Forecasting wind turbine icing
The value of icing forecasts on the day-head energy market trading

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DNV GL Short-Term Forecasting Summary

- Wind, solar and power demand forecasts
- 5 minutes to 15 days into the future
- Global Experience > 50 GW capacity > 20 countries
- Data from the World’s best forecast models
- Accurate uncertainty data for risk evaluation

**Recent Forecast Performance**

**Predicted Future Generation**

- Time (GMT Daylight Saving Time (UTC+1))
- Forecast Power (MW)
- Forecast Wind Speed (issued: 8 hour horizon)
- Actual
- Current Time

Show Data Table
Export to CSV
Forecasting – Reducing Risk

- Energy trading
- Optimised operations & maintenance
- Generation scheduling and grid operation
Wind Energy Forecasting Accuracy Through The Years

MAE (% of capacity)


Private and confidential
**Challenge – Icing losses**

- Icing losses in Scandinavia 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
Methods – icing model

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

Adapted from Froehboese 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
Value to forecast users – an advanced warning system

Icing Forecast Power
Icing Probability
Actual Power
The Nordic/Baltic day-ahead market (Elspot)

- 12:00 CET daily trade
- Hour by hour order of the next day
- Scheduled energy sold at Elspot day-ahead price
- Shortfall bought at regulation buy price
- Excess sold at regulation sell price
- Intraday market also available
Show me the money! – example trades

### Day Ahead Market

<table>
<thead>
<tr>
<th>Trade</th>
<th>Standard</th>
<th>Icing model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast (MWh)</td>
<td>20</td>
<td>11</td>
</tr>
<tr>
<td>DAM (€/MWh)</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>DAM revenue (€)</td>
<td>660</td>
<td>363</td>
</tr>
</tbody>
</table>

### Regulation Market

<table>
<thead>
<tr>
<th>Trade</th>
<th>Standard</th>
<th>Icing model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual (MWh)</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Delta (MWh)</td>
<td>-11</td>
<td>-2</td>
</tr>
<tr>
<td>Buy (€/MWh)</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Balancing (€)</td>
<td>-440</td>
<td>-80</td>
</tr>
<tr>
<td>Total (€)</td>
<td>220</td>
<td>283</td>
</tr>
</tbody>
</table>

Icing forecast benefit ~1000 EUR/winter for 15MW wind farm
Conclusion

- Short-term forecasting minimises risk
- Detailed modelling can further improve advanced forecasts
- Further research on market fundamentals
Thank you – I will be at stand no. 36

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