Pumped Hydro – technical concepts, design criteria and current development options

Global Fleet Management Hydro
October 21, 2014
Agenda

Introduction

Technical Concepts

Design Criteria

Current Development Options

Conclusion / Next Steps
E.ON is an experienced operator of an European hydropower portfolio totaling more than 6,400 MW

No. of operated hydropower plants
Efficient capacity (net installed capacity)\(^1\)
Annual net generation\(^1, 2\)
Pumped Storages Plants (PSP)

<table>
<thead>
<tr>
<th>E.ON Generation</th>
<th>E.ON Intl. Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam</td>
<td>CCGT</td>
</tr>
<tr>
<td>210</td>
<td>5,409 MW</td>
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</tbody>
</table>

1) Incl. power-procurement rights
2) Annual generation excluding pumped storage power plants
Therefore, E.ON supports hydro storage activities by knowledge transfer to other organizations

- **T&I/EIC ES support**
  - a) Political commenting
  - b) Energy storage factbook compilation

- **Active participation in PSP research activities on behalf of T&I**
  - a) Underground PSP
  - b) Hydro gravity storage
  - c) Large-scale balancing from Norwegian hydropower

- **Support of E.ON Brussels office in its advisory work (PSP position paper)**

- **Promotion of complex PSP valuation methods and tools**

- **Publications regarding PSP value and evaluation**

- **Participation in PSP expert groups, symposiums and associations**
  - a) Member of PSP advisory group of DoE, Washington
  - b) Cooperation with EFZN
  - c) Outlook: Dena PSP platform

T&I/EIC: Technology & Innovation / E.ON Innovation Center
PSP: Pumped Storage Plant
EFZ: Energy Research Center Niedersachsen
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PSPs are the most effective large scale option to store energy and react flexible on power market demand

Physical principal

The principle of PSP is to **store electrical energy** by **utilizing** the **potential energy of water**.

- In periods of low demand and high availability of electrical energy the water will be pumped and stored in an upper reservoir/pond.
- On demand the energy can be released respectively transformed into electrical power within a short reaction time.

Therefore PSPs can adjust the demand supply to balance respectively reduce the gap between peak and off-peak periods, and play an important role of levelling other power generation plants and stabilizing of the power grid.
Basically there are four types of PSP concepts which are distinguished by the water regime

Types of PSP

**Off-stream**, this type consist of an upper and lower reservoirs connected by a power waterway. Off-stream are PSP mainly divided in single purpose (pure pumped storage) or multiple purpose usage.

**Pump-back**, reversible units installed at an on-stream hydropower plant to firm up peaking capacity during occasional periods of low flow.

**Diversion type** or so called water transfer PSP divert water from one river basin to another.

**Seawater**, the Okinawa Seawater demonstration plant by utilization of seawater for the lower reservoir has been erected in Japan.
PSPs are the most mature storage concept in respect of installed capacity, storage volume and operation benefits.

Main components

- Two water reservoirs/ponds (upper and lower),
- Power waterway to connect both reservoirs/ponds
- Hydro power station equipped with ternary machine sets or pump-turbines

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<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td><strong>Power range</strong> (1)</td>
<td>10 MW – 3.0 GW</td>
</tr>
<tr>
<td><strong>Energy range</strong></td>
<td>1 MWh – some 100 GWh</td>
</tr>
<tr>
<td><strong>Discharge time</strong></td>
<td>minutes – some 10h</td>
</tr>
<tr>
<td><strong>Cycle life</strong></td>
<td>unlimited</td>
</tr>
<tr>
<td><strong>Calendar life</strong></td>
<td>&gt; 100 years</td>
</tr>
<tr>
<td><strong>Reaction time</strong></td>
<td>some s – few min</td>
</tr>
<tr>
<td><strong>Efficiency</strong> (2)</td>
<td>70 - 85 %</td>
</tr>
</tbody>
</table>

1) in general no limitation  
2) cycle efficiency
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The design criteria are mainly derived by the power market demands and actual site characteristics.

### Basic impacts and input data

**Power market characteristics**
- Load curves
- Generation portfolio
- Grid stability
- Power market development projection

**Site characteristics and natural conditions**
- Topography
- Geology
- Seismology

**Environmental impacts**

### Operation aspects

- Dispatching scenarios
- Reserve market, provision of ancillary services e.g.
  - frequency control
  - primary reserve
  - voltage control
- Operation modes (hydraulic circuit, black start availability, short/long term storage capacity, …)

### Design criteria

- Operational concept
- Installed capacity
- Storage capacity
- hydro-mechanical setup
  - selection of pump respectively turbine type
  - concept of power waterway arrangement
- Electromechanical setup
  - type of motor-generator
To develop a PSP project the design criteria have to be transferred into a technical concept

- There is no common approach to transfer design criteria to develop a PSP project
- It is a “puzzle” of engineering judgment and knowledge transfer as well as experience
- The following aspects will be presented in more detail:
  1. Desirable site characteristics
  2. Machine type selection criteria
  3. Analyzing dispatching scenario
  4. Purpose of transient analysis
The layout of the PSP project will be developed based on the site existing characteristics

Desirable site characteristics

- Geological conditions should be suitable for watertight reservoirs
- Head is proposed to be as high as possible
- The ratio of minimum head to maximum head is preferable greater than 0.8
- Length of the water conduit should be as short as possible. The ratio of head to length should be strived smaller than 1.2
- Suitable size for sufficient power installation
- Site should be located reasonable close to load centers or transmission corridors
Machine types differ in their flexibility to participate in the reserve markets and in their investment cost.

Three technical alternatives are available:

- **Pumped turbine with synchronous generator (SM)**
  - Limited flexibility (no controllability of pump, high min. load of turbine)

- **Pumped turbine with asynchronous generator (DFIM)**
  - Medium flexibility (variation of pump, medium min. load of turbine)

- **Ternary machine set**
  - Maximum flexibility (hydraulic shortcut can be applied, low min. load of turbine)

Cost impact for turbines and generator ranges between 30 to 50% of the total project costs.

SM: Synchronous Machine  
DFIM: Doubly Feed Induction Machine
The power market demands determine the machine configuration and the storage volume

Example for machine configuration and development of reservoir size

- How much additional pumped storage fits to the market?
- How much flexibility is required in today’s market?
- Which machine type should be applied?
- What is the market optimal capacity and storage basin size?
Transient analysis during pumping must be evaluated as hydr. characteristics differ significantly to turbine mode.

**Requirement for transient analysis:**

**Hydraulic transient events** are disturbances in the water conduit cased during changes in the state from flowing to non-flow conditions and vice versa. Typical cases are:
- Pump start up or shut down,
- Valve opening and closing (variation in cross-sectional flow area),
- Changes in boundary conditions (e.g., adjustments in the water level at reservoirs)
- Rapid changes in demand conditions,
- Changes in transmission conditions, and
- Pipe / tunnel filling or draining

The main design techniques generally used to mitigate transient conditions such as:
- Alteration of pipeline characteristics
- Improvement in valve and pump control procedures, and
- Design and installation of surge protection devices
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Future system demands require highly flexible PSP with optimized revenues and cost structures

**Status quo**

**Electricity market:** wholesale day-head market, intraday market

**Reserve market:** primary, secondary and tertiary control reserve

**Portfolio effect:** indirect revenue component from synergies in hydro-thermal portfolio

**Balance circle management:** ramping capacities, flexibility for feed-in deficits

**De-central feed-in remuneration:** energy and capacity price for de-central feed-in

**Further system services:** black start capability, reactive power, voltage control

**Additional future tasks**

System relevant integration of renewable energy generation by providing
- flexibility
- storage capability

Pumped-storage plants support already today to integrate the renewable production, but providing flexibility and storage capacity is not specifically remunerated
Alternative hydro storage concepts will not outperform conventional PSP concepts

Evaluated alternative storage concepts

- Underground Pumped Storage Plants (UPSP), based on the mature PSP technology, could be seen as an additional storage possibility to balance the fluctuation in the power grid.

- Energy Membrane – Underground Pumped Storage Plant (EM-UPSP) concepts could be an option for additional storage capacity with less topographical, locational and geological restrictions.

- Hydraulic Gravity Storages (HGS): The hydrostatic head on the turbine is build-up by a piston in a vertical shaft in generation mode; the piston is lifted by water pressure in storage (pump) mode. ⇒ HGS concepts are outranged by other technologies
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Conclusion – next steps

Currently, pumped storage plants (PSPs) are the only mature large scale option to store energy and react flexible on system demand.

The design criteria are mainly derived by the power market demands and actual site characteristics by considering environmental and operational aspects.

Future system demands require highly flexible PSP due to the integration of renewable energy by optimized revenues and cost structures.

The future role of pumped hydro will become even more complex as today which will not be outperformed by alternative hydro storage concepts.

The current market environment for pumped-storage plants is difficult. To promote system-relevant pumped storage plants, market mechanisms must be changed in such a way that all services are fairly remunerated, investment security and profitable operation is given.
Global Unit Generation

Hydro Fleet

Backup
Excerpt engineering and design documents

US Army Corps of Engineers (USACE)

- EM 1110-2-1701
  “Engineering and Design Hydropower”, Chapter 7
- EM 1110-2-3001
  “Engineering and Design of Hydroelectric Power Plant Structures”

American Society of Civil Engineering (ASCE)

- Civil Engineering Guideline for Planning & Design Hydroelectric Development”, Volume 5 Pumped Storage and Tidal Power

Jürgen Giesecke · Emil Mosonyi

- Wasserkraftanlagen Planung, Bau und Betrieb

1) Text