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Multifunctional Power Plant
Pumped storage

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A successful energy transition – with pumped storage hydropower plants

The energy transition is completely transforming the German electrical energy system. The previous primary energy sources, such as coal or uranium, are to be replaced by volatile renewable energies (RE). However, the successful integration of these fluctuating sources requires a change of the existing system architecture of the German electricity supply. That is because the generation of renewable energies from wind and photovoltaics occurs independently of demand. As a result, systems with a high percentage of RE generation must store the electric energy so that it will be available for later demand.

At the moment, the focus is on expansion of the network, demand-side management, and the use of new thermal power plants (e.g. gas-fired power plants) in order to compensate for fluctuations in generation and to minimize RE curtailment. However, there are two important challenges which have not been considered enough in previous studies. One is the availability of sufficient flexibility in the German electricity grid when electricity generation from renewable energies is very high. And the other is ensuring the system adequacy (reliable available capacity) if little energy is generated from renewable sources.

Consideration of pumped storage hydropower plants as "multifunction power plants"

In order to illuminate these aspects, Voith Hydro commissioned a study in 2013 from the Chair and Institute of Power Systems and Power Economics (IAEW) at the RWTH Aachen University. The study examined the role of pumped storage power plants (PSP) which not only fulfill the required job of storage, but also provide reliable available capacity and flexibility. It was based on a simulation of the entire German generation system and its operation. The special feature of the examination was the macro-economic evaluation of the combined usage options in daily cycling storage operation mode. The study looks at two future scenarios offering a detailed analysis of a new role of pumped storage plants within the German electricity system. The first scenario considers power production in Germany in the year 2030 with an RE share of 60 %, the second assumes an RE share of 80 % in the year 2050.

The study showed that pumped storage hydropower plants are able to reduce the reliable available power previously provided by thermal power plants. In a 60 % scenario, pumped storage hydropower plants with a capacity of 15 GW and a storage volume of 96 GWh replace up to 13 GW from gas-fired power plants. In the 80 % scenario, 23 GW pumped storage hydropower plants with a storage volume of around 152 GWh replace up to 16.6 GW thermal power plants.

Pumped storage hydropower plants store excess "green" energy and release it later. This significantly prevents the curtailment of renewable energies. The study showed that, with pumped storage hydropower plants, we in Germany could re-cycle approximately 70 % of the excess generated by wind power and photovoltaic plants in 2030. The stored RE excess would be stored and released CO_2-free.

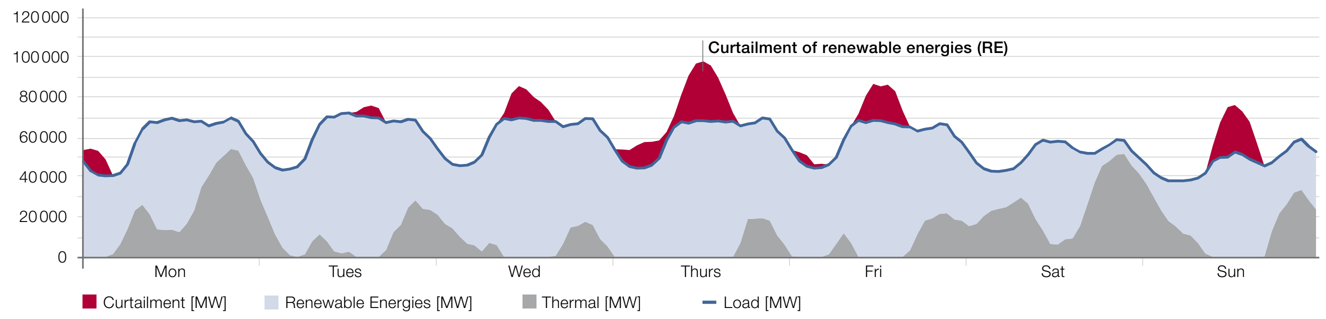
Pumped storage hydropower plants react very flexibly and dynamically to fluctuations in generation and consumption and can compensate for them reliably and at short notice. This flexibility is very important for a high quality of supply, especially with the planned further expansion of renewable energies. Even in the event of negative residual loads, that is when there are still excesses from renewable energies despite shut down thermal power plants, pumped storage can prevent the curtailment of wind and photovoltaic plants. Thermal power plants are not able to provide such "negative" power.

The use of pumped storage hydropower plants allows for a more resource-efficient and economical operation of the existing thermal generation system, and supply interruptions for consumers in both industry and private households can be largely avoided. In this way, they ensure that fewer thermal backup power plants must be maintained, while power is nevertheless assured – and with high efficiency. Because pumped storage hydropower plants have a very high efficiency of 80 %. Conventional thermal power plants achieve only approximately 40 %, gas and steam power plants or combined heat and power plants around 60 %.

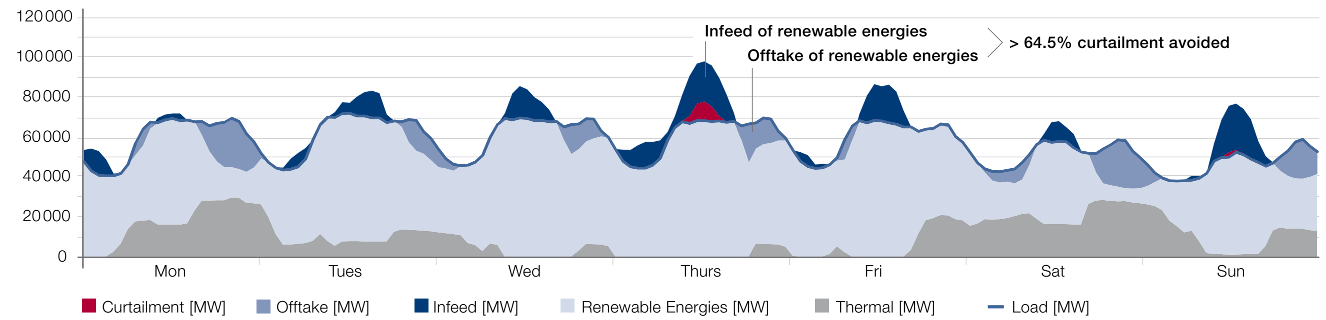
Impact of pumped storage use at 80 % share of renewable energies (2050)

Load profile[2] over one week with and without pumped storage power plants 2050 (80 % renewable energies)

Without pumped storage power plants



With pumped storage power plants



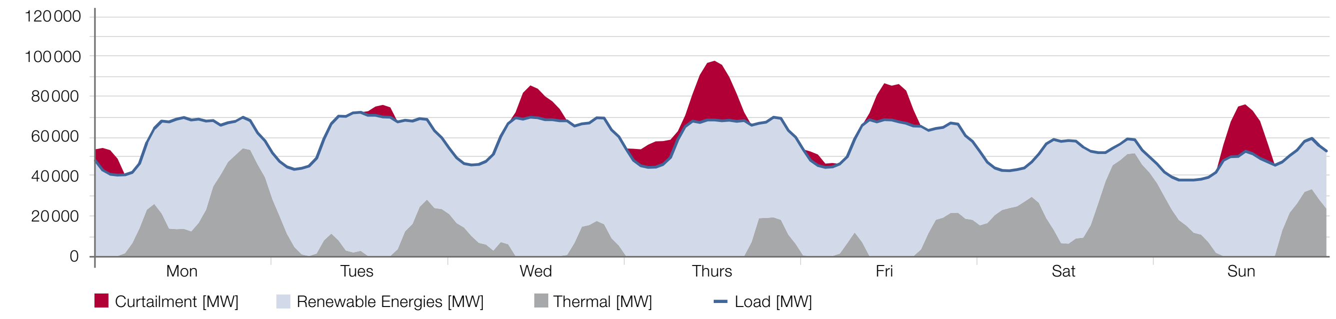
[2] Example load profile with reference to all of Germany from the IAEW survey

Integration of renewable energy surpluses by pumped storage power plants

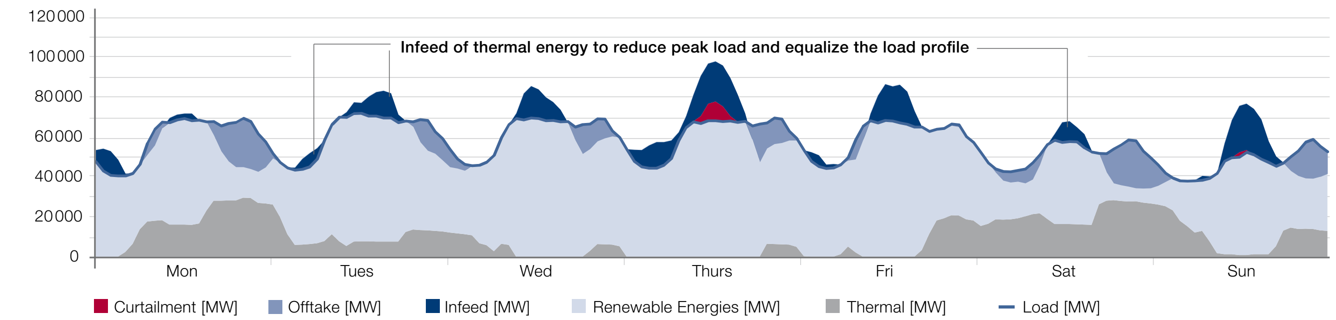
Almost on a daily basis, excess electricity is generated from renewable energies that cannot be compensated even if all thermal power plants are completely shut off. During these times the pumped storage fleet absorbs 64.5 % of the renewable energy surpluses and returns them back to the grid again a short time later, thus avoiding curtailment of wind power and photovoltaic systems.

Load profile[2] over one week with and without pumped storage power plants 2050 (80 % renewable energies)

Without pumped storage power plants



With pumped storage power plants



[2] Example load profile with reference to all of Germany from the IAEW survey

Optimization of thermal power plants by pumped storage power plants

Through targeted peak electricity generation from pumped storage power plants, fewer fossil-fired power plants need to be in operation. In the 80 % scenario there are no longer any lignite-fired power plants. The full-load hours of the efficient combined heat and power plants (CHP) and remaining power plants are increased. As in the 60 % scenario, the load profile of the fossil-fired power plants is also balanced out by pumped storage, resulting in the same benefits.

Economic and ecological benefits
Furthermore, the study demonstrates that the expansion of pumped storage hydropower plants by 8 GW by 2030 and by 16 GW by 2050 can be macro-economically viable. The macro-economic benefits are already clear through balancing the savings for investments in gas-fired power plants and in levelized cost of electricity (80 % fuel costs / 20 % emissions certificates) against the investment costs for pumped storage hydropower plants. In 2050, this results in an economic benefit of 184.4 million Euro per year.

Another macro-economic advantage comes from the optimized use of the remaining thermal generation systems. For example, start-up and shut-down losses are minimized, because the load of the remaining conventional power plants is peak-shaved and smoothened, and thus they are in longer and constant use, but at a lower level. Furthermore, additional ancillary services can be supplied by pumped storage for improving grid stability. However, these services were not monetarily evaluated in the study. In exceptional situations, such as a blackout, pumped storage hydropower plants are able to build up the network without external auxiliary energy, because unlike thermal power plants they are capable of black starts.

The CO_2 balance is improved through the "recycling" of electricity from renewable sources. In 2050, CO_2 emissions will be reduced by up to 2 million metric tons per annum through the use of storage, because it prevents curtailment of RE and therefore the released RE from storage substitutes CO_2-free fossil fuels. Moreover, efficient combined heat and power plants can be better used over the long-term and achieve a higher utilization.

Regulation and legislation authorities
However, these benefits can only be achieved, if some factors regarding regulation and legislation are adopted:

a) The majority of existing studies on the development of the power plant fleet in Central Europe only consider a provision of reliable available capacity by flexible thermal generating systems, i. e. gas turbines and gas power plants. However, as is shown here, PSPs can provide reliable available capacity as well. Therefore PSPs should be considered, when potential capacity mechanisms are discussed. This is state of the art in other European countries.

b) Changes in electricity market design should focus more on the value of short-term available flexibility. PSPs will also benefit from such measures, as they are multifunctional power plants (reliable available capacity, balance energy in case of forecast errors, extremely steep load gradients etc.).

c) Explicit consideration of energy storage in legislation and exemption from load duties. These measures should affect the existing PSP fleet as well as planned expansions.

d) Present and future net export of German RE surpluses to neighboring countries (often at very low prices) should be significantly reduced in order to substitute Germany's own fossil fuels consumption. Presently these RE exports replace fossil and nuclear energy carriers abroad and improve the CO_2 balance of the neighboring countries at the cost of the German parties paying the EEG surcharge (German renewable energy surcharge). One of the consequences thereof is that one of the main goals of the energy transition is presently being missed.

From a political point of view, the expansion of pumped storage can also be of interest beyond the context presented here. Firstly, the associated investments result in macro-economical benefits (e. g. additional jobs) especially compared to the consumption of fossil energy carriers. Secondly, another obvious political benefit is the reduced dependence on gas imports.