Impact of Wind Power Forecasting on Unit Commitment and Dispatch

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Increasingly important to make use of the information in wind power forecasts in system and market operations

Stochastic methods can help system/market operators handle increased uncertainty and variability from wind power
United States recently became the *world leader* in wind power capacity with over 8 GW installed in 2008 and almost 30 GW total installed capacity (AWEA)

*Source: Berkeley Lab estimates based on data from BTM Consult and elsewhere*
Does Wind Power Influence Market Operations?

Midwest ISO Wind Power and MN Hub Prices, May 11-17, 2009:

Wind power ramping events

Negative prices (LMPs)

Based on data from www.midwestiso.org
Our Project: “Development and Deployment of Advanced Wind Forecasting Techniques”

**Goal:** To contribute to efficient large-scale integration of wind power by developing improved wind forecasting methods and better integration of advanced wind power forecasts into system and plant operations.

**Collaborators:** Institute for Systems and Computer Engineering of Porto (INESC Porto), Portugal

**Industry Partners:** Midwest ISO (MISO) and Horizon Wind Energy

**Sponsor:** U.S. Dept. of Energy (Wind and Hydropower Tech. Program)

The project consists of two main parts:

- **Wind power forecasting**
  - Review and assess existing methodologies
  - Develop and test new and improved algorithms

- **Integration of forecasts into operations (power system and power plants)**
  - Review and assess current practices
  - Propose and test new and improved approaches, methods and criteria
Outline

- Background

- Forecasting and electricity market operations

- Stochastic vs. deterministic unit commitment
  - Model description
  - Case study (preliminary)

- Concluding remarks
Steps in US Electricity Market Operations (based on Midwest ISO)

**Day ahead:**
- Post operating reserve requirements
- Prepare and submit DA bids
- Clear DA market using SCUC/SCED
- Re-bidding for RAC
- Post-DA RAC using SCUC

- Post results (DA energy and reserves)

**Operating day:**
- Intraday RAC using SCUC
- Prepare and submit RT bids
- Clear RT market using SCED (every 5 min)
- Post results (RT energy and reserves)

Role for wind forecasting

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DA – day ahead
RT – real time
SCUC – security constr. unit commitment
SCED – security constr. economic dispatch
RAC – reliability ass. commitment

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Argonne National Laboratory
Wind Power Forecasts are not Perfect…..

Error sources:
- Error in meteorological forecasts
- Errors in wind-to-power conversion process
- Errors in SCADA information (wind power and met data)

Error depends on several factors:
- Prediction horizon
- Time of the year
- Terrain complexity
- Spatial smoothing effect
- Level of predicted power

What are the consequences for economics and security?
What is the best way to handle these uncertainties?
Deterministic vs. Stochastic Approach to Operation and Reliability

- How to deal with increased uncertainty in system operation?
  - How to account for load uncertainty, generator outages, and wind uncertainty in the day-ahead unit commitment?

- Deterministic unit commitment and reserve requirements
  - Traditional approach used in industry
  - Deterministic optimization problem with reliability constraints
  - Solution may deviate from economic optimum
  - Need to revisit current operating reserve requirements

- Stochastic unit commitment
  - Explicit representation of uncertainty in problem formulation
  - Minimization of expected costs
  - May become computationally too intensive
  - Increasing relevance due to additional uncertainty from wind power
Representing Uncertainty in Wind Power Forecasts

<table>
<thead>
<tr>
<th>Uncertainty Representation</th>
<th>Probabilistic</th>
<th>Risk Indices</th>
<th>Scenarios of Generation</th>
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</thead>
<tbody>
<tr>
<td>Probability Mass Function</td>
<td></td>
<td>Meteo Risk Index</td>
<td>Scenarios with temporal dependency</td>
</tr>
<tr>
<td>Probability Density Function</td>
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<td>Prediction Risk Index</td>
<td>Scenarios with spatial/temporal dependency</td>
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<td>Quantiles</td>
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<td>Interval Forecasts</td>
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Interval forecast

Scenarios

Risk Indices of Generation
Scenarios with temporal dependency
Scenarios with spatial/temporal dependency
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A Stochastic Unit Commitment (UC) Model w/Wind Power Uncertainty

- Formulation using wind power forecast scenarios \((s)\) w/probabilities \((\text{prob}_s)\):

\[
\begin{align*}
\text{Min } & \sum_{s=1}^{S} \text{prob}_s \times \left( \sum_{k=1}^{K} \sum_{j=1}^{J} c^f_{js}(k) + \sum_{k=1}^{K} C_{ens} \times \text{ens}_s(k) \right) + \sum_{k=1}^{K} \sum_{j=1}^{J} [c^y(k)] \\
\sum_{j=1}^{J} \text{pmf}_s(k) + \sum_{j=1}^{J} \text{ptf}_s(k) &= D(k) - \text{ens}_s(k) , \quad \forall k, \forall s \\
\sum_{j=1}^{J} [\text{ptf}_s(k) - \text{pmf}_s(k)] &\geq R(k) , \quad \forall k, \forall s \\
p_j(k) &\in \pi_j(k) , \quad \forall j, \forall k
\end{align*}
\]

- Objective function
  (min expected cost)
- Energy balance
- Reserve requirements
  (spinning)
- Unit commitment
  constraints (ramp, min. up/down)

- A two-stage stochastic mixed integer linear programming (MILP) problem
  - First-stage: commitment
  - Second-stage: dispatch
Case Study Assumptions

- 10 thermal units
  - Base, intermediate peak load
  - Total capacity: 1662 MW
- Wind power capacity: 400 MW
- Peak load: 1500 MW
- No transmission network
- 30 days simulation period
  - Day-ahead unit commitment w/wind power forecast
  - Real-time dispatch w/realized wind power generation
Simulated Cases

- Comparing four deterministic and two stochastic unit commitment strategies

<table>
<thead>
<tr>
<th>Case</th>
<th>Unit Commitment</th>
<th>Wind Power Forecast</th>
<th>UC Reserve Requirement*</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>Deterministic</td>
<td>Perfect</td>
<td>10%</td>
</tr>
<tr>
<td>D2</td>
<td>Deterministic</td>
<td>Point</td>
<td>10%</td>
</tr>
<tr>
<td>D3</td>
<td>Deterministic</td>
<td>Point</td>
<td>15%</td>
</tr>
<tr>
<td>D4</td>
<td>Deterministic</td>
<td>No</td>
<td>10%</td>
</tr>
<tr>
<td>S1</td>
<td>Stochastic</td>
<td>Scenarios</td>
<td>10%</td>
</tr>
<tr>
<td>S2</td>
<td>Stochastic</td>
<td>Scenarios</td>
<td>8%</td>
</tr>
</tbody>
</table>

* Reserve requirement kept at 10% in real-time dispatch for all cases, to handle other contingencies.
Example of Wind Power Forecast (Day 15)

Note: forecast error (point forecast) < average forecast error (scenarios)
Results: Thermal Commitment and Realized Reserves (Day 15)

- Stochastic UC gives higher commitment and more available operating reserves
- Similar result for deterministic UC w/additional reserve requirement
The potential value of forecasting illustrated by perfect forecast (D1)

Deterministic UC with point forecast (D2) appears too risky

Deterministic UC w/add reserves (D3) and stochastic UC (S2) give similar total cost
Summary of Other Results (30 days simulation)

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<tbody>
<tr>
<td>D1</td>
<td>165</td>
<td>162.5</td>
<td>30.5</td>
</tr>
<tr>
<td>D2</td>
<td>163</td>
<td>175.6</td>
<td>80.1</td>
</tr>
<tr>
<td>D3</td>
<td>197</td>
<td>214.3</td>
<td>29.5</td>
</tr>
<tr>
<td>D4</td>
<td>154</td>
<td>281.5</td>
<td>25.1</td>
</tr>
<tr>
<td>S1</td>
<td>190</td>
<td>191.0</td>
<td>43.5</td>
</tr>
<tr>
<td>S2</td>
<td>199</td>
<td>178.5</td>
<td>123.1</td>
</tr>
</tbody>
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- Stochastic unit commitment tends to give more start-ups
- Available operating reserves in real-time highest in scenarios D3 and D4
- Unit commitment policy has huge impact on prices
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Model and Case Study: Preliminary Conclusions and Future Work

- Preliminary conclusions
  - Wind power forecasting is important
  - Stochastic unit commitment shows potential
  - The interaction between reserve requirements and UC strategy must be further investigated

- Future work
  - Longer UC horizon
  - Unit re-commitment between day-ahead and real-time
  - Transmission constraints and locational prices
  - Demand response
  - Analysis of financial settlement (energy and ancillary services)
  - Alternative ways of generating forecast scenarios
  - Case study with real-world data
Key Challenges for Wind Power Forecasting and Market Operation

- Improved wind power forecasting models
  - Improved point forecasts
  - Generating consistent and reliable *wind power uncertainty* forecasts
  - Forecasting *ramping events*

- Improved use of wind power forecasting into market operation
  - Integrate the wind power forecast into operating procedures and tools (reserve requirements, unit commitment and dispatch models)
  - Make efficient use of *uncertainty information* in wind power forecast in system operations: *stochastic methods to commitment and dispatch*
  - Market incentives for wind power: Wind power bidding, dispatch, curtailment, control (energy and ancillary services)
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