Pumped Storage: Technology for flexible Operation
Dr.-Ing. Christof Gentner
Golden, CO, USA, November 2012

Contents

- The role of pumped storage
- Machine concepts
- Advantages of variable speed
- Application example variable speed
- Standardized pump turbines
- Hydraulic short circuit
- Pump turbine technology
Pumped Storage: Technology for flexible Operation

Changing storage requirements

- Power mix as a major driver
- Share of intermittent production will increase significantly, positive and negative reserve required
- Partly legal requirement to buy power from renewable production (Germany)
- Increasing demands relating to peaking and grid-frequency control
- World wide around 150 GW installed pumped storage capacity (2011)

Pumped Storage: Technology for flexible Operation

Influence of non dispatchable power on pricing

- Non dispatchable power influences price structure
- Storage capacity, both positive and negative is a technical requirement
- Required storage up to 80% of installed wind and solar, depending on grid structure
Pumped Storage: Technology for flexible Operation

Required response time becomes shorter

- Renewable energy (wind, solar) is extremely volatile, difficult to predict and non-dispatchable
- The stability of the grid is in danger with large percentage of wind and solar power
- The larger the wind and solar power capacity, the larger the problems in the grid
- The amount of renewables in the electricity portfolio is increasing rapidly
- New technologies for electricity storage are needed to compensate for those influences

Pumped Storage: Technology for flexible Operation

From static to dynamic

- Cheap, domestic source of energy
- Combination with irrigation and creation of navigable waterways
- Pump storage as long term storage
- Renewable, clean energy
- Quick grid control
- Hydro for grid stabilization
- New interest in pump storage
- Hydro as compensation for wind and solar
- Hydro as Smart-Grid Player
Pumped Storage: Technology for flexible Operation

Machine concepts

**Reversible unit**
- Smaller cavern required
- Cost attractive solution (investment and maintenance cost)
- Lower complexity
- Longer change-over time (pump ↔ turbine)
- Pump start with drained runner
- Preferred method for pump startup
  - Electrical shaft “back to back”
  - static frequency converter (SFC) in air

**Ternary unit**
- Both turbine and pump optimized
- Quick change-over time (pump ↔ turbine)
- Higher investment cost
- No start up device necessary
- Direct hydraulic short circuit possible

---

**Advantages of variable speed**

**Variable speed**
- Ability for variation of input power in pump operation
- Improved efficiency in pump and turbine operation
- Increased operation range pump and turbine operation
- Improved operation behavior
- Reduced pressure pulsation and vibration
- Increased life time of the hydraulic machines
- Reduced dynamic loads
- Additional loss of converter

**Fixed speed**
- No power variation in pump
- Non-optimal turbine operation
- No additional losses of converter
- Lower investment cost
Pumped Storage: Technology for flexible Operation

Advantages of variable speed

### Fixed speed

<table>
<thead>
<tr>
<th></th>
<th>Head</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>H max</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H min</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Variable speed

<table>
<thead>
<tr>
<th></th>
<th>Head</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>n sync + Δn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>n sync - Δn</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Pump Characteristics**

- Efficiency
- Cavitation limit
- Stability limit

**Turbine Characteristics**

- Efficiency
- Head

---

chriso.gentner@andritz.ch
Pumped Storage: Technology for flexible Operation

Advantages of variable speed

Variable speed

Main data, size of pump-turbine

Trend curve for maximum head, size of pump-turbine
Pumped Storage: Technology for flexible Operation
Application example variable speed

- Fix speed \( n = 428.6 \text{ rpm} \) layout: Main characteristic

- Variable speed, pump mode: Main characteristic
  - \( n: 400 \text{ rpm} - 440 \text{ rpm} \)
  - \( P_{\text{max}} = 250 \text{ MW} \)
  - Power variation possible between 30–70 MW
  - Operation of pump at best efficiency possible over wide head range
Pumped Storage: Technology for flexible Operation

Application example variable speed

- Comparison: Turbine mode, operating area, fix - and variable speed
  - Hill chart, fix speed = 428.6 rpm
  - Hill chart, var speed min = 400 rpm for best efficiency

Hill chart, fix speed = 428.6 rpm
Hill chart, var speed min = 400 rpm for best efficiency

Turbine mode, at head 400m
fixed and variable speed
Improved efficiency over wide range
with variable speed

To stabilize the grid a large amount of reserve capacity is needed
The classical storage technology is
HYDRAULIC PUMPED STORAGE (HPS),

However:
- Large HPS plants are in mountain regions, often far away from wind farms
- Large distance between HPS plants and wind farms: additional loading for already stressed grid, additional transmission losses
- To compensate the very volatile wind and solar energy, the pump input power should be varied continuously. This was so far only possible with variable speed units (double-fed asynchronous motor-generators) which are rather expensive. Only few references in Europe and Japan are available.
Pumped Storage: Technology for flexible Operation

Comparison of fix and variable speed

Benefit of variable speed: ability to follow a variable demand for input power
Fixed speed: variation only by ON-OFF for complete units

Graph showing comparison of pump power with variable and fixed speed.

Pumped Storage: Technology for flexible Operation

Standardized pump turbines

Solution for grid stabilization based on:
- Projects of smaller size for better chance of realization
- Flexibility in operation
- Progress in Full size converter technology

ANDRITZ HYDRO has developed a new innovative concept:
- Small decentralized pump storage plants with
- Standardized pump turbines with variable speed
- Synchronous motor-generator and
- Full size converter
Pumped Storage: Technology for flexible Operation

Standardized pump turbines

Concept

- Two different hydraulic designs
- 17 machine sizes
- Full size converter, with speed variation from 0–100%
- Application range $H=20–250$ m and $P=5–50$ MW
Pumped Storage: Technology for flexible Operation

Advantages of the new concept

- The pump input power can be varied continuously due to full size converter
- Large power variations in pump mode possible
- Flat efficiency characteristics
- Large speed variation (DFAM: only max. +/- 5–10%)
- Standardization due to variable speed (cost advantage compared to tailor-made small HPS units)
- Investment costs not significantly higher than fixed speed solution

KOPS 2, Ternary units
- Customer: Vorarlberger Illwerke, Austria
- 3 x 180 MW Pelton turbines,
- 3 stage Pumps
- 3 x 200 MVA Generator/Motor
- Head range 696 – 826 m
- n = 500 rpm
- Highlights:
  - Hydraulic short circuit enables variation of input power by ± 100%
  - Pelton turbines pressurized
  - Designed up to 60 load changes per day
  - Ramp-up time to full load < 20 sec in pump and turbine
Pumped Storage: Technology for flexible Operation

Summary

Hydro power, pumped storage in particular, is becoming increasingly dynamic
- Price spread is reduced
- Flexibility and grid stability become important

Consequences for manufactures and operating utilities

Peak efficiency alone not a sufficient measure to evaluate quality
Focus on operating life and availability

Technical solutions for flexible operation

Variable speed
Ternary sets with short switch-over times
Full size converters
Small scale, standardized pump storage plants

Benefit for operation

Optimized hydraulic performance and cavitation safety
Smooth and stable operation in wide operation range
Maximum reliability though dynamic operation
Extended service life

Pumped storage will very likely be the most beneficial storage solution to integrate a high percentage of non dispatchable renewables in the grid