Robust Dispatch to Manage Uncertainty in Real Time Electricity Markets

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Outline

- Introduction
- Robust Dispatch to Manage Uncertainty
- Application Examples
- Conclusions
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Introduction: Smart Grid Challenges

- A lot of emphasis of renewables, distributed energy resources (DER) and demand response (DR), PHEVs etc.
- Increase amount of uncertainties:
  - Generations and Demand Response
  - Demand forecast
  - Transmission constraints
  - Resource characteristics
- Modeling of uncertainties
  - Confidence Interval
  - Scenario-based
- Volumes and distributiveness of DERs and DRs
  - Aggregation model
- Smart Dispatch
  - Holistic forward-looking view of system conditions
  - More robust solution
Introduction: Problems with Current Resource Dispatch

Current operation

- Alternative “independent” single interval dispatches: Medium, High (+ΔD) and Low (−ΔD) demand
- Operator must choose one
- No trend (profile) of generation instructions
  → non/late-responsive generators
  → turn-around for generators

Problems

- Excessive turn-around for generators
- Non-responsive generation
Look-Ahead Scheduling Functions (SKED1, 2 & 3): security constrained unit commitment and economic dispatch sequences with different look-ahead periods (e.g. 6 hours, 2 hours and 20 minutes) used to update the Comprehensive Operating Plan (COP), considering the “reality” (from State Estimator) as well as more updated forecasts of the future.

- For SKED1 and SKED2, the studies shall be time-coupled.

- Due to the concern of pricing, SKED3 shall have the flexibility of being configured as either time coupled or not coupled. When running in a decoupled mode, for each SKED3 interval, the latest available SE shall be the initial status, and each SKED3 interval shall consider the envelope provided by the Comprehensive Operating Plan (COP).
COP is an application to coordinate scheduling data to and from a certain class of power system applications and present a comprehensive, synchronized and more harmonized view of scheduling data to applications, to system operators or other stakeholders for the purpose of power system operations.
SKED 1, 2 & 3 Execution Sequences

- SCED3 launch time & granularity
- SCED2 launch time & granularity
- SCED1 launch time & granularity
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SKED3: Current Approach

Three "independent" solutions

Dispatcher can switch between H/M/L solutions; however reachability is not guaranteed
SKED3 Future: Robust Dispatch

One robust solution

- Three demand scenarios coordinated into one robust solution
  - “reach-ability” between medium and high and between medium and low demand scenarios

Envelope: Coupling between SKED2 and SKED3 to ensure that SKED3 solution gets into the envelope of SKED2.
Deployment (avoid overcompensation)

\[
\text{steam deviation} = \Sigma \text{Pg real} - \Sigma \text{Pg instructed}
\]

If (steam deviation < \(-\text{tol}\)) and (\(\text{ACE} < \text{tol ace}\)) then

\[
K = \frac{-\text{steam deviation}}{(\text{Pdh} - \text{Pdm})} \quad \quad 0 \leq K \leq 1
\]

\[
\text{Pg} = \text{Pgm} + K(\text{Pgh} - \text{Pgm})
\]

end if

If (steam deviation > \text{tol}) and (ACE > \text{tol ace}) then

\[
K = \frac{\text{steam deviation}}{(\text{Pdm} - \text{Pdl})} \quad \quad 0 \leq K \leq 1
\]

\[
\text{Pg} = \text{Pgm} - K(\text{Pgm} - \text{Pgl})
\]

end if

---

Robust Solution

- High
- Medium
- Low

SKED2 (M)

\(P_g^{\text{max}}(t_n)\)

\(P_g^{\text{min}}(t_n)\)

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Robust Dispatch
Robust Dispatch (Basic Formulation)

Minimize

\[
\sum_{t} \left\{ \sum_{i} \left( c_{i,t} \times P_{gm_{i,t}} \right) \times (time_{t} - time_{t-1}) / 60 \right\} + \sum_{t} \left\{ \sum_{i} \left( c_{i,t} \times P_{gh_{i,t}} \right) \times (time_{t} - time_{t-1}) / 60 \right\} + \sum_{t} \left\{ \sum_{i} \left( c_{i,t} \times P_{gl_{i,t}} \right) \times (time_{t} - time_{t-1}) / 60 \right\}
\]

subject to for \( \forall t = \{ t_1, \ldots, t_n \} \)

\[
\sum_{i} P_{gm_{i,t}} = P_{demand_{M,t}}
\]

\[
P_{g_{i,t}}^{min} \leq P_{gm_{i,t}} \leq P_{g_{i,t}}^{max}
\]

\[
- (time_{t} - time_{t-1}) \times RRD_{n_{i,t}} \leq P_{gm_{i,t}} - P_{gm_{i,t-1}} \leq (time_{t} - time_{t-1}) \times RRU_{p_{i,t}}
\]

\[
- F_{k,t}^{max} \leq \sum_{i} D_{fax_{Fk_{i,t}}} \times P_{gm_{i,t}} \leq F_{k,t}^{max}
\]

\[
\sum_{i} P_{gh_{i,t}} = P_{demand_{H,t}}
\]

\[
P_{g_{i,t}}^{min} \leq P_{gh_{i,t}} \leq P_{g_{i,t}}^{max}
\]

\[
- (time_{t} - time_{t-1}) \times RRD_{n_{i,t}} \leq P_{gh_{i,t}} - P_{gh_{i,t-1}} \leq (time_{t} - time_{t-1}) \times RRU_{p_{i,t}}
\]

\[
- F_{k,t}^{max} \leq \sum_{i} D_{fax_{Fk_{i,t}}} \times P_{gh_{i,t}} \leq F_{k,t}^{max}
\]

\[
\sum_{i} P_{gl_{i,t}} = P_{demand_{L,t}}
\]

\[
P_{g_{i,t}}^{min} \leq P_{gl_{i,t}} \leq P_{g_{i,t}}^{max}
\]

\[
- (time_{t} - time_{t-1}) \times RRD_{n_{i,t}} \leq P_{gl_{i,t}} - P_{gl_{i,t-1}} \leq (time_{t} - time_{t-1}) \times RRU_{p_{i,t}}
\]

\[
- F_{k,t}^{max} \leq \sum_{i} D_{fax_{Fk_{i,t}}} \times P_{gl_{i,t}} \leq F_{k,t}^{max}
\]
Limiting the Cost of Robustness

\[ \sum_i \left\{ \sum_i \left( c_{i,t} * Pgm_{i,t} \right) * \frac{(Time_t - Time_{t-1})}{60} \right\} \leq (1 + DeltaCost) * CostBC \]
Introduction
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Examples

**5-Bus System**

- **Brighton**
  - Gen

- **Alta**
  - Gen
  - Park city

- **Sundance**
  - Gen

- **Solitude**
  - Gen

- **XCD = 2.97%**
- **XED = 2.97%**
- **XAB = 2.81%**
- **XEA = 0.64%**
- **XBC = 1.08%**
- **XBA = 2.81%**

- **XAD = 3.04%**

- **16-Bus System**

- **Load**
- **Load**

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Kwok Cheung
# SKED3

## Sequential vs. Dynamic Dispatch

### Value of Pre-ramping

<table>
<thead>
<tr>
<th>Cost</th>
<th>t1</th>
<th>t2</th>
<th>t3</th>
<th>t4</th>
<th>Total</th>
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<tbody>
<tr>
<td>Dynamic dispatch</td>
<td>9570</td>
<td>10670</td>
<td>20845</td>
<td>15570</td>
<td>56655</td>
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<tr>
<td>Sequential dispatch</td>
<td>9420</td>
<td>10495</td>
<td>23220</td>
<td>20070</td>
<td>63205</td>
</tr>
</tbody>
</table>

### Price, Max Ramp up, Max Ramp down, Pg SE

<table>
<thead>
<tr>
<th>Price</th>
<th>Max Ramp Up</th>
<th>Max Ramp Down</th>
<th>Pg SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alta</td>
<td>11</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>Parkcity</td>
<td>15</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>Solitude</td>
<td>30</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Sundance</td>
<td>95</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Brighton</td>
<td>10</td>
<td>10</td>
<td>100</td>
</tr>
</tbody>
</table>

### Pg Min

<table>
<thead>
<tr>
<th>Alta</th>
<th>Parkcity</th>
<th>Solitude</th>
<th>Sundance</th>
<th>Brighton</th>
</tr>
</thead>
<tbody>
<tr>
<td>t0</td>
<td>20</td>
<td>10</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>t1</td>
<td>20</td>
<td>10</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>t2</td>
<td>20</td>
<td>10</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>t3</td>
<td>20</td>
<td>10</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>t4</td>
<td>20</td>
<td>10</td>
<td>0</td>
<td>50</td>
</tr>
</tbody>
</table>

### Pg Max

<table>
<thead>
<tr>
<th>Alta</th>
<th>Parkcity</th>
<th>Solitude</th>
<th>Sundance</th>
<th>Brighton</th>
</tr>
</thead>
<tbody>
<tr>
<td>t0</td>
<td>150</td>
<td>150</td>
<td>0</td>
<td>400</td>
</tr>
<tr>
<td>t1</td>
<td>150</td>
<td>150</td>
<td>0</td>
<td>400</td>
</tr>
<tr>
<td>t2</td>
<td>150</td>
<td>150</td>
<td>0</td>
<td>400</td>
</tr>
<tr>
<td>t3</td>
<td>150</td>
<td>150</td>
<td>0</td>
<td>400</td>
</tr>
<tr>
<td>t4</td>
<td>150</td>
<td>150</td>
<td>0</td>
<td>400</td>
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</tbody>
</table>
SKED3
independent vs. robust dispatch
Value of reach-ability

<table>
<thead>
<tr>
<th>Cost</th>
<th>t1</th>
<th>t2</th>
<th>t3</th>
<th>t4</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>M independent t1 &amp; t2 + H t3 &amp; t4</td>
<td>2035</td>
<td>2125</td>
<td>6310</td>
<td>5048</td>
<td>15517</td>
</tr>
<tr>
<td>M robust (M→H) t1 &amp; t2 + H t3 &amp; t4</td>
<td>2037</td>
<td>2129</td>
<td>5352</td>
<td>4089</td>
<td>13607</td>
</tr>
<tr>
<td>perfect forecast M t1 &amp; t2 + H t3 &amp; t4</td>
<td>2048</td>
<td>2139</td>
<td>5362</td>
<td>3298</td>
<td>12846</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>PriceE</th>
<th>MaxRampUp</th>
<th>MaxRampDn</th>
<th>PgSE</th>
<th>Gbus</th>
<th>Pgmin</th>
<th>Pgmax</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alta</td>
<td>11</td>
<td>5</td>
<td>100</td>
<td>20</td>
<td>A</td>
<td>20</td>
</tr>
<tr>
<td>Parkcity</td>
<td>15</td>
<td>5</td>
<td>100</td>
<td>10</td>
<td>A</td>
<td>10</td>
</tr>
<tr>
<td>Solitude</td>
<td>30</td>
<td>10</td>
<td>100</td>
<td>0</td>
<td>C</td>
<td>0</td>
</tr>
<tr>
<td>Sundance</td>
<td>395</td>
<td>100</td>
<td>100</td>
<td>50</td>
<td>D</td>
<td>50</td>
</tr>
<tr>
<td>Brighton</td>
<td>10</td>
<td>10</td>
<td>100</td>
<td>420</td>
<td>E</td>
<td>350</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>t0</th>
<th>t1</th>
<th>t2</th>
<th>t3</th>
<th>t4</th>
</tr>
</thead>
<tbody>
<tr>
<td>time 0</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Pdm  500</td>
<td>510</td>
<td>605</td>
<td>610</td>
<td>620</td>
</tr>
<tr>
<td>Pdh  500</td>
<td>510</td>
<td>605</td>
<td>800</td>
<td>810</td>
</tr>
<tr>
<td>Pdl  500</td>
<td>505</td>
<td>600</td>
<td>605</td>
<td>615</td>
</tr>
</tbody>
</table>

GCA - Dynamic Dispatch (DSPD)
**GCA - Dynamic Dispatch (DSPD)**

- **Robust dispatch**
  - Brighton ($10)
  - Sundance ($395) can produce even less

- **Perfect forecast**
  - Brighton ($10) further backs down to allow pre-ramping
  - Alta ($11) and Parkcity ($15) pre-ramp

- **Independent**
  - Robust dispatch
  - Brighton ($10) backs down to allow pre-ramping
  - Sundance ($395) can produce less

- **Robust dispatch**
  - Alta ($11) pre-ramp
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- Discussed the needs for robust dispatch.
- A simple approach to deal with uncertainties in the real-time security constrained economic dispatch is proposed.
- A mathematical formulation of the proposed robust dispatch solution is presented.
- A robust solution that coordinates multiple demand scenarios could guarantee “reachability”.
- An 5-bus example is given to illustrate the proposed concept of robust dispatch.
Q & A