany, they are able to effectively reduce the rate at which residual load changes. Indeed, the remaining variation is less than the typical ramp rate encountered in the early evening, such that it can be safely supplied by other types of generation, imports, exports and, where necessary, demand response. This example clearly shows how even a limited volume of pumped storage capacity makes it possible to deal effectively with extreme events caused by variable RES.

Flexible use of pump storage plants can help to mitigate the impact of increasing volatility from variable RES even during extreme events

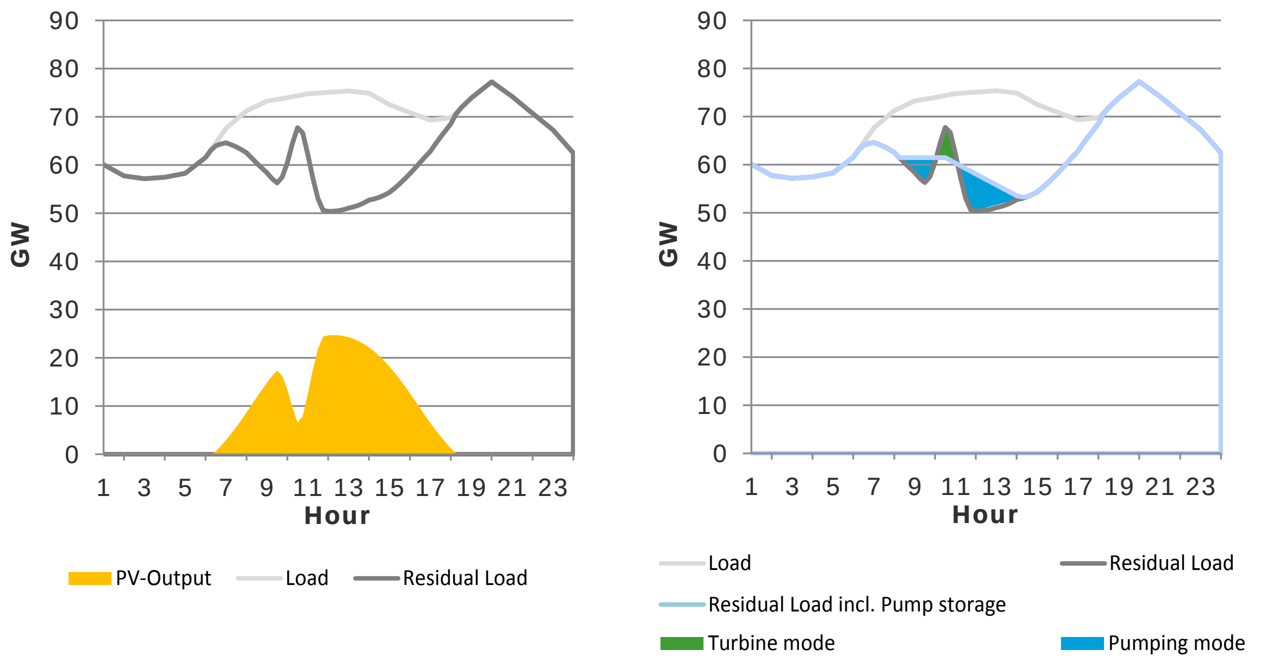


Figure 2: Compensation of PV ramp rates by pump storage plants during solar eclipse in Germany

Similarly, hydropower plants support the compensation of variations in wind and solar generation over several hours or even days. This is illustrated in **Figure 3**, which shows the projected hourly pattern of load and generation on the Iberian Peninsula over a week in summer 2030. This figure shows how the operation of hydropower, including both generation and pump load, is optimised overall several days, in order to balance between days and hours with higher and lower generation from wind and solar plants. Moreover, one can again observe how hydropower helps to “flatten” the generation profile of other generation technologies, thereby also contributing to reduce thermal or mechanical stress and to improve the efficiency of operations of these plants.

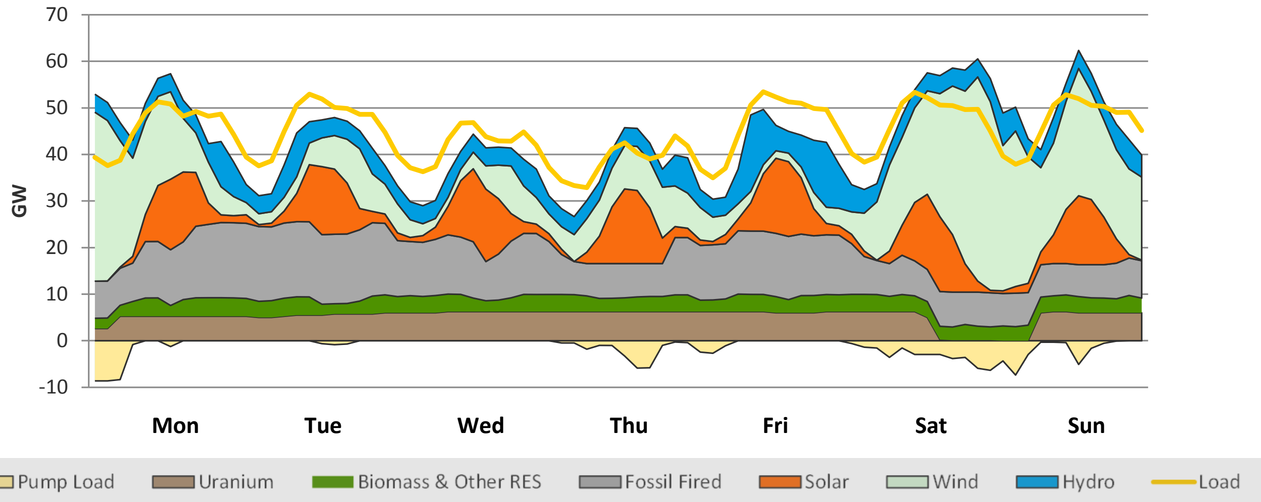


Figure 3: Hourly electricity generation in Iberia for a selected week June 2030, projection

Note: Net electricity exchanges are indicated as difference between electricity demand and generation

Source: DNV GL analysis

Firm capacity

By way of example, **Figure 4** shows the contribution of pumped storage plants to generation adequacy in Southern Germany in winter 2015/2016. German TSOs are planning to procure 6,000 MW of "Grid Reserves" for this period in order to ensure generation adequacy in the region. As Figure 4 illustrates, the need for grid reserves would increase by about one third if there were no pumped storage plants in Southern Germany. Similarly, the need for grid reserves can nearly be covered by pumped storage plants from the "DACH"[4] region, even without considering the potential contribution from hydropower storage.

Pumped storage plants are able to help to reduce the expected 6,000 MW deficit of generation adequacy in Southern Germany

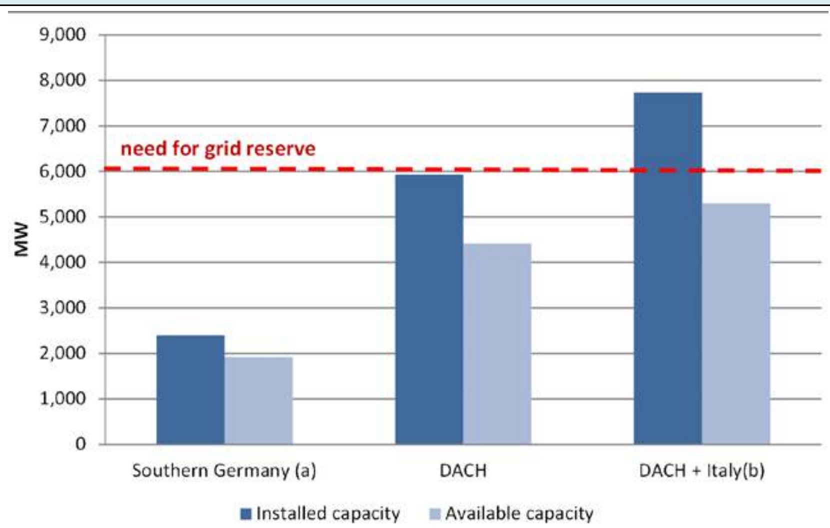


Figure 4: Contribution of Alpine pumped storage plants to generation adequacy

Notes: Available capacity based on installed capacity, assuming an average availability of 80% and additionally considering the available storage volume from all relevant pumped storage plants (assuming an average specific storage capacity of 8 h)

DACH - Germany, Austria and Switzerland

(a) – Analysis limited to pumped storage plants located in Southern Germany

(b) – Contribution of Italian pumped storage limited to maximum export capacity to Switzerland

Source: DNV GL analysis

[4] Germany, Austria and Switzerland.

Electric Storage

Figure 5 shows the positive effects of Nordic hydropower on the use of wind power in Western Denmark. In the year 2013, the close coupling of Western Denmark with hydropower in Southern Norway made it possible to resolve most instances of negative residual load (i.e. cases when there was an excess of electricity in Western Denmark).

Access to Nordic hydropower avoids curtailment of wind power in Western Denmark by exporting excess electricity to Norway

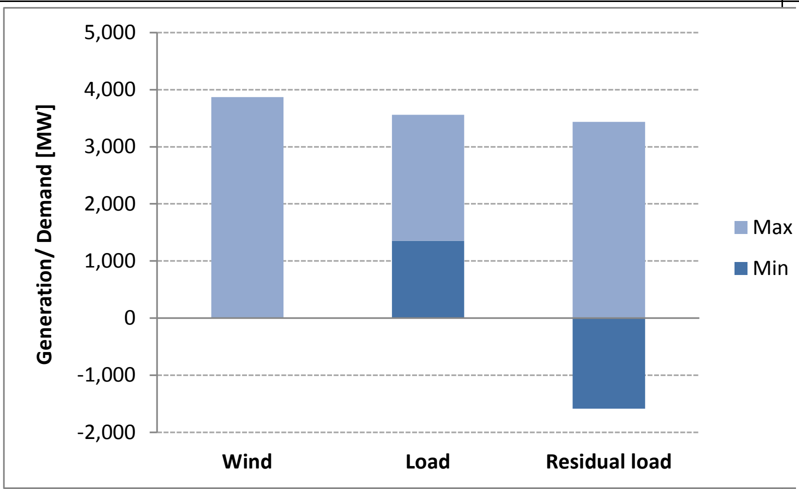
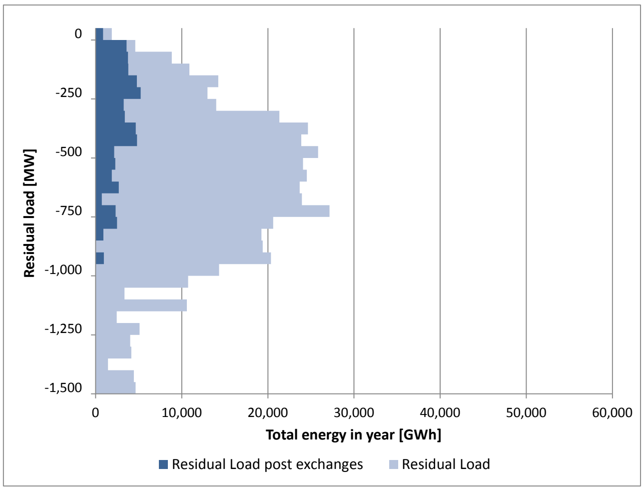
Wind generation vs. demand (minimum and maximum values)	Distribution of negative residual load (excess electricity) with and without cross-border exchanges
	

Figure 5: Reduction of negative residual load in Western Denmark by Nordic hydropower (2013)
Note: Right graph shows total energy available in hours with excess electricity (negative residual load) in the year 2013
Source: DNV GL analysis

Case study 5: Flexibility – Secure Electricity Supply, One Core Skill of Hydropower

(*Peter Matt, Vorarlberger Illwerke AG*)

It is significant that the turnaround in energy policy has led to a huge increase in the capacities of (photovoltaics) PV and Wind-Power. But PV and wind alone cannot guarantee secure electricity supply. Recent studies from Fraunhofer, BDEW, DENA, CONSENTEC etc. have shown that the amplitudes of oscillations of the residual load will increase. Furthermore, a trend to more negative values will arise, while positive values are decreasing. Four compensatory measures are therefore considered necessary in order to ensure security of electricity supply:

- Flexible power plants
- Energy storage
- Transmission lines
- Load management

Today, pumped storage and storage hydropower plants are the most efficient way to meet the challenge of flexibility and storage. They help to integrate renewables (wind and PV) by controlling the surplus energy or satisfying the demand immediately. What are the conditions for the design of new pumped storage power plants (PSPP)?

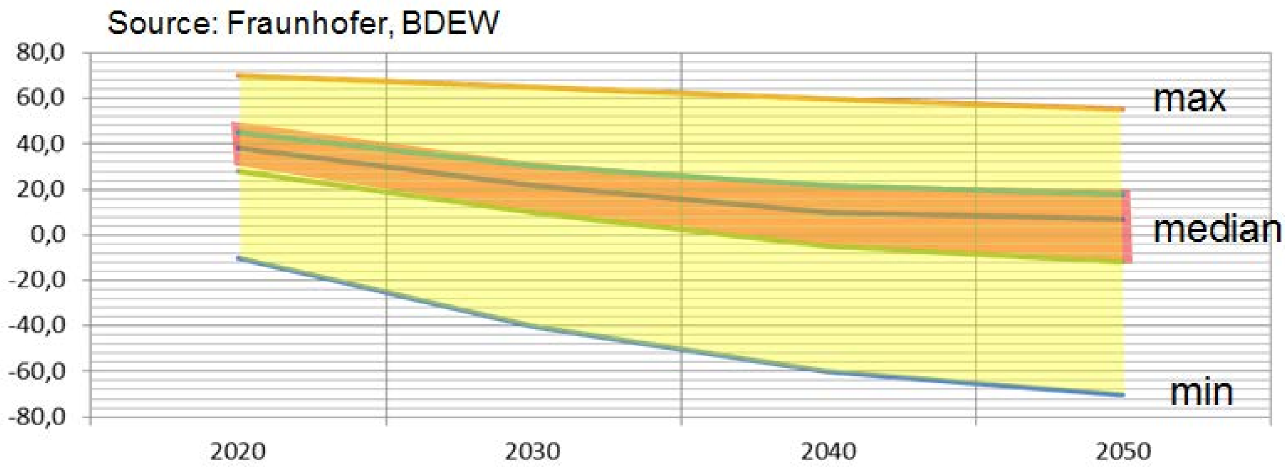


Figure 6: "Development of Residual Load until 2050"

Source: Fraunhofer, BD

- Positive value of residual load will decrease
- Residual load tends to negative values
- Spread between max and min will increase -> Increase of flexibility,

Today, maximum amplitudes of the residual load are from -1 to +1 GW within 15 min. German TSOs' predicted maximum power ramps within 15 min ranging from -2 to +3 GW in 2020 and from -6 to +7 GW in 2050.

On 20 March 2015, the solar eclipse provided a stress test of Germany`s existing electricity system. One can say we passed the stress test for the future. Austria met the challenge of the steep ramps from -280MW/min to +370MW/min which this day presented by excessive tendering of primary and secondary reserve. For example, all generators of the storage hydropower plants in Austria were under rotation and the responsible operational staff was on call. Predictions for 2050 estimate ramps between +/-700 MW/min.

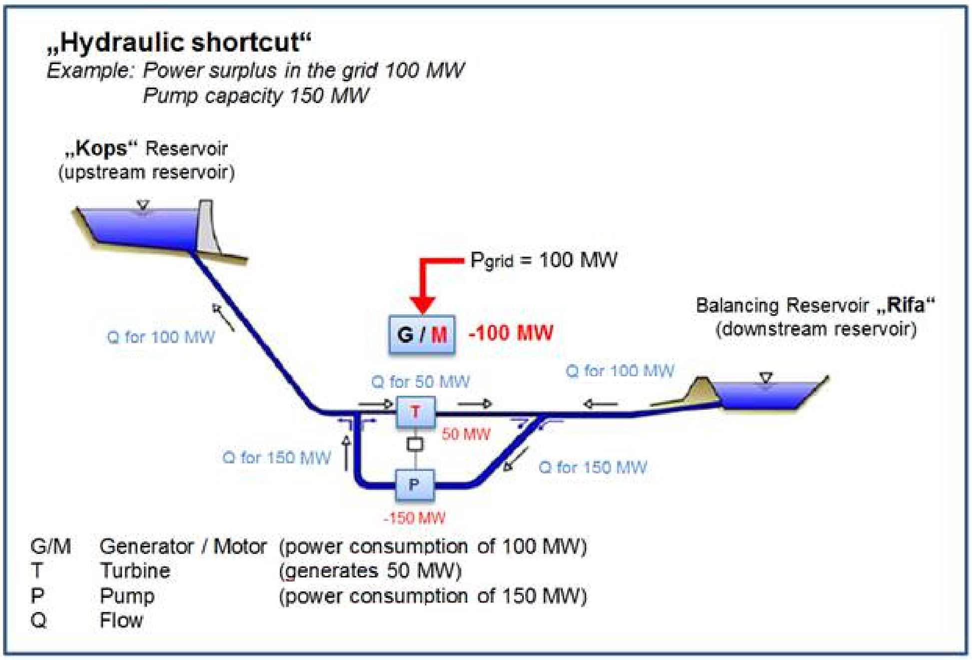
Flexibility and storage are among the key features of hydropower. It is not possible to separate both terms because opportunities for storage are needed in order to have flexibility. Hydropower in Europe currently provides storage capability of 220 TWh. The bigger the energy storage opportunities, the bigger the flexibility is. In addition to storage, the technology for units of hydropower plants is relevant for flexibility.

The conventional pump turbine design (the reversible single stage Francis pump turbine, which acts as turbine in one direction and as pump in the other) is able to generate in a very flexible way. The limiting factor to this flexibility is the hydraulicity of Francis-pump turbines and their characteristics in pump mode. Usually pump turbines in turbine mode have low efficiency in the part load area ranging from 0 to 40% of the maximum load. Due to vibration characteristics, this part load area for generation should be avoided. In the reversible mode (pump mode) the Francis pump turbine is like a digital instrument – the pump is either on or off. Exemptions are variable speed units: these make it possible to improve the part load operation range to 30% of rated output in turbine mode, and the controllable load in pump mode operation to between 70% and 100% of the rated power. In order to change from one mode to the other, the rotation direction must be reversed within minutes. To dispatch operation between +100% and – 100% of the rated power it is possible to use two or more units.

At the beginning of the turnaround in energy policy, Vorarlberger Illwerke AG planned to add a parallel PSPP Kops II to the existing hydropower plant Kops I, with an upper reservoir of 40 Mio m³, a lower reservoir with 1.2 Mio m³ and a gross head of 800 m. With a view to the future electricity market, the core intervention was to design most flexible units to meet all power control demands. Kops II was commissioned in 2008 with 3 ternary units (pump with hydraulic coupling, generator, Pelton turbine). Since then, every unit has been operating for more than 8000 hours a year. The technical details are as follows:

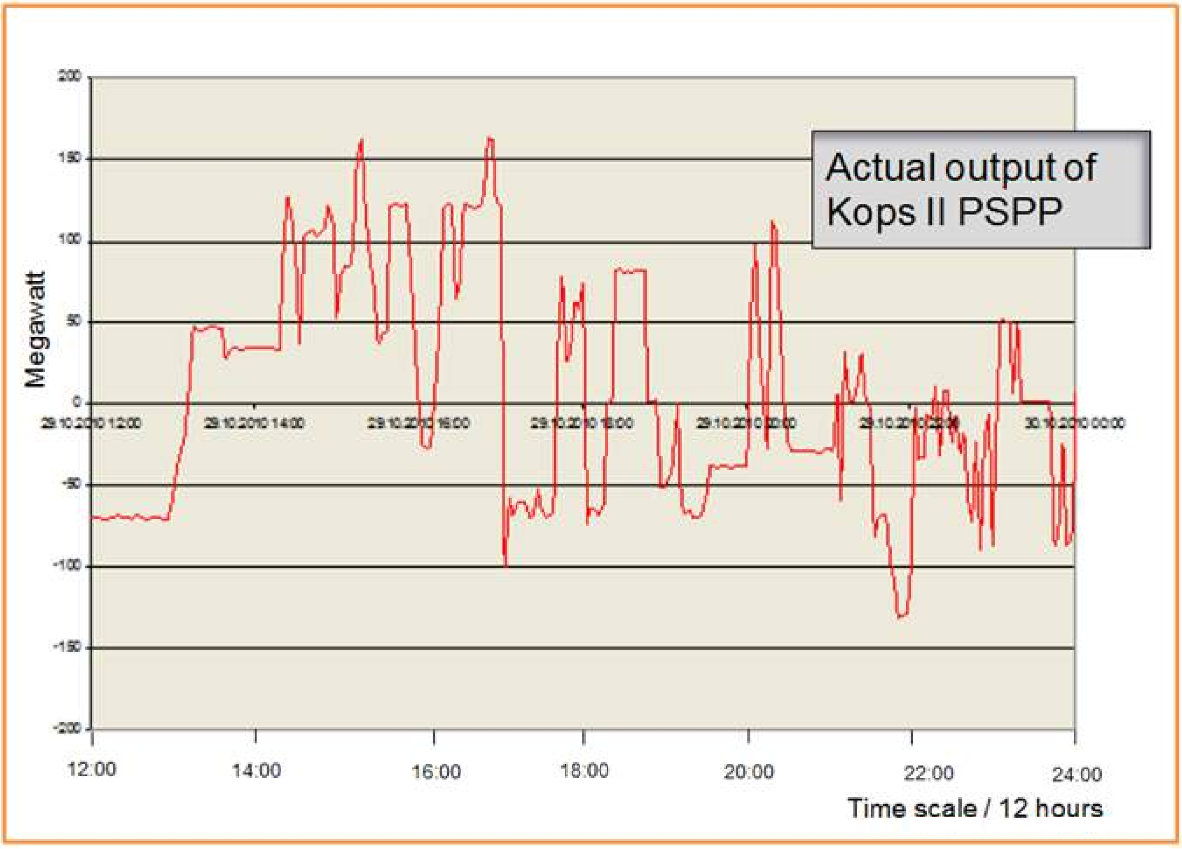
- operational bandwidth ranges from -150 MW to + 170 MW (per unit); and
- the quick response time of 30 sec from 0 load to full load (+/-)

This can be realised by using the hydraulic short circuit with a controllable pump by the turbine (possible with Pelton and Francis turbines).

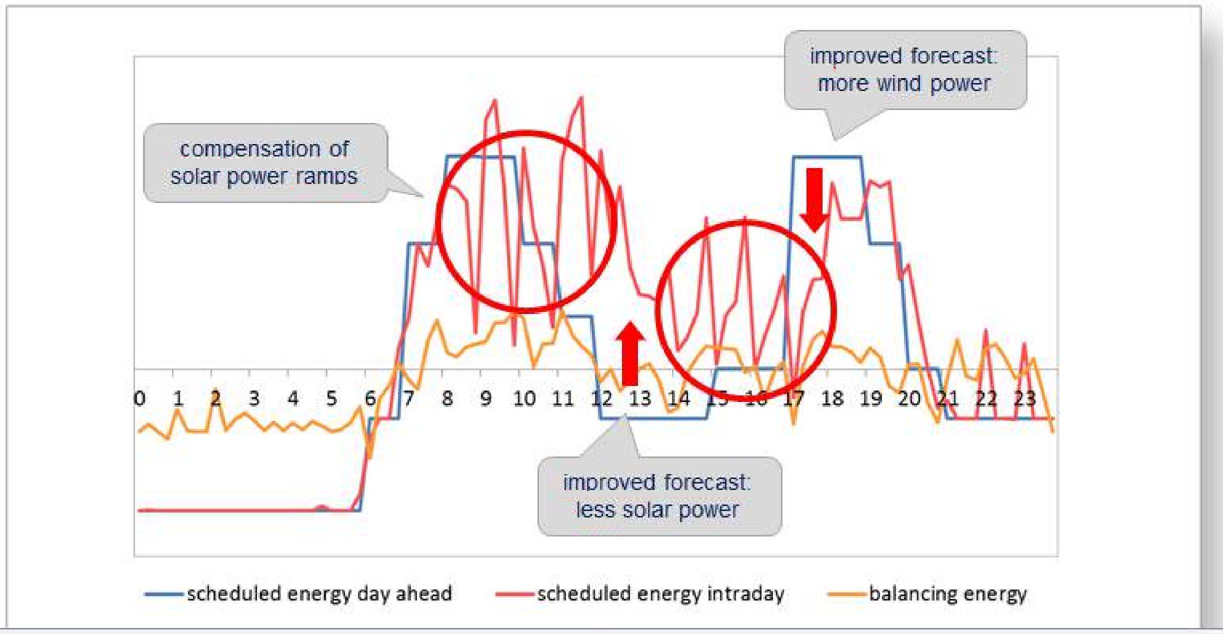


Due to the design of the hydraulic short circuit, there is an opportunity (with one unit) to meet the whole operation area between -100% and + 100% of the rated power. Within less than 30 seconds, a change from turbine to pump mode or from pump mode to turbine mode is available.

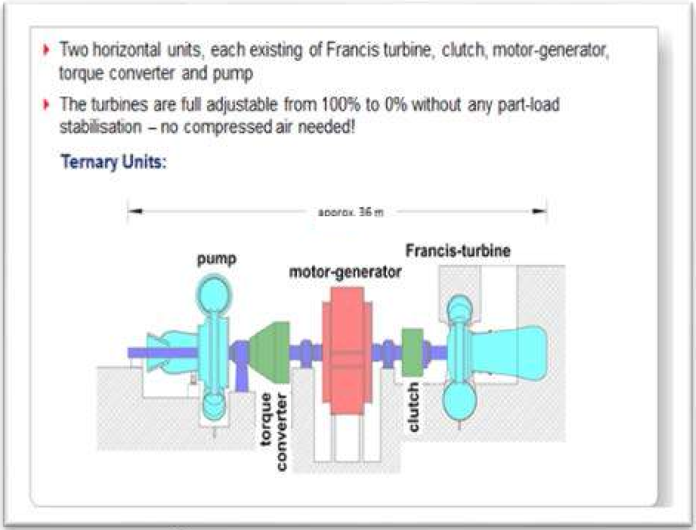
The diagram below shows a day load of one unit of Kops II with several mode changes (ternary units – Pelton turbine, motorgenerator, pump).



The following diagram shows an example of dispatch of a PSPP considering the winning bids (day ahead, intraday, secondary reserve)



With this design of the PSPP, as well as the constraints of the existing infrastructure (large reservoirs, high precipitation, natural inflow, huge gross heads, very well connected to the high voltage transmission lines in Germany and Switzerland), the storage hydropower plant and the PSPP in the Alps are essential in order to enable the turnaround in energy policy. In parallel with sustainable primary generation, hydropower covers all system requirements with the most efficient technology today e.g. inertia reserve, primary reserve, secondary reserve, minute reserve, reactive energy, black start facilities etc.



One unit OBERVERMUNTWERK II (under construction 2 x +/- 180 MW)

One unit KOPS II (3 x -150/+170 MW)

Technical data:	KOPS II	OVW II
Long term storage	75 GWh	30 GWh
Short term storage	3 GWh	5 GWh
Capacity turbine mode	**520 MW (3 x 173 MW)**	**360 MW (2 x 180 MW)**
Capacity pump mode	450 MW (3 x 150 MW)	360 MW (2 x 180 MW)
Full load hours pump mode	6 hours	12 hours

Experience with Kops II shows that each unit is under operation for over 8000 hours a year, with 10 to 20 mode changes a day. Because of the high number of transient procedures there are impacts on the lifecycle of the plant, especially components which are exposed to cavitation. Therefore the costs of operation and maintenance are higher compared to conventional units.

Specific costs of PSPP capacity with the ternary machine sets without new reservoirs are between 800.-EUR/kW to 1400.-EUR/kW. The difference depends on the existing infrastructure e.g. existing reservoirs, existing high voltage transmission lines, gross head, natural inflow into the reservoirs etc.

Machine cavern Kops II

Access tunnel OVW II – under construction

EURELECTRIC pursues in all its activities the application of the following sustainable development values:

Economic Development

- Growth, added-value, efficiency

Environmental Leadership

- Commitment, innovation, pro-activeness

Social Responsibility

- Transparency, ethics, accountability

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