Risk-Constrained Coordination of Cascaded Hydro Units with Volatile Wind Power Generation

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The problem:

- Independent system operators (ISOs) use a security-constrained unit commitment (SCUC) tool that takes submitted hourly energy bids to clear the day-ahead market based on forecasted demand.
- ISOs balance supply with loads in a secure and economic fashion.
- However, perfect information on the day-ahead market price and wind speed is not available.
- How to maximize the GENCO’s payoff while minimizing its financial risks?
The strategy:

- Wind energy variations occur within minutes while the day-ahead schedule is hourly.
- The ISO may consider preventive and corrective actions for managing the secure operation of power systems with intermittent and volatile wind energy.
- Thus, an intrahour-based model is proposed in this paper to firm up the coordinated wind and hydro generation.
- This work shows that the fast ramping and storage capabilities of cascaded hydro units could compensate wind energy volatilities.
- The Monte Carlo simulation is used to generate scenarios.
The methodology:

- The objective of PBUC is to maximize a GENCO’s payoff, which is the revenue from the sales of energy or bilateral contracts minus the operation cost of GENCO.
- The operation cost includes the production cost, start-up/shut down costs, and imbalance energy charges incurred by wind energy variations.

A) Uncoordinated Scheduling of Wind and Hydro Units
B) Coordinated Scheduling of Wind and Hydro Units
C) Expected Downside Risk-Assessment
Numerical Examples: Three-hour ahead scheduling

<table>
<thead>
<tr>
<th>Description</th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
<th>H4</th>
<th>H5</th>
<th>H6</th>
<th>H7</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{\text{min},h}$ (MW)</td>
<td>9.0</td>
<td>4.0</td>
<td>17.0</td>
<td>30.0</td>
<td>9.0</td>
<td>2.0</td>
<td>19.0</td>
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<tr>
<td>$P_{\text{max},h}$ (MW)</td>
<td>70.0</td>
<td>70.0</td>
<td>115.0</td>
<td>194.0</td>
<td>80.0</td>
<td>60.0</td>
<td>120.0</td>
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<tr>
<td>$RD_h$ (MW/min)</td>
<td>1.17</td>
<td>1.17</td>
<td>1.92</td>
<td>3.23</td>
<td>1.33</td>
<td>1.00</td>
<td>2.00</td>
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<tr>
<td>$RU_h$ (MW/min)</td>
<td>1.17</td>
<td>1.17</td>
<td>1.92</td>
<td>3.23</td>
<td>1.33</td>
<td>1.00</td>
<td>2.00</td>
</tr>
<tr>
<td>$a$ (MW/(Hm³/h)²)</td>
<td>-42</td>
<td>-30</td>
<td>-12.5</td>
<td>-31</td>
<td>-38.8</td>
<td>-31.2</td>
<td>-14.4</td>
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<tr>
<td>$b$ (MW/(Hm³/h))</td>
<td>113</td>
<td>106.2</td>
<td>78.8</td>
<td>155.1</td>
<td>121.75</td>
<td>98.42</td>
<td>85.5</td>
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<td>$c$ (MW)</td>
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<td>-6.0</td>
<td>7.26</td>
<td>7.5</td>
<td>-2.64</td>
<td>-7.23</td>
<td>6.45</td>
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<td>$q_{\text{min},h}$ (Hm³/h)</td>
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<td>0.1</td>
<td>0.13</td>
<td>0.15</td>
<td>0.1</td>
<td>0.1</td>
<td>0.15</td>
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<td>$q_{\text{max},h}$ (Hm³/h)</td>
<td>1.0</td>
<td>1.0</td>
<td>2.0</td>
<td>2.0</td>
<td>1.0</td>
<td>1.0</td>
<td>2.0</td>
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<tr>
<td>$r_h$ (Hm³/h)</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0.3</td>
<td>0.3</td>
<td>0.2</td>
<td>0.12</td>
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<tr>
<td>$s_{\text{min},h}$ (Hm³/h)</td>
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<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
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<tr>
<td>$s_{\text{max},h}$ (Hm³/h)</td>
<td>1.0</td>
<td>1.0</td>
<td>2.0</td>
<td>2.0</td>
<td>1.0</td>
<td>1.0</td>
<td>2.0</td>
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<tr>
<td>$V_{0,h}$ (Hm³)</td>
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<td>8.0</td>
<td>17.0</td>
<td>11.0</td>
<td>10.0</td>
<td>9.0</td>
<td>18.0</td>
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<tr>
<td>$V_{NT,h}$ (Hm³)</td>
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<td>8.0</td>
<td>17.0</td>
<td>11.0</td>
<td>10.0</td>
<td>9.0</td>
<td>18.0</td>
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<tr>
<td>$V_{\text{min},h}$ (Hm³)</td>
<td>7.0</td>
<td>4.0</td>
<td>10.0</td>
<td>7.0</td>
<td>6.0</td>
<td>5.0</td>
<td>12.0</td>
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<tr>
<td>$V_{\text{max},h}$ (Hm³)</td>
<td>15.0</td>
<td>13.0</td>
<td>24.0</td>
<td>16.0</td>
<td>16.0</td>
<td>14.0</td>
<td>30.0</td>
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<td>Catchment Index</td>
<td>1</td>
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<td>1</td>
<td>1</td>
<td>2</td>
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<tr>
<td>Upstream Unit</td>
<td>-</td>
<td>-</td>
<td>H2,H1</td>
<td>H3</td>
<td>-</td>
<td>H5</td>
<td>H6</td>
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<tr>
<td>Downstream Unit</td>
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<td>H3</td>
<td>H4</td>
<td>-</td>
<td>H6</td>
<td>H7</td>
<td>-</td>
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<tr>
<td>Delay Time</td>
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<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

**Wind Unit** | **Capacity**
---|---
1 | 200MW

**Diagram:**
- Wind speed (m/s)
- MCP ($/MWh$)
- Cases Coordinate Stochastic Balancing Price ($/MWh$)

<table>
<thead>
<tr>
<th>Cases</th>
<th>Coordinate</th>
<th>Stochastic</th>
<th>Balancing Price ($/MWh$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No</td>
<td>No</td>
<td>5.00</td>
</tr>
<tr>
<td>2</td>
<td>No</td>
<td>Yes</td>
<td>5.00</td>
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<tr>
<td>3</td>
<td>No</td>
<td>No</td>
<td>50.00</td>
</tr>
<tr>
<td>4</td>
<td>No</td>
<td>Yes</td>
<td>50.00</td>
</tr>
<tr>
<td>5</td>
<td>Yes</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Yes</td>
<td>Yes</td>
<td>-</td>
</tr>
</tbody>
</table>
Numerical Examples: Three-hour ahead scheduling (cont.)

The expected payoff decreases with an increase in energy balancing price until the price is high enough to eliminate wind power deviations; so the payoff is the highest at the zero energy balancing price.
Numerical Examples: Day-Ahead Scheduling

- 3 wind farms (W1-W3) and 7 hydro units in two river basins
- The wind farm capacities are 200MW, 200MW and 250MW
- W1 and W2 are located near river basin 1 and W3 is close to river basin 2
- Coordinated scheduling for W1-H2, W2-H3, and W3-H6 is considered
Numerical Examples: Day-Ahead Scheduling (cont.)

**Case 1 - Without W-H Coordination**

<table>
<thead>
<tr>
<th>Power (MW)</th>
<th>Random Scenarios</th>
<th>Generation Dispatch</th>
</tr>
</thead>
</table>

**Case 3 – With W-H Coordination**

<table>
<thead>
<tr>
<th>Power (MW)</th>
<th>Random Scenarios</th>
<th>Generation Dispatch</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Case</th>
<th>Expected Payoff ($)</th>
<th>Downside Risk ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>897,956</td>
<td>7,648</td>
</tr>
<tr>
<td>2</td>
<td>897,498</td>
<td>7,000</td>
</tr>
<tr>
<td>3</td>
<td>914,083</td>
<td>3,082</td>
</tr>
<tr>
<td>4</td>
<td>913,756</td>
<td>3,000</td>
</tr>
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</table>

Scheduling coordination will increase the expected payoff and decrease the downside risk.
Conclusions:

• Scheduling coordination of cascaded hydro and wind units can:
  – Firm up wind energy,
  – Increase expected payoffs,
  – Reduce downside risks of GENCOs.
  – Lower wind curtailment

• When wind and hydro units are not coordinated, energy balancing prices would affect the generation dispatch decisions
• Expected payoff will decrease when the energy balancing price is increased.
• However, depending on the energy balancing price, the payoff in uncoordinated hydro and wind unit cases may be larger than that in coordinated cases.
• It depends on the accuracy of forecast of the day-ahead energy balancing price.
• The stochastic scheduling solution would lower the GENCO’s expected downside risk as compared to the deterministic scheduling solution.