Wind Dispatch Using Do-not-Exceed Limit

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Outline

• Motivation
• Current Practice and Issues
• The Proposed Wind Dispatch Process
• DNE Problem and Solution Method
• Numerical Example
• Conclusion
Motivation

• More wind resources are being integrated into the system operation.

• Different from conventional generators, wind resources are
  – Variable
    • Increased level of uncertainty in the real-time operation
  – Non-dispatchable
    • Wind generation can be only curtailed when reliability issues arise
  – Low operating cost
    • Negative marginal cost

• How do we better utilize the low cost wind resources recognizing their variability?
Existing Real-time Wind Dispatch Practice

- **Manual Dispatch**
  - Fixed at SCADA values
  - Do not set real-time prices
  - Curtailment through phone calls in the event of transmission violation
  - No enforcement of performance penalty

- **Automatic Dispatch**
  - Expected output forecasted by the system operator or participants
  - Dispatch between 0 and the expected output
  - Utilize economic offers in the dispatch and pricing
  - Automatic curtailment as long as basepoint < expected output
  - Electronic dispatch with basepoint and/or curtailment flag
  - Allow a wider deviation range when no curtailment is activated
Issues with Existing Practice

• The dispatch signal does not provide a clear guideline of dispatch following for wind resources.
  – They do not know whether additional wind generation beyond the basepoint will cause any reliability problem.

• The curtailment action is ex post and may not be efficient.
  – Manual Curtailment
    • Is implemented when system already experiencing security problem.
  – Automatic Curtailment
    • Does not differentiate economic-based from reliability-based curtailments
The Proposal: Do not Exceed (DNE) Limit

• Send a do-not-exceed limit to each wind unit
  – Do-not-exceed limit = Reliability limit

• The DNE limit is the maximum amount of wind generation that system can accommodate without causing any reliability issues.
  – Reliability: Capacity and Transmission
  – Uncertainty: Any realization

• Benefits of DNE limit:
  – Provide a dispatch guideline for wind resources
  – Provide incentives for dispatch following
    • Units exceeding their DNE limits are subject to penalty
  – Allow low cost wind resource to provide as much energy as possible
Real-time Wind Dispatch Framework

Wind CA

Transmission Constraints

RT Dispatch

DDP

DNE Limit Calculation

DNE Limit

DDP for non-wind resource

Forecast

Market & Network

CA – Contingency Analysis
ED - Electronic Dispatch System
DDP – Desired Dispatch Point
DNE – Do-not-Exceed Limit
Wind CA

- N-1 Contingency Analysis
  - Loss of line
  - Loss of generator

- Enhancement with wind dispatch
  - Security under expected wind generation
    - Contingency analysis with expected wind output scenario
    - Constraints are generated for the economic dispatch
  - Security under extreme wind realization
    - Zonal basis
    - Loss of wind resource
    - Extreme wind generation
    - Constraints are generated for the DNE limit calculation
Real-time Dispatch

- Market participants submit
  - Real-time high operating limit
  - Generation forecast
  - Meteorology data
  - Outage information

- ISO forecasts the expected output of each wind resource.

- In the dispatch, each wind unit is
  - Dispatchable (allowed for price setting)
  - Dispatched between 0 and its expected output level
  - Dispatched against its energy offer
DNE Limit Calculation

• Produce the reliability limit for each wind resources by taking account system control actions.

• DNE Limit Problem Formulation
  – An optimization problem to find the minimum and maximum output level of a wind resource while satisfying the following conditions:
    • System is able to maintain energy balance under any output variation of wind resources by adopting a set of control actions,
    • The flow on any transmission line remains within its limit under any realization of uncertain output level of wind resources,
    • The corrective control action must be subject to its corresponding physical limits,
    • The output variation of a wind resource should be within its physical limits.
Not a Standard Robust Optimization Problem

• A standard two-stage robust optimization problem:
  \[
  \min_{x, p(\bullet)} \left( c^T x + \max_{w \in [w_{LB}, w_{UB}]} g(p(w)) \right) \\
  \text{s.t. } Ax + Bp(w) + Dw \leq h, \forall w \in [w_{LB}, w_{UB}] \\
  x \in X \\
  \text{– Determine the best control decision } x \text{ to accommodate the worst case} \\
  \text{– The uncertainty set is pre-defined}
  \]

• DNE limit problem:
  \[
  \min_{p(\bullet), w_{LB}, w_{UB}} f(w_{LB}, w_{UB}) \\
  \text{s.t. } Ax^* + Bp(w) + Dw \leq h, \forall w \in [w_{LB}, w_{UB}] \\
  (w_{LB}, w_{UB}) \in \mathcal{W} \\
  \text{– Determine the largest uncertainty range that a system can accommodate} \\
  \text{– The uncertainty set is to be determined}
Solution Strategies

• The DNE Limit problem can be considered as a reverse of an adaptive robust optimization problem, which is difficult to solve in general.

• Approximation can be made to the adaptive/corrective actions to reduce the complexity of the solution method.

• Three approximation strategies
  – Affine policy with fixed participation factor
  – Affine policy with optimal participation factor
  – Fully adaptive strategy
Affine Policy

• Assume that the output of a corrective action unit changes linearly with respect to the uncertainty realization

\[ p_j(w) = p_j^* + E_j \cdot (w - w^*) \]

Participation vector

• Substitution and Dualize the robust constraint

\[
\begin{align*}
&\min_{p^*(\cdot), w^{LB}, w^{UB}} f(w^{LB}, w^{UB}) \\
&\text{s.t. } Ax^* + Bp(w) + Dw \leq h, \forall w \in [w^{LB}, w^{UB}] \\
&(w^{LB}, w^{UB}) \in \mathcal{W}
\end{align*}
\]

\[
\begin{align*}
&\min_{w^{LB}, w^{UB}, E, \alpha} f(w^{LB}, w^{UB}) \\
&\text{s.t. } (Ax^* + Bp^* - BEw^*) + \alpha^+ w^{UB} - \alpha^- w^{LB} \leq h \\
&\alpha^+ - \alpha^- = (D - BE)^T \\
&(w^{LB}, w^{UB}) \in \mathcal{W}
\end{align*}
\]
Affine Policy

- Affine policy with fixed participation factors
  - The participation vector \( E \) can be fixed based on engineering experience.
  - \( \alpha^- \) and \( \alpha^+ \) can be predetermined
  
  \[
  \{\alpha^-\}_{j,k} = \min((D - BE)_{j,k}, 0) \quad \{\alpha^+\}_{j,k} = \max((D - BE)_{j,k}, 0) 
  \]
  
  - The corresponding problem is an LP problem

- Affine policy with optimal participation factors
  - Participation vector \( E \) is a decision variable
  - \( \alpha^- \) and \( \alpha^+ \) are variables too
  - DNE problem is a bilinear problem
Fully Adaptive Strategy

- For any $w_k$ in the interval $[w_k^{LB}, w_k^{UB}]$, it can be expressed as follows:
  \[ w_k = z_k w_k^{LB} + (1 - z_k) w_k^{UB}, \forall z_k \in [0,1] \]

- Reformulation: two-stage adaptive robust optimization problem

\[
\begin{align*}
\min_{p(\bullet), w^{LB}, w^{UB}} & \quad f(w^{LB}, w^{UB}) \\
\text{s.t.} & \quad Ax^* + Bp(w) + Dw \leq h, \forall w \in [w^{LB}, w^{UB}] \\
& \quad (w^{LB}, w^{UB}) \in \mathcal{W} \\
\end{align*}
\]

\[ w = Zw^{LB} + (I - Z)w^{UB}, Z \in [0, I] \]

\[
\begin{align*}
\min_{p(\bullet), w^{LB}, w^{UB}} & \quad f(w^{LB}, w^{UB}) \\
\text{s.t.} & \quad Ax^* + Bp(z) + DZw^{LB} + D(I - Z)w^{UB} \leq h, \forall Z \in [0, I] \\
& \quad (w^{LB}, w^{UB}) \in \mathcal{W} \\
\end{align*}
\]
Comparison of Three Solution Strategies

Solution Methodologies:

- Fully adaptive strategy
  - Two-stage adaptive robust problem (Benders’ decomposition)
- Affine policy with optimal participation factor
  - Bilinear Problem (NLP)
- Affine policy with fixed participation factor
  - LP Problem (CPLEX)

Less conservative (or larger DNE Limits)

Easier to implement
5-Bus Examples

- Generator Information

<table>
<thead>
<tr>
<th>Resources</th>
<th>Type</th>
<th>Location</th>
<th>Bid ($/MWh)</th>
<th>Dispatch Min (MW)</th>
<th>Dispatch Max (MW)</th>
<th>Physical Min (MW)</th>
<th>Physical Max (MW)</th>
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<tbody>
<tr>
<td>Gen0</td>
<td>Wind</td>
<td>Bus0</td>
<td>0</td>
<td>0</td>
<td>80</td>
<td>0</td>
<td>150</td>
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<tr>
<td>Gen1</td>
<td>AGC</td>
<td>Bus1</td>
<td>10</td>
<td>40</td>
<td>100</td>
<td>0</td>
<td>100</td>
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<tr>
<td>Gen2</td>
<td>Conventional</td>
<td>Bus2</td>
<td>15</td>
<td>50</td>
<td>100</td>
<td>0</td>
<td>150</td>
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<tr>
<td>Gen3</td>
<td>Wind</td>
<td>Bus3</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>150</td>
</tr>
<tr>
<td>Gen4</td>
<td>AGC</td>
<td>Bus4</td>
<td>20</td>
<td>120</td>
<td>150</td>
<td>0</td>
<td>150</td>
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<tr>
<td>Load1</td>
<td>Fixed</td>
<td>Bus1</td>
<td>50</td>
<td>50</td>
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<td></td>
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<tr>
<td>Load2</td>
<td>Fixed</td>
<td>Bus2</td>
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<td>100</td>
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<td></td>
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<tr>
<td>Load3</td>
<td>Fixed</td>
<td>Bus3</td>
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<tr>
<td>Load4</td>
<td>Fixed</td>
<td>Bus4</td>
<td>200</td>
<td></td>
<td>200</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Only AGC units are assumed to perform corrective control in the example.
Transmission flow limit for each line is 100 MW.
## 5-Bus Example: DNE Limits

<table>
<thead>
<tr>
<th>Approaches</th>
<th>Gen0 (DNE Limit)</th>
<th>Gen1 (e)</th>
<th>Gen2 (DDP)</th>
<th>Gen3 (DNE Limit)</th>
<th>Gen4 (e)</th>
<th>Total Range of DNE Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affine (fixed e)</td>
<td>[58.3~100]</td>
<td>0.4</td>
<td>50 MW</td>
<td>[71.7~113.3]</td>
<td>0.6</td>
<td>83.3 MW</td>
</tr>
<tr>
<td>Affine (optimal e)</td>
<td>[24~100]</td>
<td>0.714</td>
<td>50 MW</td>
<td>[100~150]</td>
<td>0.286</td>
<td>126 MW</td>
</tr>
<tr>
<td>Fully adaptive</td>
<td>[80~100]</td>
<td>N/A</td>
<td>50 MW</td>
<td>[30~150]</td>
<td>N/A</td>
<td>140 MW</td>
</tr>
</tbody>
</table>

- Fully adaptive approach results in the largest total DNE limit range
- Affine policy approach with fixed participation factor results in the smallest total DNE limit range
- The fixed participation factor can be very different from the optimal counterpart.
ISO New England System Example

- Jun 1st, 2011 Data
  - 6 wind generators with total capacity of 250 MW
  - 1~3 AGC units with regulation capability of 20~140 MW

- Two affine approaches yield the same results
- The advantage of the adaptive approach is not significant
Conclusion

• A wind dispatch framework using the DNE limit is proposed.

• The proposed dispatch framework
  – Provides a more clear dispatch guideline for wind resources
  – Provides better incentives for dispatch following
  – Accommodates more low cost wind generation

• A systematic way of determining the DNE limits for wind power resources is proposed based on the robust optimization technique.

• Three solution strategies are investigated.
  – The fixed participation factor affine policy approach is more suitable for the real-time operation.
Questions