Storing wind energy underground

Abandoned mines could serve as pumped storage power stations – researchers looking into strategies and potentials

Pumped storage power plants have been in use for over a hundred years to balance fluctuating electricity loads and to cover peak loads. The energy transition creates additional storage demand with its fluctuating feed-in of wind and solar power into the grid. New sites, however, are scarce. Whether the large differences in the tunnel heights of abandoned mines are usable or not is currently being investigated by an interdisciplinary team of researchers on the basis of two viable locations.

Pumped storage power plants store electricity in the form of potential energy. Using surplus electricity, water is pumped out of a lower reservoir into a higher surface reservoir. With a water turbine, the potential energy can then be converted back into electricity during demand peaks. The efficiency of the overall process is on average about 75%. The storage capacity is proportional to the usable height difference and the stored water volume.

Nearly 40 above-surface pumped storage power plants with a total output of about 7 GW and a capacity of about 40 GWh are currently in operation in Germany. A further expansion is possible only to a very limited extent because conventional pumped storage power plants rely on suitable terrain profiles. Such locations do exist but environmental impact and significant land use cause acceptance issues for these projects.

For this reason, it is appealing to use existing mines as underground storages – an idea that is yet to be implemented anywhere. The main components, the upper and lower reservoirs, the hydroelectric power cavern with the generating set and the electrical systems as well as supply and return lines for electrical power and grid connection are mostly arranged underground. In a hybrid variant, a pond or lake may serve as an upper or lower reservoir. This not only reduces the effort underground...
but it also increases the drop height of the pumped storage power plant and thus its storage capacity.

The potential in Germany

Mostly hard coal, pitch coal, potash salt, rock salt, ores, spar and shale are or were mined underground in Germany. In total, there are more than 100,000 underground mining structures. However, only a small number of those are suitable for use as underground pumped storage power plants. For example, explosive gases are to be expected in hard coal and pitch coal mines, dissolution and reprecipitation processes in salt mines while mines in loose rock require extensive safety efforts. Exclusion criteria also include toxic or environmentally hazardous materials that could be released. Access to still mineable deposits must also remain secured.

Summarising all restraints, ore mining regions in which suitable mines can be found with a high probability remain viable. In Germany, these include the Erzgebirge, the Siegerland with the Lahn-Dill area and the Harz. Within the framework of the project “Windenergiespeicherung durch Nachnutzung stillgelegter Bergwerke“ (wind energy storage through the reuse of abandoned mines) funded by the German Federal Ministry for the Environment, the scientists at the Clausthal University of Technology and their project partners identified 104 underground mining structures that were either suitable or suitable to a limited extent.

For a rough estimate of the total potential, the researchers made the simplifying assumption that a storage system can be built with an output of 100 MW and a capacity of 400 MWh at each of these locations. This results in a theoretical total output of around 10 GW and a storage capacity of 40 GWh. This would double today’s installed pumped storage capacity and output in Germany.

Taking a closer look at model mines

Based on two specific case studies, an interdisciplinary team of mining professionals, mechanical engineers, electrical engineers, lawyers and businessmen examined the complex problems that have to be solved when constructing an underground pumped storage system. They selected the former ore mine Pöhla in the Erzgebirge and the Wiemannsbuchtschacht mineshaft in the abandoned ore mine Grund in the Harz as model mines. For these locations, they explored technical, legal, planning and economic aspects that will be presented here using the Grund mine as an example. In conclusion, they consider both mines viable.

Grund mine: Storage construction scenario

Geologically, the Grund ore mine is part of the north-western Upper Harz. Various metal ores, especially silver-rich lead ores and their accompanying ores, were mined here. The Wiemannsbuchtschacht mineshaft along with three other shafts comprise the mining claim of the ore mine. It reaches down to a depth of 761 m and its inner diameter is at least 3.5 metres. It is currently sealed by a concrete plug down to a depth of 130 m. Accumulating pit water has flooded the lower cavities up to the height of the Ernst-August Gallery. In order to retrofit the mine, the researchers developed the following scenario:

After removing the concrete plug and the water inside the mine workings, the shaft is then to be restored. At the same time, drivage and securing of the reservoirs and the hydroelectric machine cavern begins. The storage tanks are not designed as a single contiguous cavity but as a linked system with a cross-section of 5 m by 7.5 m and with a spacing of 15 m. This way, a usable storage capacity of about 240,000 to 260,000 m³ can be created with an average drop height of 700 m. Additional shafts and drifts are constructed as transport and escape routes. Depending on the output of the power plant, a cable channel for high or extra-high voltage cables may also be required. For grid connection on a voltage level of 110 kV, approximately 6 km need to be bridged up to the 110-kV overhead power line of Harz Energie Netz GmbH.

The sub-assemblies of the generating set are brought into the hydroelectric machine cavern via the shaft. For power generation, the water flows from
the upper reservoir into the lower reservoir through a Francis turbine that drives an electric generator. While pumping, the generator operates as the motor of a two-stage pump that returns the water.

**Economic efficiency**

Depending on the scenario, the specific investment costs of the pumped storage power plant at the Grund site are within the approximate range of 1,800 euros/kW at a storage capacity of 400 MWh. For a pilot plant, the expected costs would amount to a total of around 180 million euros. The largest cost item is underground work with 60%. The expected cost for mechanical engineering is 26% and around 12% for the grid connection. With a hybrid solution, i.e. the construction of an aboveground reservoir, further savings are possible. Underground work increases the specific investment costs significantly more than aboveground pumped storages (between 650 euros and 1,435 euros per kW). However, it is unknown to which extent new locations for surface pumped storage power plants are even eligible for approval or would be publicly accepted. Adding to that, the costs of mitigation and compensation measures may be significantly higher than in the past. After comparing costs with possible revenues, it becomes clear that trading on the spot market exclusively is by far not enough for an amortisation. Reactive power provision or marketing black-start capability as a service is not enough. This could change if a majority of the revenue could be generated by pure power provision alone. The researchers therefore see the uncertainties in how the legal framework for the electricity market might develop rather than technical issues as the biggest obstacle to a specific investment decision.

**Approval and acceptance**

An underground pumped storage power plant has not yet been realised in Germany. Therefore, there is no experience in terms of its legal classification. Issues investigated were in particular emission control, mining law, water law, construction law, waste legislation, energy industry provisions and environmental impact assessment. An approval seems to be generally possible under the current regulatory framework. A consideration of each specific case is necessary because the approval-related legal situation depends on the location. Given the scale of pumped storage schemes, joint processing of approval requirements in one administrative proceeding would be desirable. Acceptance risks arise mainly from the competitive relationships with other goods, such as water protection zones, the preservation of the country’s historical heritage and damage to the environment or persons. For example, the Ernst-August Gallery has recently been declared part of the World Heritage of the “Upper Harz Water Management System”. The shaft buildings are listed national monuments. The nearby water protection zones and landscape conservation areas and a site protected under the Habitats Directive must also be considered when planning.

The locations of Bad Grund and Pöhla exhibit highly complex characteristics, so that no general statements on acceptance can be made based on individual case assessments. In addition, the factors influencing acceptance can indeed be identified qualitatively, but their actual weight in the population can only be discerned after implementing the pumped storage power plant.

**Conclusion**

The researchers reached the conclusion that the construction of a pilot plant at the Wiemannsbuchtschacht mineshaft is in principle possible in technical, legal, environmental and economic terms given a careful consideration of environmental consequences and acceptance. In further steps, they aim to draw a detailed plan for a pilot plant and evaluate it with a cost-benefit analysis. The preliminary investigations could be completed in 2014. A first small pilot plant for research purposes could be realised in the period between 2015 and 2018 at the earliest.
Energy storage systems in the grid

The electrical power supply system is facing the biggest upheaval since its liberalisation in 1998. While power generation – especially wind energy – tend to be increasingly shifted to regions in northern and eastern Germany with their relatively low demand for electrical energy, the main consumption areas are in the west or in the south of Germany. In addition, there are temporal fluctuations in generation and load curves, whose compensation pose an increasingly difficult challenge to grid and power plant operators. Energy storages could play an important role in facing this challenge.

To compensate for the longer-term variations over weeks, months or even seasons, very large energy storages are needed. No technology is yet established on a large scale for this purpose. The small number of storage cycles throughout the year also makes it difficult to develop economical solutions.

Short-term load and generation fluctuations, for example as caused by storm shut downs of wind turbines, require high-performance and responsive flexibilities, for example on the consumption side (by load management) or by storages. Underground pumped storage power plants can start up automatically upon failure of grid power supply and in turn supply other power plants with the power required for startup. With this black-start capability, they increase security of supply within the power grid.

With the Energy Storage Funding Initiative, the three German Federal Ministries of Economics and Technology, the Environment and Research pool research expertise and resources to give the energy transition the necessary tools. The ministries are providing around 200 million euros for research projects of the funding initiative until 2017. The aim is to develop a wide range of storage technologies for electricity, heat and other energy sources. Two “flagships” are in the spotlight: the material storage of wind energy in the form of hydrogen or methane as well as the further development of battery systems for grid stability. Another research focus is heat storage. In particular, latent heat storage and chemical storage as well as projects related to renewable energy are being focussed on. The projects of the funding initiative are being documented continuously on the web portal at forschung-energiespeicher.info.