Scheduling when reservoirs are batteries for wind- and solar-power

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5th International Workshop on Hydro Scheduling in Competitive Electricity Markets
Renewable power generation in EU

- More than doubled since 2000
- Targets for further increases towards 2020 and 2030
- Reducing the cost of this policy is an important motivation for the ongoing liberalization/legislation process in the EU
Can hydropower reservoirs be batteries for wind- and solar-power?

■ The battery idea
  - 86 TWh storage capacity in Norwegian reservoirs
  - Could we utilize some of it to balance renewables in Europe?
  - Then we need to increase generation capacity and build new cables!

■ Some existing studies
  - Solvang et al. (2012): Identified a potential 20 GW extra generation capacity, utilizing existing reservoirs in Southern Norway
  - Solvang et al. (2014) studied the impacts on the expected hydropower operation based on wind-power variability
  - Korpås et al. (2015) introduced the concept "levelized costs of peaking capacity", and compared hydropower incl. cables with gas-power
Our study

■ Within CEDREN HydroBalance (KPN)
  – Feasibility check for large-scale balancing from Norway
  – http://www.cedren.no/Prosjekter/HydroBalance

■ Research questions
  – How will hydropower be operated in the future?
  – What is the impact of several markets?
  – Will pumped storage investments be profitable?
Market types

- **Day-ahead**
- **Intraday**

Activation of reserves

Many prices for a single operating hour
General approach

**Develop methodology**
- Hydropower optimization
- With several markets

**Forecast prices**
- HydroBalance scenario
- 2050
- Several markets

**Case-study**
- Real river system
- Relevant pumped-storage project
Applied model: ProdRisk

- One of SINTEF's optimization tools for hydropower
  - Local producer / river system
  - Objective: Maximize profits
  - Stochastic variables: inflow, prices
  - Time-resolution/horizon: e.g. hour/year

- However, model is only for one power market (day-ahead)
Accounting for several markets

- A full multi-market optimization not feasible in ProdRisk

- However, the following strategy can be evaluated
  - Supply for day-ahead market as if it was the only market
  - Adjust production in subsequent market when profitable
  - Reserve capacity is a parameter (to be optimized iteratively)

- Similar approach taken by others, e.g. ECN's COMPETES model

- Klæbu and Fosso (2013): So far not many studies have indicating gains of coordinated bidding for several markets
Implementation in ProdRisk

- So far we have included only two markets
  - Day-ahead
  - Activation of replacement reserves (e.g. 15 min response)

- ProdRisk production for a given hour: $f(p)$
  1. Optimize for day-ahead prices: $f(P^\text{day-ahead})$
  2. Optimize for price of reserves: $f(P^\text{reserves})$
  3. "upward" / "downward" regulation: $\Delta f = f(P^\text{reserves}) - f(P^\text{day-ahead})$
  4. Total income for hour:
     $P^\text{day-head} \cdot f(P^\text{day-head}) + P^\text{reserves} \cdot \Delta f$

- Water values and reservoir levels are calculated from actual operation:
  $f(P^\text{day-ahead}) + \Delta f$
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IAEW study on future prices

- Quantification of HydroBalance scenario for 2050
  - Based on EU trend study, Eur. Commission (2013)
  - Adjustments include:
    - 20-30 GW new generation capacity in Norway
    - Sufficient increase in cable capacity

- Price simulation
  - Model concept: Schäfer et al. 2014
  - Day-ahead prices for European countries, weather years 2007-2011
  - Reserves (procurement and activation: FCR/FRR/RR), Germany, 2008
Prices: Duration curves

- Statistics
- Big Storage
- Niche Storage
- Reserves

€/MWh
Example of within-week variability

Winter

Summer
General approach

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Otra river system

- Production capacity: 1.1 GW (14 plants)
- Storage capacity: 3.7 TWh (13 reservoirs)
- Annual production: 5 TWh
- ProdRisk input provided by Agder Energi
Otra river system - upper part
Pumped storage investment

- 1000 MW: extra generation capacity and pump
- Reservoirs: 15 days to empty/fill
- Total efficiency (pump x generation): 72.2 % (conservative, cf. Ibrahim 2007)
- Estimated total costs: 416 M € (Henden, 2014)
Scenario

- Statistics
- Big Storage
- Niche Storage
- Multi-market

Supply only for day-ahead market

day-ahead + RR activation

➢ All scenarios: With and without investment
Results - Production

Duration curve

Average day

Continuous lines is existing production system
Dotted lines is with investment
Production and prices within a week

Continuous lines are prices
Dotted lines are productions

Figure at the top is existing production system
Figure at the bottom is with investment in 1000 MW PSP
Results – Reservoir level

- Upper reservoir, Reinevatn/Urevatn
- 2008

Continuous lines are existing production system
Dotted lines are with investment
## Economic results (in M € per year)

<table>
<thead>
<tr>
<th></th>
<th>Day-ahead only (Climate years 2007-2011)</th>
<th>German prices (Climate year 2008)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Statistics</td>
<td>Niche Storage</td>
</tr>
<tr>
<td>Average yearly income</td>
<td>205</td>
<td>474</td>
</tr>
<tr>
<td>Additional operating profits</td>
<td>9</td>
<td>23</td>
</tr>
<tr>
<td>Investment cost *)</td>
<td>-24</td>
<td>-24</td>
</tr>
<tr>
<td>Investment profits *)</td>
<td>-15</td>
<td>-2</td>
</tr>
<tr>
<td>Break even interest rate</td>
<td>-0,5 %</td>
<td>4,5 %</td>
</tr>
</tbody>
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*) With 5 % annual interest rate
Summery of results

■ Variability in operation
  – Increased with pumped storage (short term and during a year)
  – Highest for multi-market strategy
  – Traditional day/night trend is changed because of solar radiation

■ Income
  – Future scenarios gives 2-3 times higher total income
  – Multi-market strategy gives about 2% extra income

■ Payback for investment in pumped storage
  – Negative profits for historical prices
  – About break-even for day-ahead strategy at future prices
  – Multi-market strategy: Income from investment increase by 21%
Conclusions

■ Multi-market
  - Methodology is performing as intended
  - Evaluated strategy is not 100% optimal but reasonable / pragmatic
  - Next: Include reserve power (MW), and possibly intra-day

■ Price-level is important for total income

■ Price-variability (and therefore market participation) is important for profitability of pumped-storage investment

■ Based on our study, environmental impacts in reservoirs will be studied further in HydroBalance
References

- Cf. full paper