New perspectives – revenue and cost optimized pumped storage concepts

Dr. Klaus Engels
Louisville, KY – July 19, 2012
Future system demands require highly flexible PSP with optimized revenues and cost structures

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

Considering all revenue streams – wholesale market, ancillary services and portfolio effect – PSPs are profitable, even in tough market environment.

The remaining optimization lever is cost of a PSP – beside other positions, the machine set is a main cost driver, which can be optimized.

To display the value contribution of a PSP – technically and economically - the optimal dispatch needs to be simulated with modern tools.

As the plant flexibility becomes more important, the majority of the revenues come from the ancillary services (secondary reserve).

Thus, the optimal machine concept is highly flexible at minimal costs and has the right size in the market portfolio.
E.ON’s Waldeck 2+ project is an extension of the existing interconnected Waldeck Group.

**European hydro power portfolio**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of operated hydro plants</td>
<td>212</td>
</tr>
<tr>
<td>Efficient capacity</td>
<td>6.161 MW</td>
</tr>
<tr>
<td>Annual net generation</td>
<td>18.5 TWh</td>
</tr>
</tbody>
</table>

**The Waldeck Group in central Germany**

- Upper basin Waldeck 1
- Upper basin Waldeck 2 and 2+
- Lower basin Waldeck Group
- Waldeck 1: 135 MW
- Waldeck 2: 480 MW
- Waldeck 2+: 300 MW

Potential increase of upper basin.
Demand for flexibility will permanently increase within the next years due to growing share of renewables feed-in.

**Annual residual load**

<table>
<thead>
<tr>
<th>Year</th>
<th>[GW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td></td>
</tr>
</tbody>
</table>

**Decrease of residual load**

**Energy production* [TWh]**

<table>
<thead>
<tr>
<th>Year</th>
<th>[TWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
</tr>
</tbody>
</table>

**Share of renewables**

- 2010: 11%
- 2015: 25%
- 2020: 35%

**Relative frequency of load changes of annual residual load**

<table>
<thead>
<tr>
<th>Time Range</th>
<th>[h/a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>[-12: -11]</td>
<td></td>
</tr>
<tr>
<td>[-5: -3]</td>
<td></td>
</tr>
<tr>
<td>[0: 1]</td>
<td></td>
</tr>
<tr>
<td>[4: 5]</td>
<td></td>
</tr>
<tr>
<td>[8: 9]</td>
<td></td>
</tr>
<tr>
<td>[12: 13]</td>
<td></td>
</tr>
</tbody>
</table>

**Increase of fluctuation**

<table>
<thead>
<tr>
<th>Year</th>
<th>[GW/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
</tr>
</tbody>
</table>

*) Germany/ input for simulation without export, direct industry, railway or auxiliary consumption
Profitability of PSP is supported by high demand of ancillary services – increasing revenue share accordingly.
Typical investment cost structure for new build projects of hydropower plants incl. pumped storage plants

**General note:** depending on the real project, individual cost structure may be different!
To optimize the technical concept a comprehensive three-step evaluation approach has been applied.

New Build Potential

- How much additional pumped-storage capacity fits into the German market?

Extension Stage

- What is the market optimal capacity and upper basin size?

Machine Concept

- How much flexibility is required in today’s market? → Which machine type should be applied?
Machine types differ in their flexibility to participate in the reserve markets and in their investment cost

Three technical alternatives are available:

1. Pumped turbine with synchronous generator
2. Pumped turbine with asynchronous generator
3. Ternary machine set

Two main flexibility parameters of given machine types were simulated:

1. Limited flexibility (no controllability of pump, high min. load of turbine)
2. Medium flexibility (variation of power output of pump possible, medium min. load of turbine)
3. Maximum flexibility (hydraulic short circuit can be applied, low min. load of turbine)

Investments required:

Capital Expenditure €/kW
An asynchronous pump-turbine is proposed as optimal machine concept – dependent on the individual situation

Simulated contribution margins:

- Asynchronous pump-turbine: 80%
- Synchronous pump-turbine: 100%
- Ternary machine set: 99%

Capital expenditure assumptions *:

- Asynchronous pump-turbine: 95%
- Synchronous pump-turbine: 100%
- Ternary machine set: 132%

Asynchronous pumped-turbine and ternary machine set reach same level of contribution margin, whereas synchronous pumped-turbine remains 20% behind.

Cost-benefit-analysis with consideration of capital expenditure reveals pumped-turbine with asynchronous generator to be the most beneficial solution.

* Source: Lahmeyer International, only M&E part (approx. 20% of total budget)
Backup
Contact details and CV

Contact

Dr. Klaus Engels
VP Asset Risk and Governance
T +49 871 694-4010
F +49 871 694-4008
M +49 170 8562698
klaus.engels@eon.com

E.ON Generation Fleet
E.ON Wasserkraft GmbH
Luitpoldstraße 27
84034 Landshut

Curriculum Vitae

- University Degree in Electrical Engineering, RWTH Aachen University, Germany
- University Degree in Economics, FernUni Hagen, Germany
- 1997 – 2002 Academic assistant and PHD studies at RWTH Aachen University
- 2002 – 2004 Asset Manager Transmission Grid RWE Energy AG, Dortmund
- 2005 – 2008 Project Manager Roland Berger Strategy Consultants, Dusseldorf/Munich
- 2008 – 2010 Head of Business Development E.ON Wasserkraft, Landshut
- since 2010 Vice President Asset Risk and Governance Hydro, E.ON Fleet Management Generation
- Recently invited to Advisory Working Group for the study “Modeling and Analysis of Value of Advanced Pumped Storage Hydropower in the U.S.” of DoE
The energy-economic modeling of pumped-storage plants must address both wholesale and reserve markets.

### Wholesale & reserve market

- **Markets for scheduled energy**
  - Spot- and Future market
  - Wholesale and reserve market
  - Markets for scheduled energy

- **Reserve Markets (II)**
  - Criteria for award of offer/contract:
    - Only merit-order of capacity price
    - Modelling of capacity price-demand function
  - Criteria for call of reserve energy:
    - Only merit-order of energy price
    - Modelling of energy calling by energy price-dependent calling probability (price row)
  - Bilateral reserve contracts (e.g., hourly reserve):
    - Purchase and offer
    - Possibility long-term contracts
    - Design not standardized
    - Modelling as fixed amount of reserve capacity

### Thermal & hydraulic systems

- **Hydraulic generation**
  - Time variable natural inflows
  - Minimum and maximal discharge of pumps, turbines, penstocks, etc.
  - Starting unit and unit volume for each reservoir
  - Revisions and load constraints
  - Provision of scheduled energy and reserve capacity

- **Reserve provision by hydraulic power plants**
  - Pumped-storage plant participation in scheduled energy and positive minute reserve market

### Evaluation method

- Two-stage method as mixed whole-number quadratic problem for power generation and trading planning
  - Methodology:
    - Determination of the maximum contribution margin of a generation pool consisting of thermal and hydropower plants under consideration of spot and reserve markets.

- **Results:** optimized dispatch of portfolio and contribution margin
  - An integrated algorithm optimizes the power plant scheduling on wholesale and reserve market
Additional restrictions needed to be defined in simulation model to reflect machine type characteristics

Step 1:
Portfolio-simulation without restrictions in order to conclude how much reserve capacity is provided by Waldeck Group if part of the portfolio.

Step 2:
Machine type simulation on stand-alone basis for Waldeck-Group with portfolio-simulated reserve capacity provision as input and 2009 actual prices

Waldeck 2+ extracted from group results

With re-definition of optimization problem complexity increased tremendously

Simulation approach needed to be split into two steps to limit calculation times
Analysis of run-of-day schedules showed that machine type specifics were captured well in simulation.

Exemplary 24-h-schedules

Take-aways

- No full load operation in wholesale market, irrespective of machine type
- Large amount of capacity sold to reserve market
- Increasing flexibility of machine types fosters reserve market participation
- Hardly any standstill times to be able to participate in PCR market, which is very lucrative in Germany
- Simulated energy output schedule looks different from a traditional PSP schedule of today