Pumped hydro Storage Plants

Olivier Teller, Product Director PSP

15 Nov 2012
>130 GW
(99% world electricity storage)

Market: 6 GW/year
Europe: ~1.5 GW/year

100 years / illimited cycle numbers

~1000 €/kW
500€ - 2000€/kw
Possibilities of energy storage

Storage Technologies

• Technologies must correspond to power and capacity requirements
• Large Energy and Power
  - PSPs
  - CAES

Source: www.electricitystorage.org
Global efficiency ~ 80 %
Pumped Storage Plants

Storing electrical energy as potential energy of water
Solutions from 3 to 1200 m head
<table>
<thead>
<tr>
<th>PSP key facts</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Pumping power adjustment range</strong></td>
<td>&gt; 80%</td>
</tr>
<tr>
<td><strong>Ancillary Services</strong></td>
<td>70% to 100% (Variable speed machines)</td>
</tr>
<tr>
<td><strong>Output/Input</strong></td>
<td>5 to 500 MW</td>
</tr>
<tr>
<td><strong>Storage capacity</strong></td>
<td>&gt; 8 hours full load</td>
</tr>
<tr>
<td><strong>Head Range</strong></td>
<td>10 to 2000 m.</td>
</tr>
<tr>
<td><strong>Cycle efficiency</strong></td>
<td>&gt; 80%</td>
</tr>
<tr>
<td><strong>Reaction Time</strong></td>
<td>~ 15 s.</td>
</tr>
<tr>
<td><strong>50% to 100% Generation</strong></td>
<td>25% to 100%</td>
</tr>
<tr>
<td><strong>Production adjustment range</strong></td>
<td>25% to 100%</td>
</tr>
<tr>
<td><strong>General Performances</strong></td>
<td>&gt; 8 hours full load</td>
</tr>
<tr>
<td><strong>Performances</strong></td>
<td>10 to 2000 m.</td>
</tr>
<tr>
<td><strong>Head Range</strong></td>
<td>&gt; 80%</td>
</tr>
</tbody>
</table>
PSP global energy balance

~80% Global efficiency
## PSP Key development drivers

<table>
<thead>
<tr>
<th><strong>Thermal &amp; Nuclear</strong></th>
<th>Fixed power production</th>
<th>Match production &amp; consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Renewable</strong></td>
<td>Time Shift</td>
<td>Shift the excess production to provide the peaks</td>
</tr>
<tr>
<td></td>
<td>Firming</td>
<td>Compensate non predicted power variation thanks to fast power adaptability</td>
</tr>
<tr>
<td><strong>Transmission</strong></td>
<td>Close to production</td>
<td>Suppress peak from intermittent production</td>
</tr>
<tr>
<td></td>
<td>Close to consumption</td>
<td>Smoothen peak from consumption</td>
</tr>
</tbody>
</table>
Complement Intermittent Renewable Energy

Wind Production in Denmark in 2009

Average (765 MW)

Actual

Forecast

Time Shift

Regulation

Load

Generation

24h

1h

1min

Source ENERGIENEK

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### PSP development trends

<table>
<thead>
<tr>
<th>Continuous improvement</th>
<th>More challenging sites</th>
<th>Flexibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>• In 40 years, from 70 to 80% cycle efficiency</td>
<td>• Very High or Very Low Head (&lt;50m &amp; &gt;800m)</td>
<td>• Variable Speed offering</td>
</tr>
<tr>
<td>• Availability, Reliability, Cycling</td>
<td>• Head range increase</td>
<td>• Power range increase in turbine mode</td>
</tr>
<tr>
<td></td>
<td>• Underground reservoir</td>
<td>• Reaction time reduction</td>
</tr>
<tr>
<td></td>
<td>• Sea water operation</td>
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</tr>
</tbody>
</table>
Flexibility
- Power operating range
- Transition time

Reliability
- Condition monitoring
- Fatigue analysis

Performance
- Round trip efficiency
- Cycling
Variable speed PSP

Double Fed Asynchronous Motor Generator

Advantages

• Adjustable pumping power
• Compatible with larger head variation
• Faster power adjustment
• Pump Turbine global efficiency (+ ~ 1%)
Demand

Flexible Generation

Wind energy

Baseload (non flexible)
Baseload (non flexible)

Wind energy

Excess wind

Flexible Generation

Demand
European PSP installed Fleet

Installed power

- 10,000 MW
- 20,000 MW
- 30,000 MW
- 40,000 MW

>30 year old by 2020:
Huge opportunity for upgrade

Year Commissioning

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Flexible Hydro Storage “Everywhere”

To enable

Renewable Generation to remain Renewable
www.power.alstom.com