Applying High Performance Computing to Multi-Area Stochastic Unit Commitment for Renewable Integration

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Outline

1. Introduction
2. Model
3. Results
Motivation

Increased computational burden in power systems operations due to:

- renewable penetration and
- demand response integration

Potential applications:

- stochastic optimization
- robust optimization
- topology control
Want to quantify sensitivity of:
- unit commitment policy
- duality gaps
- cost performance
on number of scenarios.
Validation Process

- Stochastic model (renewable energy, demand, contingencies)
- Scenario selection
- Stochastic UC
  - Representative outcomes
  - Stoch < Det?
  - Outcomes
- Economic dispatch
  - Min load, startup, fuel cost
  - Slow gen UC schedule
- Deterministic UC
  - Slow gen UC schedule
  - Outcomes

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Parallel Stochastic Unit Commitment
(UC) : \( \text{min} \sum_{g \in G} \sum_{t \in T} (K_g u_{gt} + S_g v_{gt} + C_g p_{gt}) \)

s.t. \( \sum_{g \in G_n} p_{gt} = D_{nt} \)

\( P^-\ u_{gt} \leq p_{gt} \leq P^+\ u_{gt} \)

\( e_{lt} = B_l(\theta_{nt} - \theta_{mt}) \)

\((p, e, u, v) \in \mathcal{D}\)
Stochastic Unit Commitment Model

\[ (SUC) : \min \sum_{g \in G} \sum_{s \in S} \sum_{t \in T} \pi_s (K_g u_{gst} + S_g v_{gst} + C_g p_{gst}) \]

s.t. \[ \sum_{g \in G} p_{gst} = D_{nst}, \]
\[ P_{gs}^- u_{gst} \leq p_{gst} \leq P_{gs}^+ u_{gst} \]
\[ e_{lst} = B_{ls} (\theta_{nst} - \theta_{mst}) \]
\[ (p, e, u, v) \in D_s \]
\[ u_{gst} = w_{gt}, v_{gst} = z_{gt} \]
Lagrangian Decomposition Algorithm

\[ L = \sum_{s \in S} \pi_s \left( \sum_{g \in G} \sum_{t \in T} (K_g u_{gst} + S_g v_{gst} + C_g p_{gst}) \right) \]

\[ + \sum_{g \in G_s} \sum_{t \in T} (\mu_{gst} (u_{gst} - w_{gt}) + \nu_{gst} (v_{gst} - z_{gt})) \]
1. Generate a sample set $\Omega_S \subset \Omega$, where $M = |\Omega_S|$ is adequately large. Calculate the cost $C_D(\omega)$ of each sample $\omega \in \Omega_S$ against the best deterministic unit commitment policy and the average cost $\bar{C} = \frac{1}{M} \sum_{i=1}^{M} C_D(\omega_i)$.

2. Choose $N$ scenarios from $\Omega_S$, where the probability of picking a scenario $\omega$ is $C_D(\omega)/\bar{C}$.

3. Set $\pi_s = C_D(\omega)^{-1}$ for all $\omega_s \in \hat{\Omega}$. 

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Wind Production Model

- Relevant literature: (Brown et al, 1984), (Torres et al., 2005), (Morales et al, 2010)

- Calibration steps
  1. Remove systematic effects:
     
     \[
     y_{kt}^S = \frac{y_{kt} - \hat{\mu}_{kmt}}{\hat{\sigma}_{kmt}}.
     \]
  
  2. Transform data to obtain a Gaussian distribution:
     
     \[
     y_{kt}^{GS} = N^{-1}(\hat{F}_k(y_{kt}^S)).
     \]
  
  3. Estimate the autoregressive parameters \( \hat{\phi}_{kj} \) and covariance matrix \( \hat{\Sigma} \) using Yule-Walker equations.
WECC Model

- 124 units (82 fast, 42 slow), 225 buses, 375 transmission lines
## Unit Characteristics

<table>
<thead>
<tr>
<th>Type</th>
<th>No. of units</th>
<th>Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>2</td>
<td>4,499</td>
</tr>
<tr>
<td>Gas</td>
<td>88</td>
<td>18,745.6</td>
</tr>
<tr>
<td>Coal</td>
<td>6</td>
<td>285.9</td>
</tr>
<tr>
<td>Oil</td>
<td>5</td>
<td>252</td>
</tr>
<tr>
<td>Dual fuel</td>
<td>23</td>
<td>4,599</td>
</tr>
<tr>
<td>Import</td>
<td>22</td>
<td>12,691</td>
</tr>
<tr>
<td>Hydro</td>
<td>6</td>
<td>10,842</td>
</tr>
<tr>
<td>Biomass</td>
<td>3</td>
<td>558</td>
</tr>
<tr>
<td>Geothermal</td>
<td>2</td>
<td>1,193</td>
</tr>
<tr>
<td>Wind (deep)</td>
<td>10</td>
<td>14,143</td>
</tr>
<tr>
<td>Fast thermal</td>
<td>82</td>
<td>9,156.1</td>
</tr>
<tr>
<td>Slow thermal</td>
<td>42</td>
<td>19,225.4</td>
</tr>
</tbody>
</table>
Sensitivity of Optimal Policy on Number of Scenarios

Table: Day-ahead reserve capacity (MW)

<table>
<thead>
<tr>
<th></th>
<th>S10</th>
<th>S50</th>
<th>S100</th>
<th>S1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>WinterWD</td>
<td>8846</td>
<td>8575</td>
<td>8885</td>
<td>8600</td>
</tr>
<tr>
<td>SpringWD</td>
<td>9173</td>
<td>8639</td>
<td>9077</td>
<td>8572</td>
</tr>
<tr>
<td>SummerWD</td>
<td>12185</td>
<td>12327</td>
<td>12261</td>
<td>12497</td>
</tr>
<tr>
<td>FallWD</td>
<td>10039</td>
<td>10182</td>
<td>9771</td>
<td>9989</td>
</tr>
<tr>
<td>WinterWE</td>
<td>7700</td>
<td>8074</td>
<td>6978</td>
<td>7170</td>
</tr>
<tr>
<td>SpringWE</td>
<td>7588</td>
<td>7001</td>
<td>7105</td>
<td>7032</td>
</tr>
<tr>
<td>SummerWE</td>
<td>11041</td>
<td>10545</td>
<td>10795</td>
<td>10810</td>
</tr>
<tr>
<td>FallWE</td>
<td>9476</td>
<td>8669</td>
<td>8665</td>
<td>8637</td>
</tr>
<tr>
<td>Average</td>
<td>9744</td>
<td>9542</td>
<td>9538</td>
<td>9485</td>
</tr>
</tbody>
</table>
Unit Commitment: Winter Weekdays

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Parallel Stochastic Unit Commitment
Unit Commitment: Spring Weekdays
Unit Commitment: Summer Weekdays

![Graph showing power generation over time for different stochastic models.]

- **stoch10**
- **stoch50**
- **stoch100**
- **stoch1000**
Unit Commitment: Fall Weekdays

![Graph showing unit commitment results](image)

- stoch10
- stoch50
- stoch100
- stoch1000

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Unit Commitment: Winter Weekends

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Unit Commitment: Spring Weekends

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Unit Commitment: Summer Weekends

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Unit Commitment: Fall Weekends

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## Sensitivity of Bounds on Number of Scenarios

**Table:** Lower and Upper Bound ($1000s$)

<table>
<thead>
<tr>
<th></th>
<th>S10</th>
<th>S50</th>
<th>S100</th>
<th>S1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>WinterWD</td>
<td>(254, 325)</td>
<td>(100, 169)</td>
<td>(-165, -93)</td>
<td>(-180, -105)</td>
</tr>
<tr>
<td>SpringWD</td>
<td>(1073, 1123)</td>
<td>(135, 28)</td>
<td>(97, 154)</td>
<td>(115, 164)</td>
</tr>
<tr>
<td>SummerWD</td>
<td>(-367, -234)</td>
<td>(48, 87)</td>
<td>(187, 304)</td>
<td>(-76, 62)</td>
</tr>
<tr>
<td>FallWD</td>
<td>(-146, -45)</td>
<td>(-292, 397)</td>
<td>(-191, -77)</td>
<td>(-108, 7)</td>
</tr>
<tr>
<td>WinterWE</td>
<td>(185, 295)</td>
<td>(-323, 413)</td>
<td>(-504, -411)</td>
<td>(-84, 17)</td>
</tr>
<tr>
<td>SpringWE</td>
<td>(668, 783)</td>
<td>(-121, 202)</td>
<td>(-228, -153)</td>
<td>(52, 128)</td>
</tr>
<tr>
<td>SummerWE</td>
<td>(-57, 99)</td>
<td>(438, -283)</td>
<td>(-150, 93)</td>
<td>(-108, 50)</td>
</tr>
<tr>
<td>FallWE</td>
<td>(810, 913)</td>
<td>(-530, 624)</td>
<td>(-304, -207)</td>
<td>(-92, 7)</td>
</tr>
</tbody>
</table>
Table: Performance Improvement as a Function of Gap Improvement

<table>
<thead>
<tr>
<th>Policy</th>
<th>Gap ($)</th>
<th>Cost ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S10</td>
<td>97827</td>
<td>7.303</td>
</tr>
<tr>
<td>S10*</td>
<td>70559</td>
<td>7.300</td>
</tr>
<tr>
<td>S50</td>
<td>92413</td>
<td>7.308</td>
</tr>
<tr>
<td>S50*</td>
<td>62190</td>
<td>7.286</td>
</tr>
<tr>
<td>S100</td>
<td>93711</td>
<td>7.299</td>
</tr>
<tr>
<td>S100*</td>
<td>67069</td>
<td>7.289</td>
</tr>
<tr>
<td>S1000</td>
<td>98485</td>
<td>7.301</td>
</tr>
</tbody>
</table>
Running Times

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Conclusions

- **Validation of scenario selection algorithm:** The importance sampling scenario selection algorithm with 10 scenarios performs as well as a stochastic unit commitment model with 1000 scenarios.

- **Decreasing the duality gap versus increasing the number of scenarios:** Reducing the duality gap seems to yield superior benefits relative to adding more scenarios.

- **Scaling of running times:** The speedup benefits of parallelization seem to be limited beyond 20% of the problem size.
Thank you

Questions?

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http://www3.decf.berkeley.edu/~tonypap/publications.html