Forecasting Production Losses at a Swedish Wind Farm

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1: DTU Wind Energy; 2: Vestas Wind Systems; 3: DTU Informatics
Motivation

- Site location
- Wind park planning
- Energy market pricing
Production Forecast Model

Mesoscale Model
- Wind, Temperature, Clouds, Mixing Ratio

Wind Farm Management
- Power Production Forecast

Icing Model
- Ice Amount
- Ice Type
- Ice Shape

Microscale Model
- Wind, Temperature, Clouds, Mixing Ratio

Wind
Inputs

- Observational data
  - Located in central Sweden
  - Approximately 50 Vestas V90 turbines
  - Grouped into 3 parks
  - Observations from January 2011
  - Temperature, wind speed, wind direction from hubs of each turbine, production & turbine normal operation time

- WRF mesoscale simulation
  - 27 km & 9 km nests
  - Thompson microphysics & MYNN2 PBL
    - Best performing of 9 sensitivities
  - FNL for initial & boundary conditions
  - Grid nudging on the outermost domain
  - 63 vertical levels
Icing model

- Modified Makkonen model
  - Cylinder moves at blade relative velocity
    - Diameter 0.144 m
    - Located at 75% of blade length
  - Heat transfer coefficient for airfoils
  - Blade always at 80m hub height
  - Utilize all 4 WRF hydro-meteor types (QCLOUD, QRAIN, QICE, QSNOw)

- Sublimation & shedding included
  - Sublimation based on humidity gradient & radiation balance
  - Shedding set to 100% when T > 1° Celsius
Ice duration evaluation

- Timeseries comparing model icing periods to periods when any turbine was iced in a given farm.
- Compared with persistence & threshold method for several skill scores and this method outperformed both.
- For more details see paper submitted to Journal of Applied Meteorology & Climatology “Forecast of Icing Events at a Wind Farm in Sweden”
Production loss model

- Fit smoothing function to power curve
  - Wind farm average values
  - Only for temps above freezing
  - Red line in the plot
- Calculate power difference
  - Deviation from modeled power
- Investigate potential predictors for power difference
  - Ice Model outputs
  - WRF Hydrometeors
- Fit test models for all farms
  - Make use of entire dataset
  - Maximize adjusted $R^2$
Model Parameters

- **Threshold**
  - Model \( q_{\text{all}} > 1 \times 10^{-3} \)
  - Set power to 0
  - Use power curve all other times

- **Ice only**
  - Forecasted power
  - Accumulated mass
  - Average ice density
  - Sublimation
  - Temperature

- **Enhanced**
  - Ice only parameters
  - Square root of all 4 hydrometeors

![Graph showing significance levels for different parameters across farms A, B, and C.](image-url)
K-fold cross validation

- Cut into 12 pieces
- Fit 8 pieces (training), and forecast remaining 4 (test)
- Calculate RMSE & mean bias of mean farm power forecast (test)
- Monte Carlo approach with 495 different model fits
RMSE
Conclusions

- Combination of WRF output parameters & icing model parameters works best for all 3 wind parks
- Both bias and RMSE of hourly production estimates can be improved using this approach
- Both statistical approaches show improvement over the threshold based method
- For this site the icing model output was a secondary feature, with the cloud outputs from WRF performing as well as the icing model.
  - We propose this is due in part to the very cold temperatures during icing, so the physical icing model does not have as much impact.

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Future Work

- Apply this method to other sites and longer periods
  - Investigate possible time lags using time series analysis
- Ensure the modified Makkonen model is representing the turbine icing correctly
  - Develop relationships between the two if required
- Enhance the formulation of ice removal mechanisms
- Evaluate performance using forecasted winds
Questions???