Underground Pumped Hydro Storage

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SCOPE

• Pumped Hydro Storage Power Plants in General – Mode of Operation, Typical Applications, Limitations

• Underground Pumped Hydro Storage (UPHS) – Overview
  • Why to Go Underground
  • Basic Concepts in Mines
    • abandoned mines
    • active mines
    • virgin rock
  • UPHS in Salt Caverns
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Pumped Hydro Storage

- By conventional Pumped Hydro Storage large amounts of Energy are stored with a high efficiency ($\eta > 80\%$).
- PHS Goldisthal / Germany
  $W = 8\,500\,\text{MWh}; \ P = 1\,080\,\text{MW}$
  $12\,\text{Mio. m}^3\ \text{Water}$

Source efzn
Potential of PHS

Pumped hydro storage has the highest storage capacity, however below natural gas or hydrogen storage.

Produced Electricity by Pumped Hydro in GWh in Some Selected European Countries

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Belgium</td>
<td>624</td>
<td>889</td>
<td>1.237</td>
<td>1.307</td>
<td>1.348</td>
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<tr>
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<tr>
<td>Germany</td>
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<td>4.187</td>
<td>4.176</td>
<td>7.015</td>
<td>6.785</td>
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<td>0</td>
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<td>0</td>
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<tr>
<td>Finland</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>Latvia</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Luxemburg</td>
<td>746</td>
<td>743</td>
<td>737</td>
<td>777</td>
<td>1.353</td>
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<tr>
<td>Netherlands</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Austria</td>
<td>988</td>
<td>1.037</td>
<td>1.369</td>
<td>2.319</td>
<td>3.163</td>
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“Pumped-hydro energy storage: potential for transformation from single dams”, European Commission, EUR 25239 EN - 2012

- Pumped hydro storage is restricted by the geodetic conditions.
- Suitable geodetic conditions for PHS are limited and in some countries not present at all.
- Therefore underground-PHS in abandoned mines or similar locations is an option to store electricity from renewable energy.
# Pros & Cons

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
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</thead>
<tbody>
<tr>
<td>Standard practice since …. years</td>
<td>Major environmental impact</td>
</tr>
<tr>
<td>High efficiency (&gt;90%)</td>
<td>Low volumetric energy density</td>
</tr>
<tr>
<td>High reliability</td>
<td>Low acceptance for additional PHSs</td>
</tr>
<tr>
<td>Short ramp up time of sec..min</td>
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</tr>
</tbody>
</table>

**Diagram:**

- **PHS**: 2% / sec
- **Gas turbine**: 6% / min
- **Thermal**: 3% / min
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Basic Concepts in Mines

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UPHS in Salt Caverns
Motivation for UPHS Going Underground

- Possible locations for conventional PHS often in mountainous, touristic areas.
- Significant impact on the landscape.
- Underground UPHS can also be built in flat landscapes.
- Existing mines can provide already existing reservoirs.
- Minor impact on the landscape above ground.
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Principle of UPHS in Mines

Upper Reservoir

Charging

Discharge

Grid Connection

Lower Reservoir

Power House

Source efzn
In an abandoned coal mine in Germany (Prosper Haniel, Bottrop) a project is planned:

- $\Delta h = 500$ m
- $V = 600\,000\, m^3$
- 200 MW 800 MWh
Storage with Underground Upper Reservoir and Above Ground Lower Reservoir

Project Pfaffenboden (Austria) by Wien Energy
UPHS in Abandoned Mines

• Precondition are mines in stable host rock

• Existing large, unfilled openings like galleries are rather unsuitable as reservoirs, as long-term stability and tightness are questionable.

• Therefore rather new building of suitable, lined openings

• Construction of the upper reservoir above ground advantageous for cost reasons

• With a design for large electrical outputs as usual with conventional PHS, very large shaft diameter (costs!) is required for the large machines.
UPHS in an Operating mine
Schematic sketch of a pumped-storage power plant at Wohlverwahrt-Nammen mine (Germany).
Source/Quelle: Barbara Erzbergbau GmbH
UPHS In Virgine Rockmass

Possible layout of underground pumped hydro storage in newly excavated rock formation.

Source: European Energy Research Alliance, Fact Sheet 2018
UPHS In Virgin Rock Mass

- Wiscasset PSP, Maine, USA
- Upper reservoir in the Montsweag Bay (Atlantic Ocean)

<table>
<thead>
<tr>
<th>Table</th>
<th>Value</th>
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<tbody>
<tr>
<td>Total installed power</td>
<td>1 000 MW</td>
</tr>
<tr>
<td>Number of units</td>
<td>4</td>
</tr>
<tr>
<td>Max. generation time (at full power)</td>
<td>6 hours</td>
</tr>
<tr>
<td>Max. pumping time</td>
<td>8 hours</td>
</tr>
<tr>
<td>Maximum static head</td>
<td>573 m</td>
</tr>
<tr>
<td>Minimum static head</td>
<td>533 m</td>
</tr>
<tr>
<td>Plant rated discharge (turbine mode)</td>
<td>215 m³/s</td>
</tr>
<tr>
<td>Lower reservoir useful volume</td>
<td>4.6 million m³</td>
</tr>
</tbody>
</table>

**UNDERGROUND RESERVOIR**
- Height: 48 m
- Width: 27 m
- Total Length: 4 300 m
- Total volume of blasted rock: 5.6 million m³

**UNDERGROUND POWERHOUSE**
- Height: 21 m
- Width: 26 m
- Length: 126 m

**PENSTOCK**
- Number: 4
- Type: Concrete and steel lined
- Diameter: 4 m
- Length: 670 m

**PERMANENT ACCESS RAMP**
- Height: 8 m
- Width: 12 m
- Slope: 10%
- Underground length: 5 900 m

Mario Turgeon, Michel Claisse, and Geneviève Landry
Groupe RSW inc.
1010 De La Gauchetière Street West
Suite 500
Montreal, Quebec H3B 0A1
Canada
UPHS in Excavated Salt Caverns

- Both caverns for upper and lower reservoir are located sub surface (Oest, 2007).
- A concept hardly to be realized.
UPHS in Virgin Rock

The construction of a new mine involves major risks and costs, because of

• need for comprehensive geological exploration

• construction of at least two access shafts, one of which is suitable for extremely large machines
Pumped Gravity Storage

The “Heindl” gravity storage – a huge rock cylinder is pumped upwards.
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Leached Salt caverns For UPHS

- Salt caverns can be built at much lower costs (€/m³) as mines because mined from surface.

- It is a proven technology being used for natural gas storage since more than 50 years.

- There is a big potential for leaching caverns in salt formations in Europe.
The arrangement requires the sinking of a large diameter shaft for conventional excavating the cavern for the power house (DEEP 2013).
UPHS in Salt Caverns

The access to caverns from the bottom is technical hardly feasible, as well as placing parts of the machinery underground.

- Access to Caverns from Top and Bottom and Use of 2 different Media
UPHS with Two Pressurized Caverns

- Two Caverns (Lower and Upper Reservoir) are connected with a Water Pipe and a Gas Pipe. The Elevated Gas Pressure allows the Installation of Turbines and Pumps on the Surface.

- Gas compression and expansion can be used instead of a pump-turbine setup. The assembly then works as an “adiabatic” Compressed Air Energy Storage.
Conclusions

- Pumped hydro storage below surface is an analogue to a well proven and established technology as a consequence of lack of suitable geodetic locations as well as the environmental impact of land consumption.

- Many concepts on Underground Pumped hydro storage have been proposed in:
  - Abandoned mines
  - Newly excavated water reservoirs in virgin hard rock
  - Man made salt caverns.
Conclusions

- In most of the proposed designs the power house (pumps and turbines) is located beneath the surface.
  - This requires extra cost for enlarging an existing or sinking a new access shaft
  - and may also be a safety risk
  - Pumped hydro means low volumetric energy density (MWh/m³); therefore in most known UPHS projects lower capacity and power output compared to conventional pumped storage power plants