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

Using SCADA data from Scandinavian wind farms

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Winterwind 2015

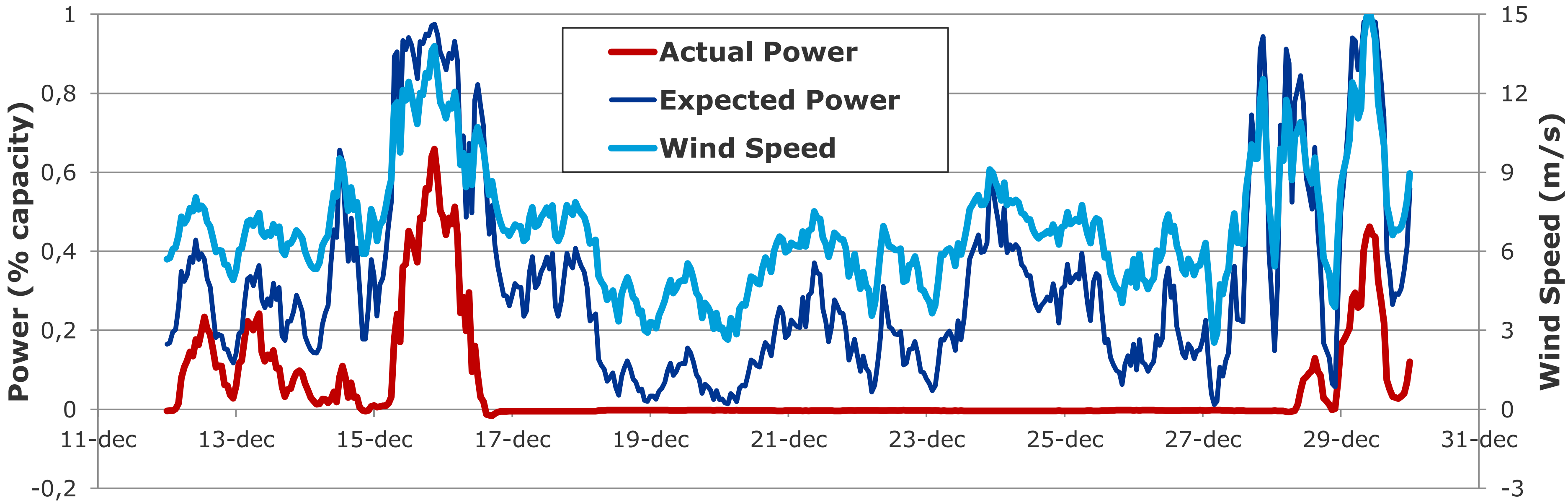
Contents

Background – 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%

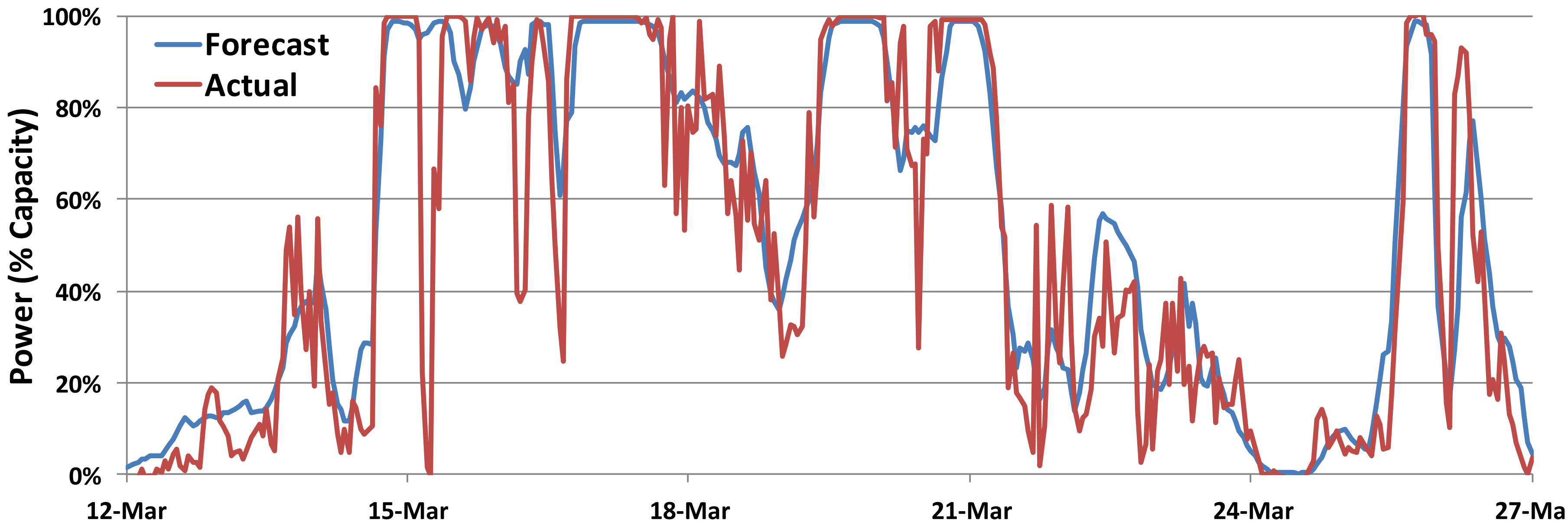
  (Staffan Lindahl: Quantification of energy losses cause by blade icing using SCADA data, Winterwind 2014)

- Individual icing events can lead to full loss of power

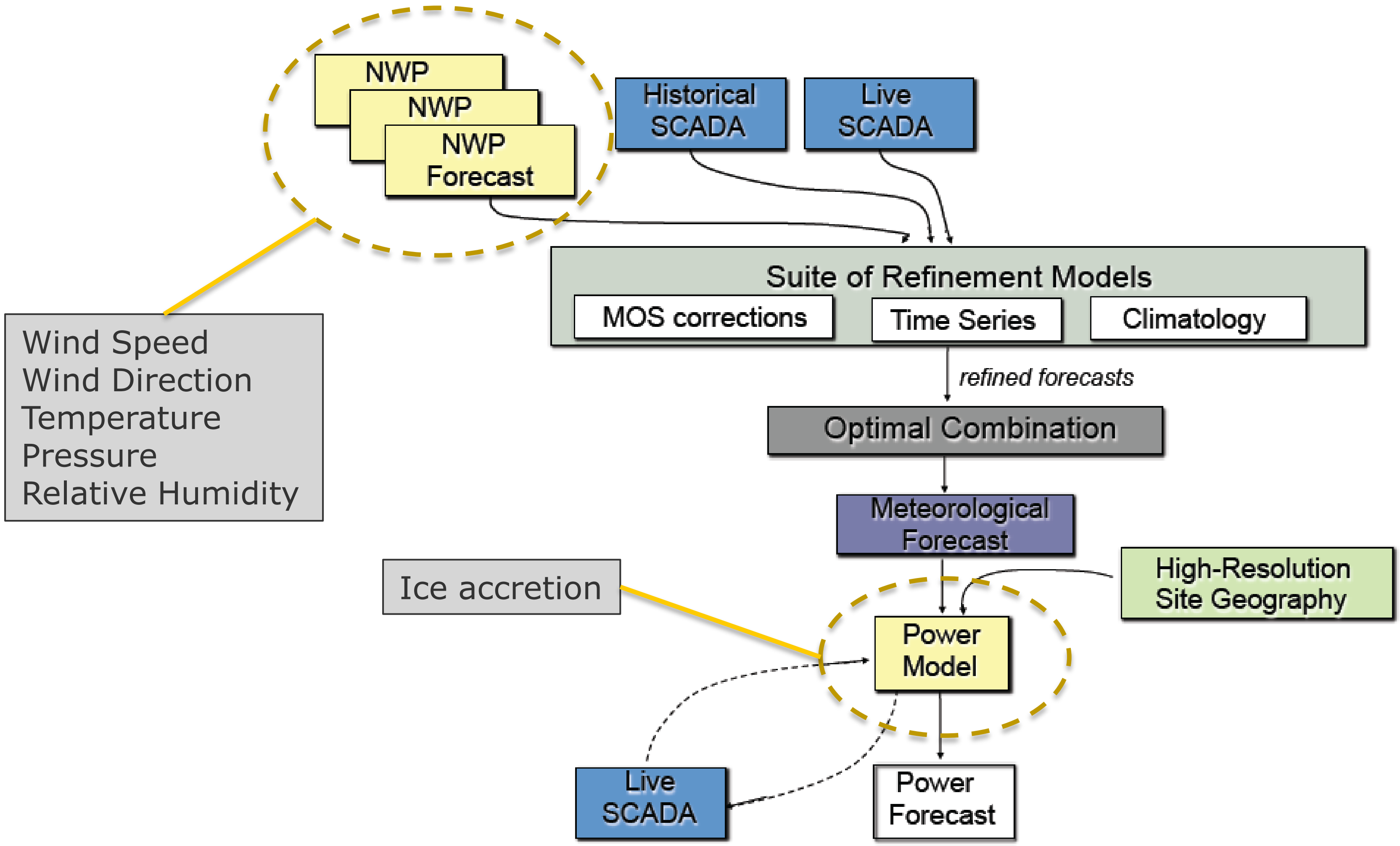


Background – Short-term forecasting

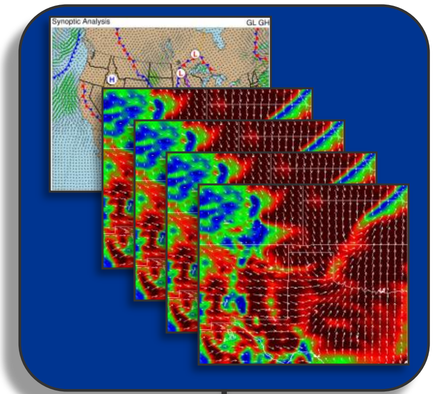
- The value of short-term forecasting is well understood
- State of the art forecasts are typically high accuracy
  - → Beneficial to model blade icing when forecasting for wind farms in cold climates
- Icing prediction is woefully unvalidated
  - – Reliable observation data is scarce



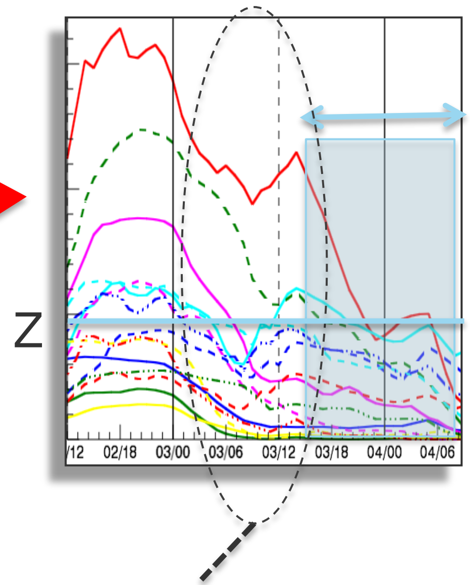
Methods – base forecast



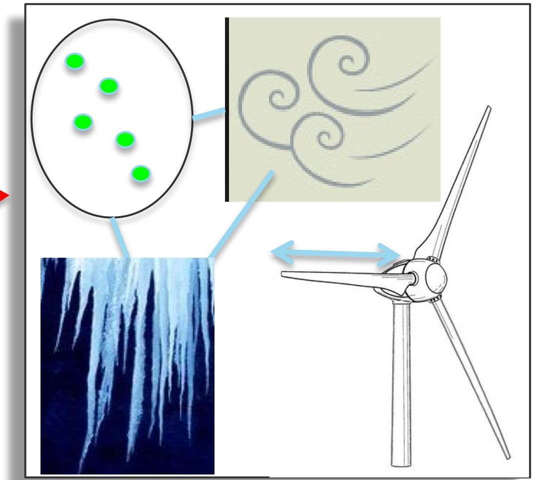
Methods – icing model



Wind Speed
Wind Direction
Temperature
Pressure
Relative Humidity

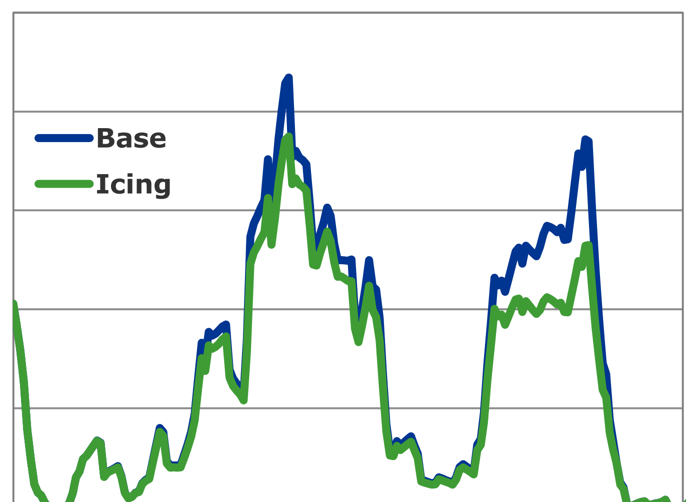


Ensemble
Predictions



Adapted from Frohboese and Anders (2007)

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



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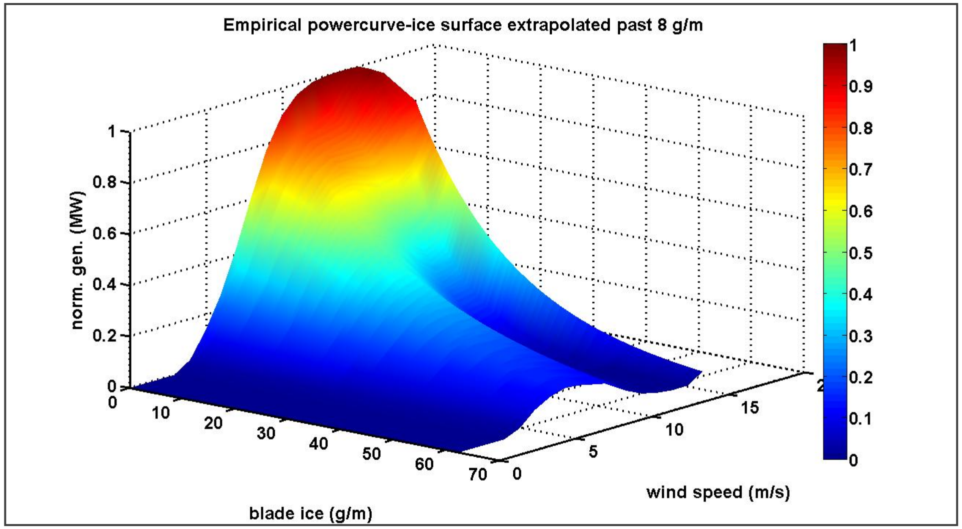
12 February, 2015

Methods – icing model power conversion



Borrowed from http://www.tuuliatlas.fi/icingatlas/icingatlas_6.html

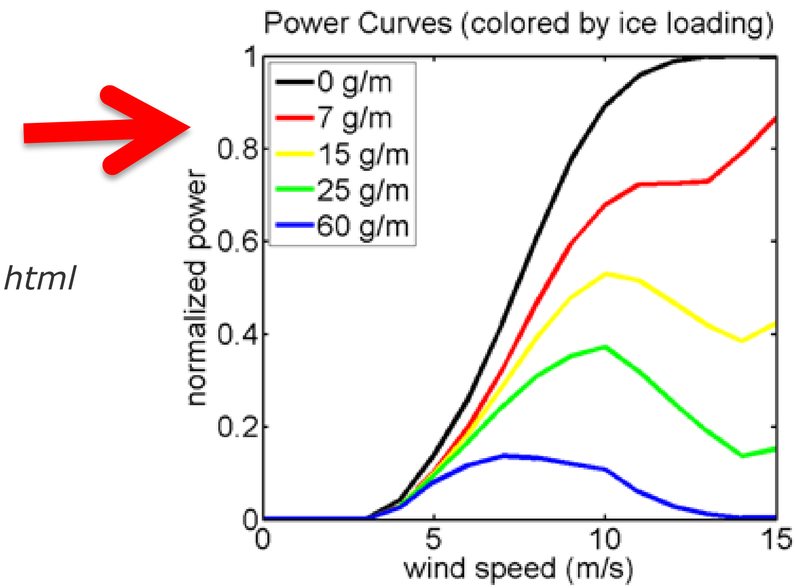


Figure 1: Adapted from Ljungberg, K. and S Niemelä (2011)

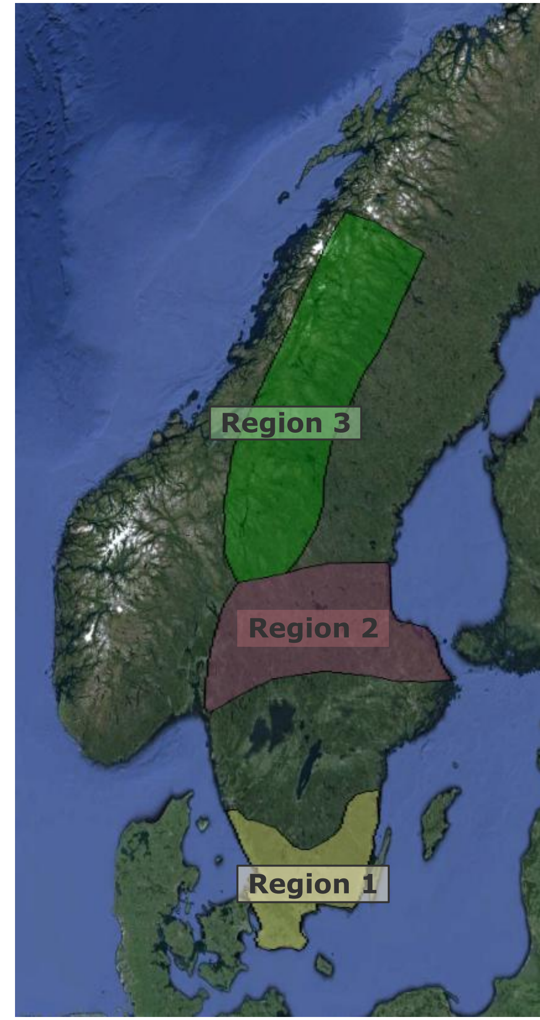
- Finnish Wind Energy Atlas

  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



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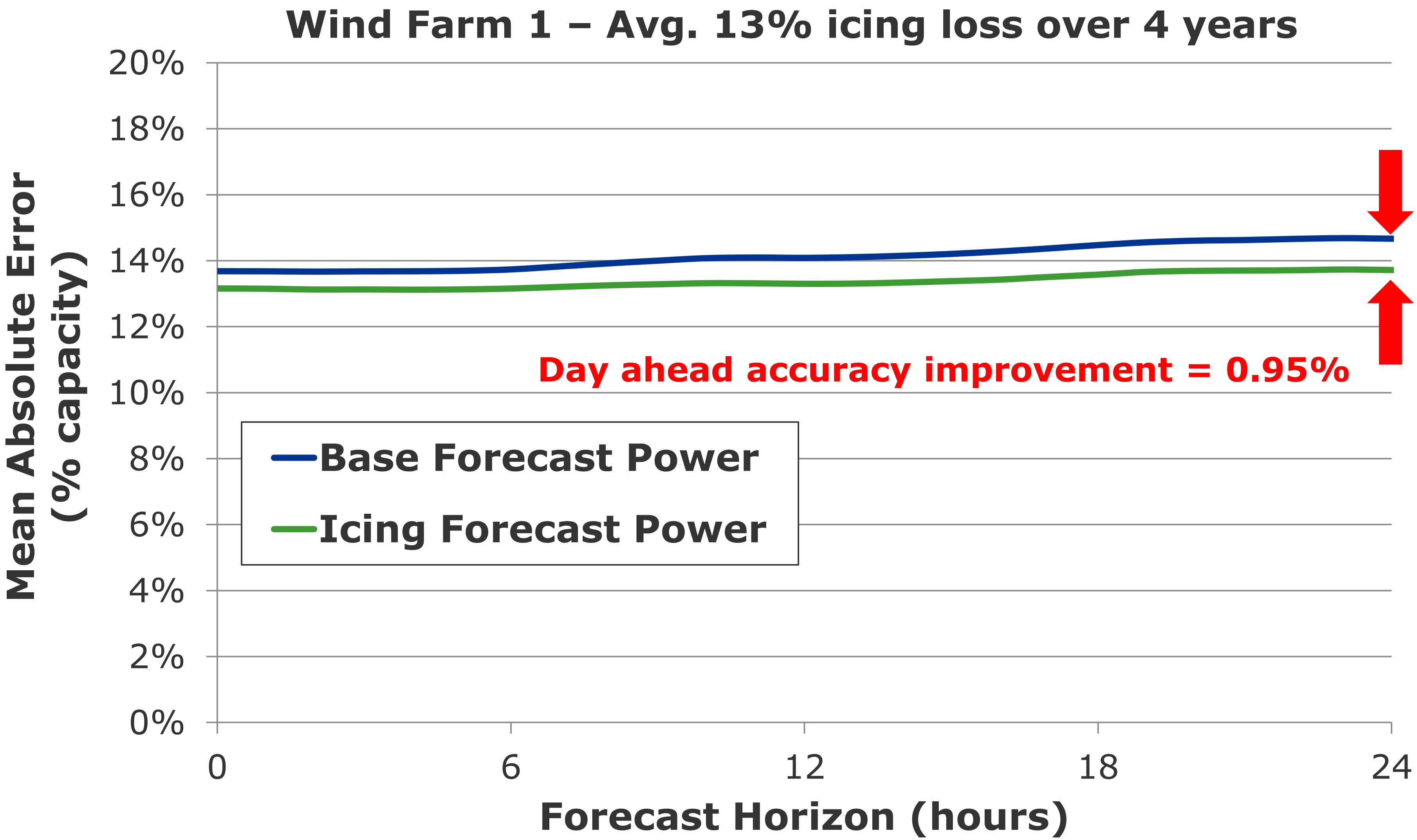
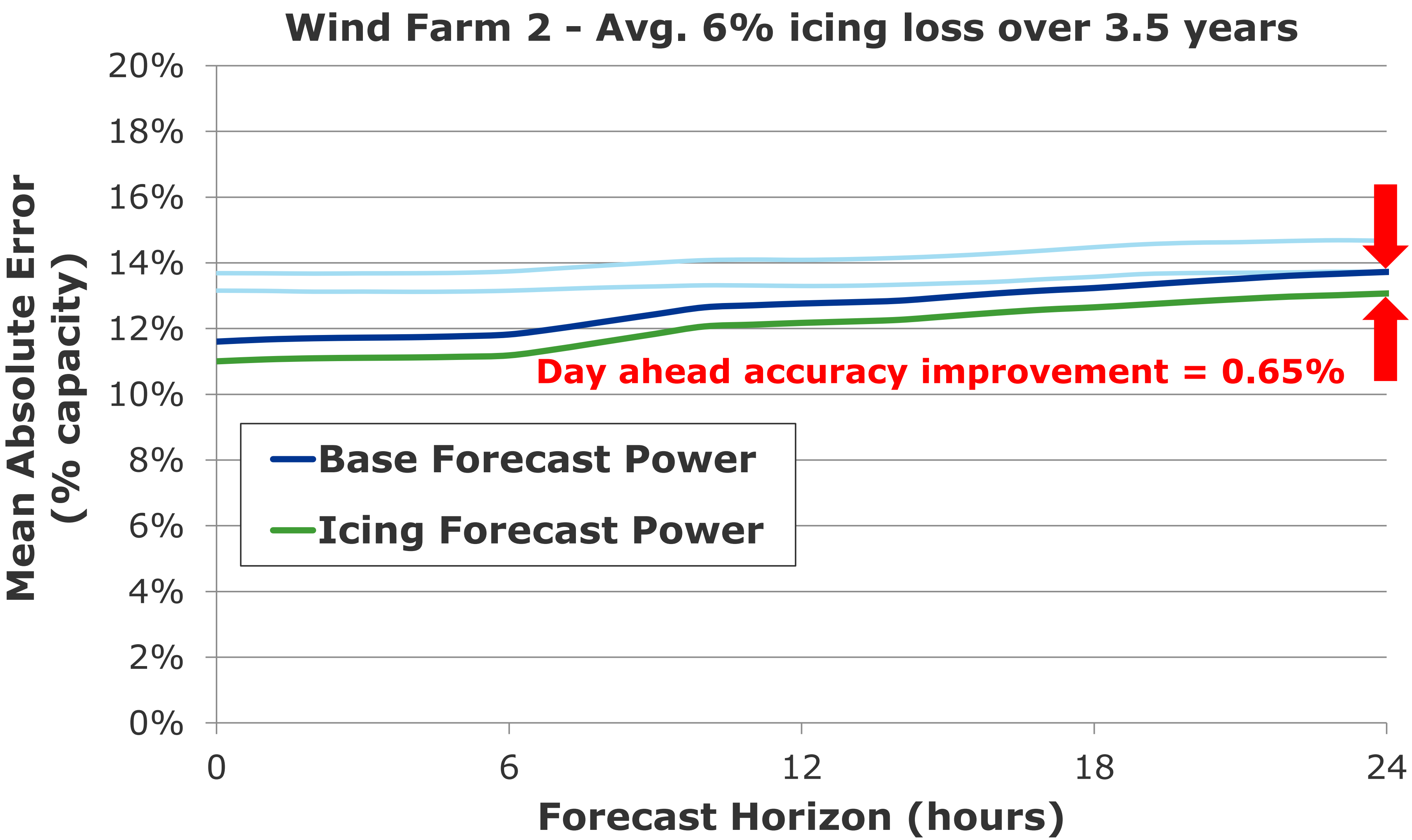
Results

Results



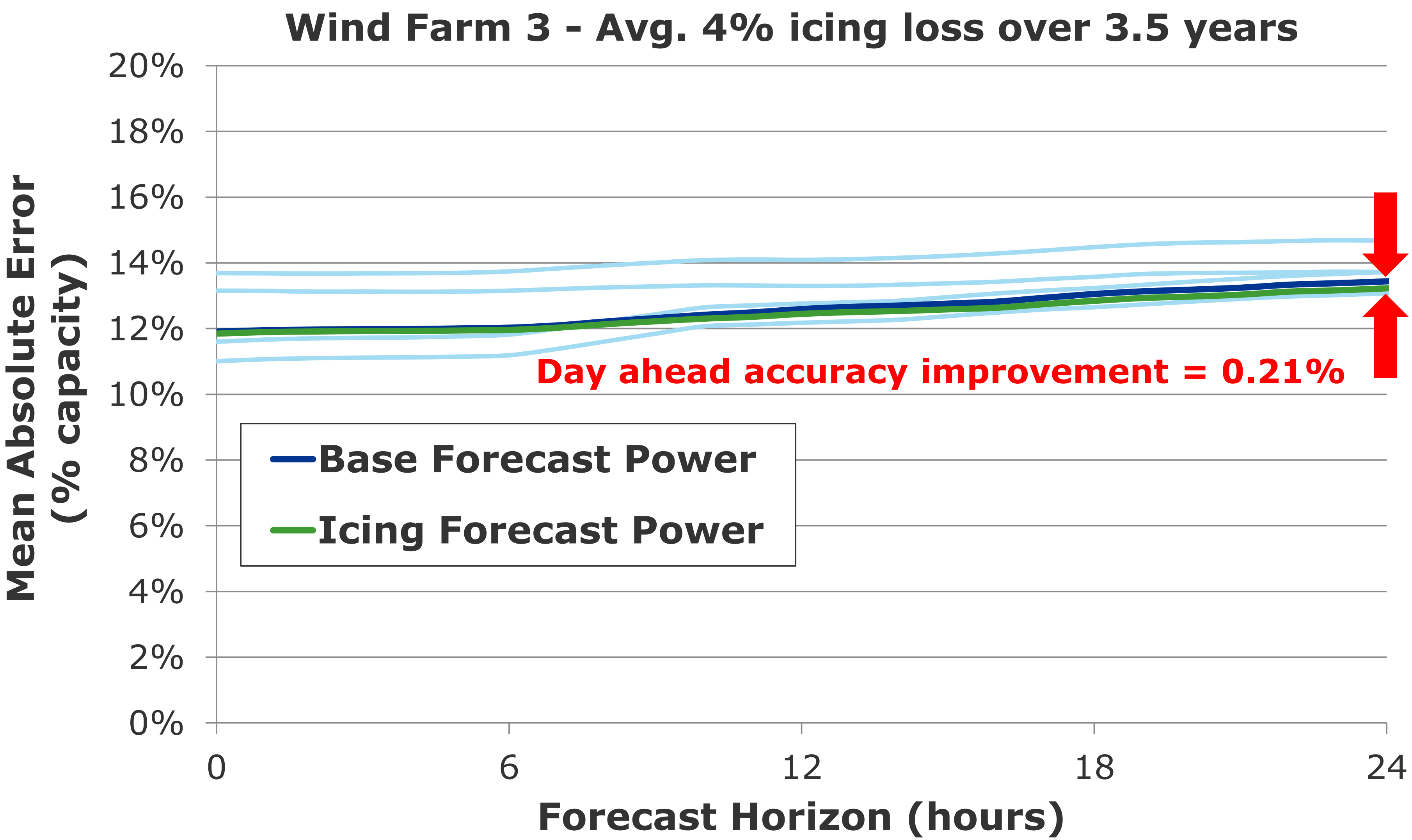
Wind Farm 1 – Avg. 13% icing loss over 4 years
Mean Absolute Error (% capacity)
20%
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
0
6
12
18
24
Forecast Horizon (hours)
Base Forecast Power
Icing Forecast Power
Day ahead accuracy improvement = 0.95%

Results

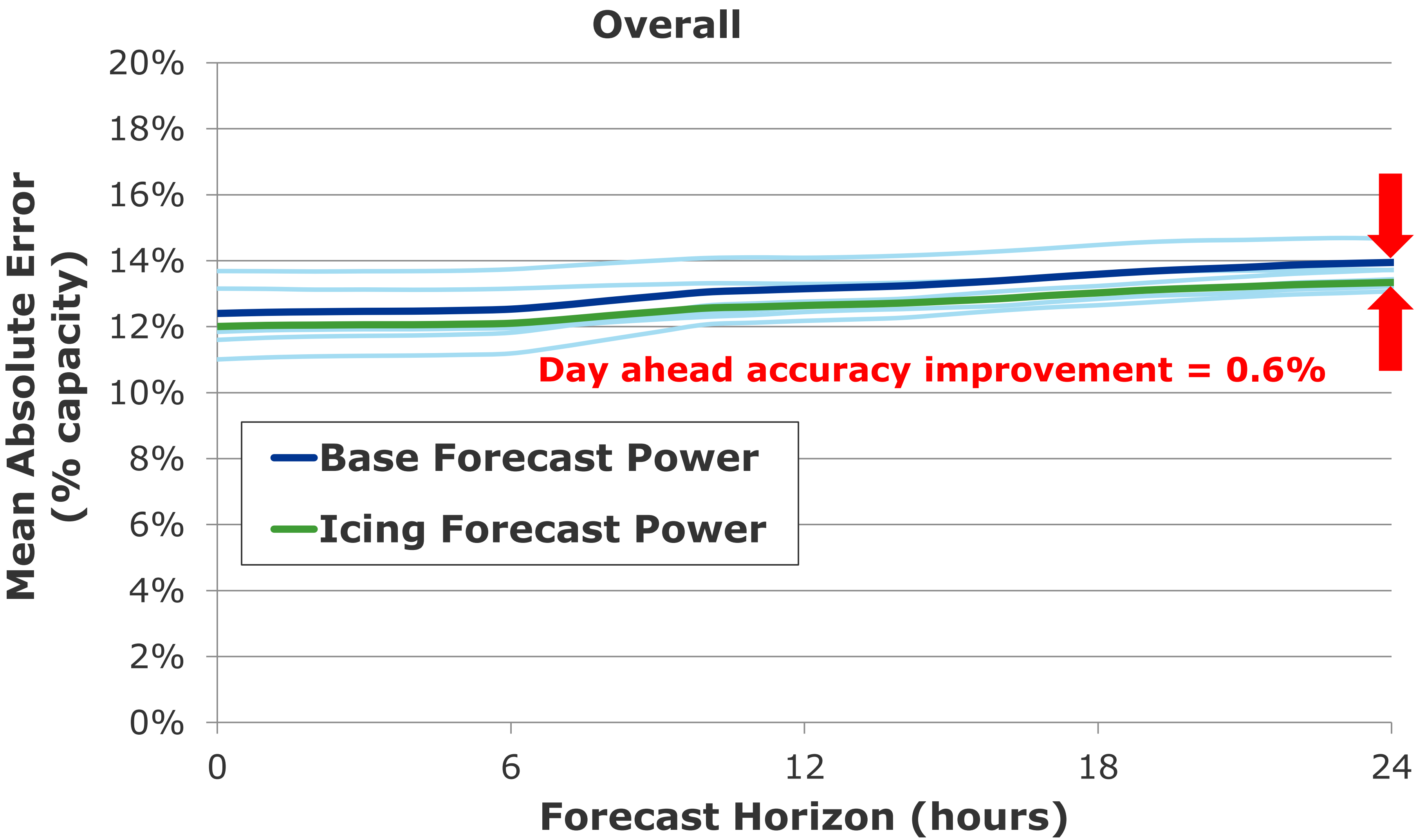


Wind Farm 2 - Avg. 6% icing loss over 3.5 years
20%
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
Mean Absolute Error (% capacity)
0
6
12
18
24
Forecast Horizon (hours)
Day ahead accuracy improvement = 0.65%
Base Forecast Power
Icing Forecast Power

Results


Wind Farm 3 - Avg. 4% icing loss over 3.5 years
Mean Absolute Error
(% capacity)
20%
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
0
6
12
18
24
Forecast Horizon (hours)
Day ahead accuracy improvement = 0.21%
Base Forecast Power
Icing Forecast Power

Results


Overall
Mean Absolute Error (% capacity)
20%
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
0
6
12
18
24
Forecast Horizon (hours)
Base Forecast Power
Icing Forecast Power
Day ahead accuracy improvement = 0.6%

Value to forecast users

- Icing modelling → improved forecast accuracy

→Increase energy revenue (based on day ahead energy trading in UK)

→Operational planning

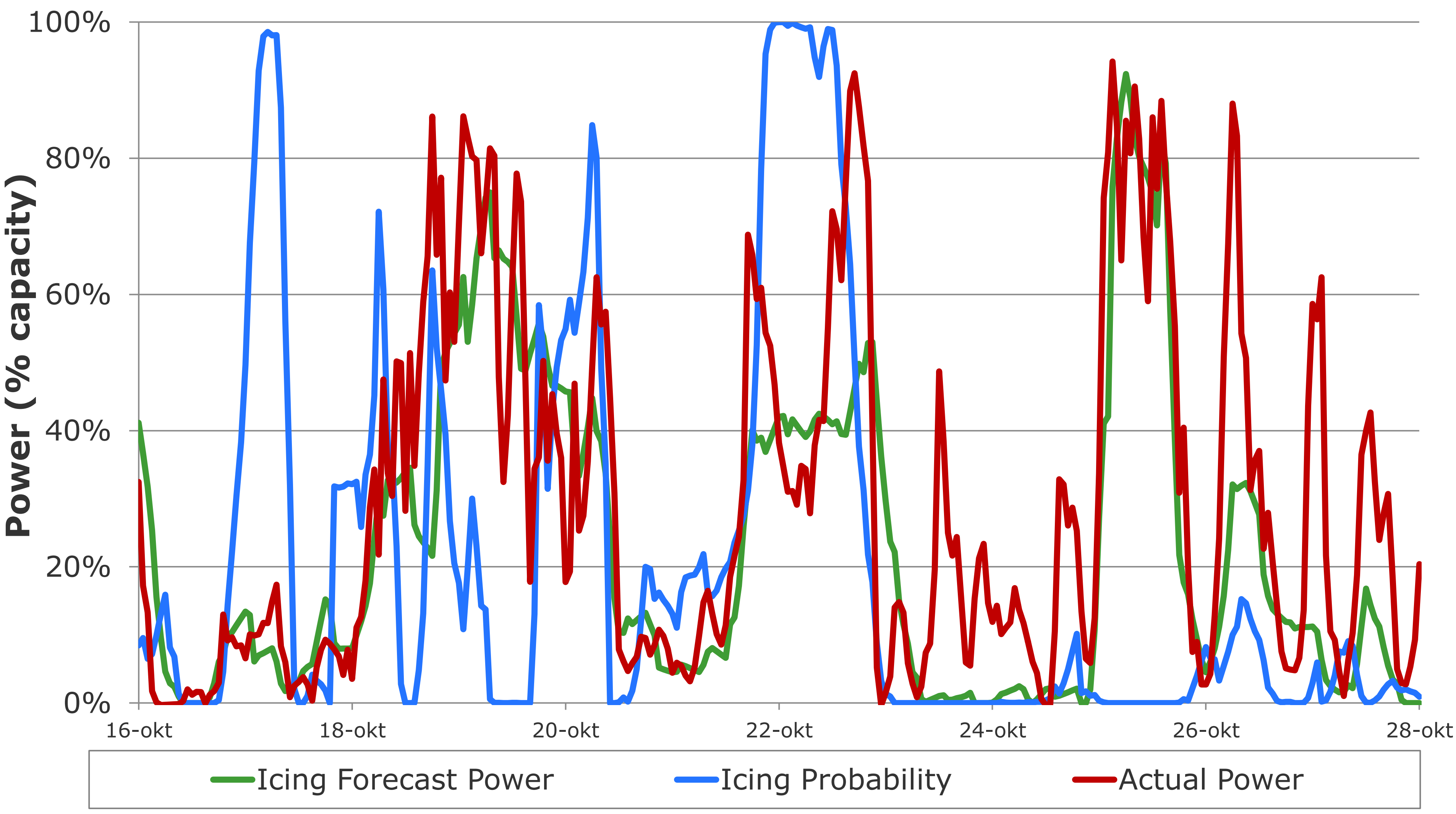
→Grid management

Forecast scenario	Average trading revenue (€/MWh)	MAE
No forecast	56.3	-
Basic forecast	57.7	22%
State of the art	61.6	12%
Perfect	64.6	0%

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



Conclusions

- Validation shows icing model adds value to forecasts
  - Model is relevant to Scandinavian climate
  - 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?

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