Icing Impacts on Wind Energy Production

Icing on wind turbine blades has a significant impact on the operation of wind parks in cold climate regions. One of the largest impacts is to the power produced when ice is present on the turbine blades. This has a large effect on the annual energy production and the accuracy of short-term power forecasts. This thesis explores the impact of icing on produced power through observational analysis and numerical modeling.

I begin by investigating the impact of icing on power production through observations. Since there are no direct observations of ice growth on the turbine blades, a methodology was developed for the identification of icing periods from the turbine power data and the nacelle wind speeds. This method was based on the spread of power production observations at cold temperatures that was not seen during warmer periods.

Using the insights gained through the observational analysis, a modeling system was designed using a combination of physical and statistical models.

The first model in the system was the Weather Research and Forecasting (WRF) numerical weather prediction (NWP) model. The NWP models estimation of cloud parameters (hydrometeors) was investigated, and it was found that their estimates varied greatly depending on the selection of microphysical parameterization. The results of the icing model, ice mass and duration, were similar when using the WSM5 parameterization of WRF or the more advanced Thompson parameterization.

The second model, iceBlade was a physical icing model developed to estimate ice mass on wind turbines. It was based on the Makkonen model for ice growth on a rotating cylinder to which several ice removal algorithms were added. The main difference from the Makkonen model was an increase in the incoming wind speed to account for the rotational speed of the turbine blade. The ice ablation algorithms also had a large impact on the duration of the icing events. The iceBlade model was found to better capture periods of turbine icing than the unadjusted model.

Finally, a statistical model was developed to simulate the relationship between the ice model results and the turbine power loss. The model took the shape of a hierarchical model that combined a decision tree model, based on the existence of ice on the turbine blade, and two Generalized Additive Models (GAM). The GAM for periods where icing was forecast was found to include the terms wind speed, total ice mass, and accumulated ice mass for the current period. This model was evaluated at six wind farms and found to improve the RMSE and mean bias at all wind farms except one. The model result was also compared with results from three other power production models that included icing impacts, and was found to have a similar range of performance.

The final conclusion was that the statistical model approach was not as important for correcting the power forecast for icing impacts as the quality of the physical model results. This was seen through the similar performance of the different power models in the intercomparison. Therefore, future research into the impact of turbine blade icing on power performance should focus on improvements to the physical icing model and NWP model estimation of hydrometeors.

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