Validation of New Model for Short-term Forecasting of Turbine Icing

Beatrice Brailey
EWEA Wind Power Forecasting 2015
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Background – Icing losses

- Icing losses for wind farms at high latitudes are variable and can be highly significant
  - Annual energy production losses from ~0% up to >10%
  - Monthly energy production losses from 1% up to >50%

(Staffan Lindahl: Quantification of energy losses cause by blade icing using SCADA data, Winterwind 2014)

- Individual icing events can lead to full loss of power
**Background – Short-term forecasting**

- The value of short-term forecasting is well understood
- State of the art forecasts are typically high accuracy
  - Beneficial to model blade icing when forecasting for wind farms in cold climates
- Icing prediction is woefully unvalidated
  - Reliable observation data is scarce
Methods – base forecast

Wind Speed
Wind Direction
Temperature
Pressure
Relative Humidity

Suite of Refinement Models
- MOS corrections
- Time Series
- Climatology

Optimal Combination

Meteorological Forecast

Ice accretion

Power Model

Live SCADA

High-Resolution Site Geography

Power Forecast
Methods – icing model

- Ensemble NWP predictions
- Predicted freezing/thawing time
- Ice accretion parameterization
- Power adjustment

Adapted from Frohboese and Anders (2007)
Methods – icing model power conversion


- Finnish Wind Energy Atlas
- Ljungberg & Niemelä Model
- Converts blade ice, wind speed to power degradation
Validation Data

- 3 wind farms, ~40 wind turbines

- Projects in Region 2 and Region 3, where there is sufficient icing to test model

- For each site:
  - ~1 year of data for model training
  - ~1 year of data for validation

- For all projects the turbines remain operational during blade icing periods
Results
Wind Farm 1 – Avg. 13% icing loss over 4 years

Day ahead accuracy improvement = 0.95%

Base Forecast Power
Icing Forecast Power
Results

Wind Farm 2 - Avg. 6% icing loss over 3.5 years

Day ahead accuracy improvement = 0.65%

Mean Absolute Error (% capacity)

Base Forecast Power
Icing Forecast Power
Results

Wind Farm 3 - Avg. 4% icing loss over 3.5 years

Day ahead accuracy improvement = 0.21%

Base Forecast Power

Icing Forecast Power
Overall

Day ahead accuracy improvement = 0.6%

Mean Absolute Error (% capacity)

Forecast Horizon (hours)
Value to forecast users

- Icing modelling → improved forecast accuracy
  → Increase energy revenue (based on day ahead trading in liberalized market)
  → Operational planning
  → Grid management

<table>
<thead>
<tr>
<th>Forecast scenario</th>
<th>Average trading revenue (€/MWh)</th>
<th>MAE</th>
</tr>
</thead>
<tbody>
<tr>
<td>No forecast</td>
<td>56.3</td>
<td>-</td>
</tr>
<tr>
<td>Basic forecast</td>
<td>57.7</td>
<td>22%</td>
</tr>
<tr>
<td>State of the art</td>
<td>61.6</td>
<td>12%</td>
</tr>
<tr>
<td>Perfect</td>
<td>64.6</td>
<td>0%</td>
</tr>
</tbody>
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Based on day ahead energy trading in the UK

Parkes et al. Wind Energy Trading Benefits Through Short Term Forecasting, EWEC 2006
Value to forecast users – an advanced warning system

![Graph showing Icing Forecast Power, Icing Probability, and Actual Power from 16-Oct to 28-Oct. The graph illustrates the power output as a percentage of capacity over time, highlighting the variability and the impact of icing on power generation.]
Conclusions

- Validation shows icing model adds value to forecasts
  - Successful in varying levels of icing
  - Reduces MAE by up to 0.95% capacity (average improvement = 0.6%)

- Ice accretion → ice load → power is well modelled

- Scope for model improvement
  - Meteorological conditions → icing → freezing time
  - Thawing/ice throw
  - Upper limit for ice load

- Forecast accuracy improvement = increased revenue, informed operations, improved grid management
Questions?

Beatrice Brailey  
Beatrice.Brailey@dnvgl.com  
+44 (0) 117 972 9900

www.dnvgl.com

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