ICING LOSSES, WHAT CAN WE LEARN FROM PRODUCTION AND METEOROLOGICAL DATA

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ABSTRACT

In cold climates the performance of wind turbines may be significantly reduced by ice accretion on the turbine blades. The magnitude of production loss has been seen to exceed 50% during winter months, and surpass 10% over the course of a year. The impact of icing is therefore a challenge for developing and operating wind farms in such regions.

The ability to predict future icing losses accurately is of critical importance for site selection and feasibility analysis, pre- and post-construction energy assessments, and decision making on the use of ice prevention or de-icing systems on the blades. This is therefore an area that has seen substantial R&D effort in the past few years across the industry, and a number of sophisticated models (atmospheric and others) have emerged. However, the accuracy of these models is subject to some uncertainty as validation is so far limited and there is as yet no industry-wide agreement on how to estimate icing losses.

In addition, icing levels are highly variable between years (up to 65% for a site with 5% annual mean loss and higher for sites with lower annual losses), making predictions for any given year difficult. Understanding this uncertainty is therefore also important for developers and operators.

SCADA and Met Mast data

DNV GL has assessed data from over 20 operational wind farms located in Sweden, Norway and Finland, along with data from more than 70 meteorological masts also located in the region. Using these datasets, DNV GL has investigated relationships between icing and geography, climatological characteristics, and, in the case of the meteorological mast data, the type of equipment used.

Analysis of the operational data has been undertaken to assess the energy loss due to ice-related degradation of the aerodynamic performance of the blades, and to shutdown of the turbines due to excessive ice load. This analysis found that, at the majority of sites, the loss due to turbine shutdown is negligible, with operators preferring to keep turbines running during most icing events. Icing losses were nevertheless found to exceed 10% of annual production at some sites and up to 16% at individual turbine locations.

Altitude

A strong polynomial relationship between hub height altitude and icing loss was found for all Swedish wind farms included in the study. The relationship between altitude and icing was observed to be different for the coastal Norwegian sites and those in Finland, suggesting that different icing climates exist in these areas. From this relationship, an icing map of Sweden has been developed which applies this function to the topography of the country and an assumed 100-metre hub height.

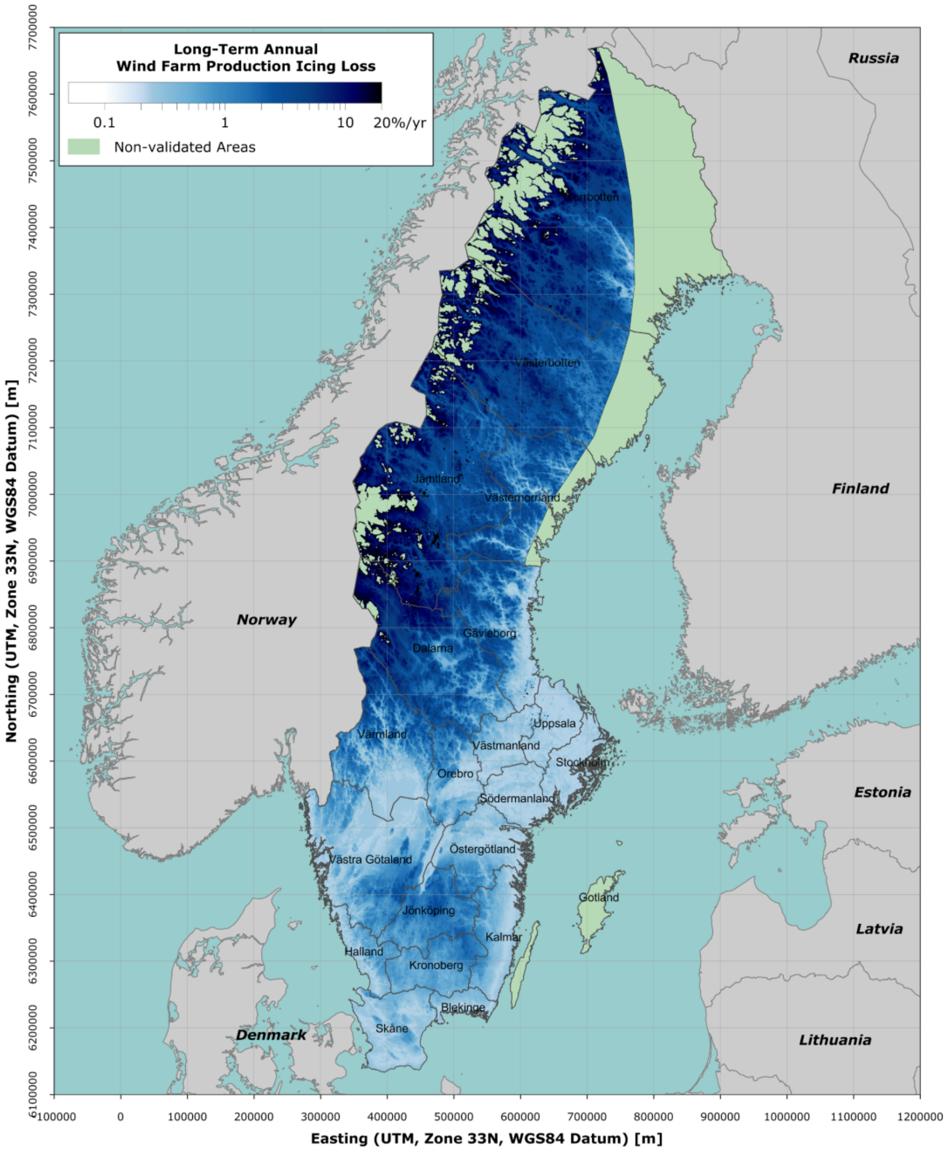

Figure 1 - Validated icing map of Sweden derived from operational SCADA data

The map is considered to be reasonably representative of long-term conditions, as the production data used span a period of at least six years and are spatially diverse.

From the analysis of pre-construction meteorological data, a linear relationship between sensor altitude and the accumulated number of annual days of icing at the sensors was found for the masts located in Sweden, yet again no such relationship was observed at the Finnish or Norwegian masts, or masts in northeaster part of Sweden.

From this, it follows that the correlation between sensor icing in pre-construction data and energy loss in operational data is non-linear. A methodology that predicts icing losses based on this non-linear correlation has been developed by DNV GL, whereby the square of the days of icing observed in the pre-construction anemometer data corresponds to the expected average annual icing loss of the proposed wind farm. This methodology is dependent on the existence of onsite measurements and, although it has been validated using mainly Swedish wind farms, is valid for any site across the Nordic region as it does not infer that the icing losses are based on site altitude, but instead on the number of accumulated days of icing observed at the onsite anemometer data.

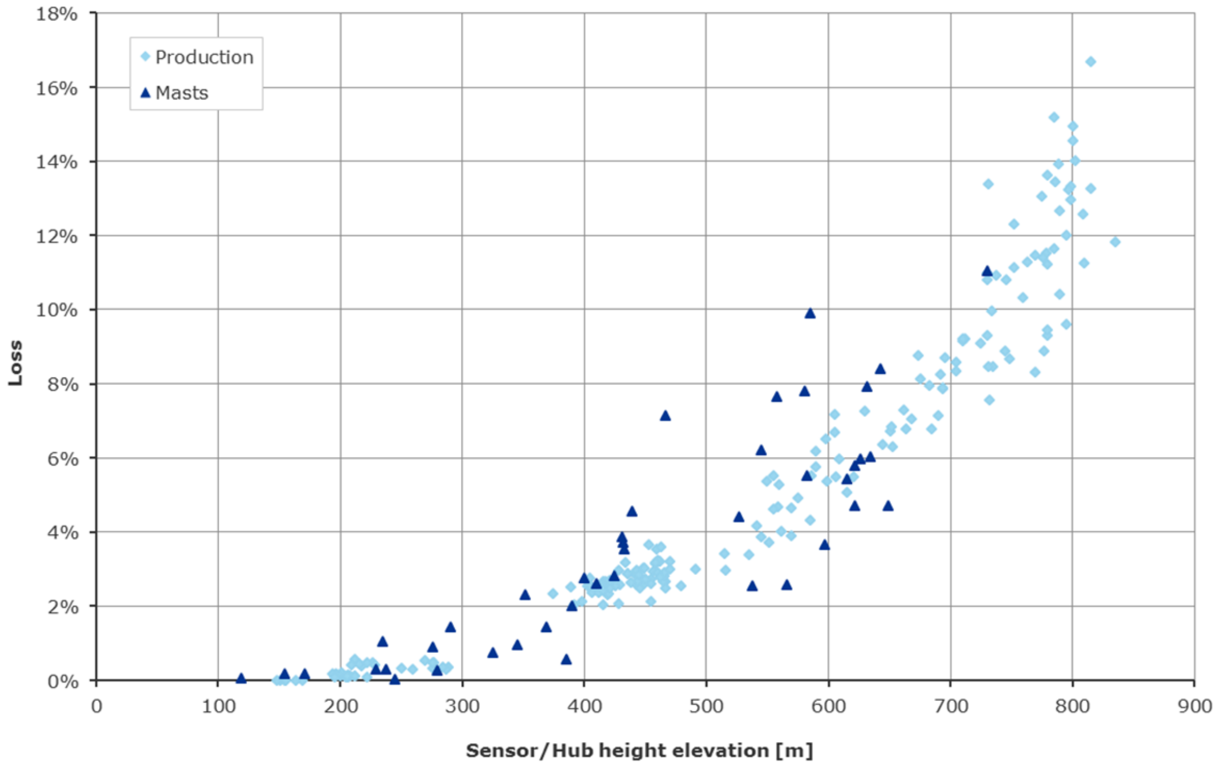

Figure 2 – Actual and predicted icing losses in Sweden Vs hub/sensor altitude

Altitude correlation varying with longitude

The relationship between altitude and energy loss appears to follow a different pattern in coastal Norway and Finland, where the icing climate is seen to be less and more severe than in Sweden respectively. It was however found in anemometer icing data that the correlation with altitude stands when different longitudinal zones are considered, increasing in slope eastwardly. From this it follows that icing losses may increase further with altitude the further east the wind farm is located. Additional work is needed to investigate potential Atlantic coastal effects, the effects of latitude, the influence of continental weather systems, cloud base height and other factors.

Temperature, relative humidity and long-term context

As annual variability of energy losses due to icing has been shown to be high, there is greater uncertainty in estimating icing based on short periods of onsite pre-construction measurements. A long-term adjustment methodology is therefore needed.

A strong relationship between temperature, relative humidity and the occurrences of anemometer icing in pre-construction data was observed, and matrices of these parameters can be derived. Icing conditions are typically seen to happen when certain temperature and relative humidity levels are in place (typically between 95% and 100% relative humidity at temperatures below 1˚ or 2˚Celsius). Different years will have different frequencies of such typical icing conditions and will therefore be more or less icy.

Based on temperature and relative humidity data from long-term meteorological stations or reanalysis datasets, it is possible to know the year-on-year variation of the frequency of these conditions and the long-term average of a consistent set of years. The comparison of that long-term average and the period of measurements average will indicate the magnitude of long-term adjustment needed. DNV GL is now working further developing and validating this long-term adjustment method.

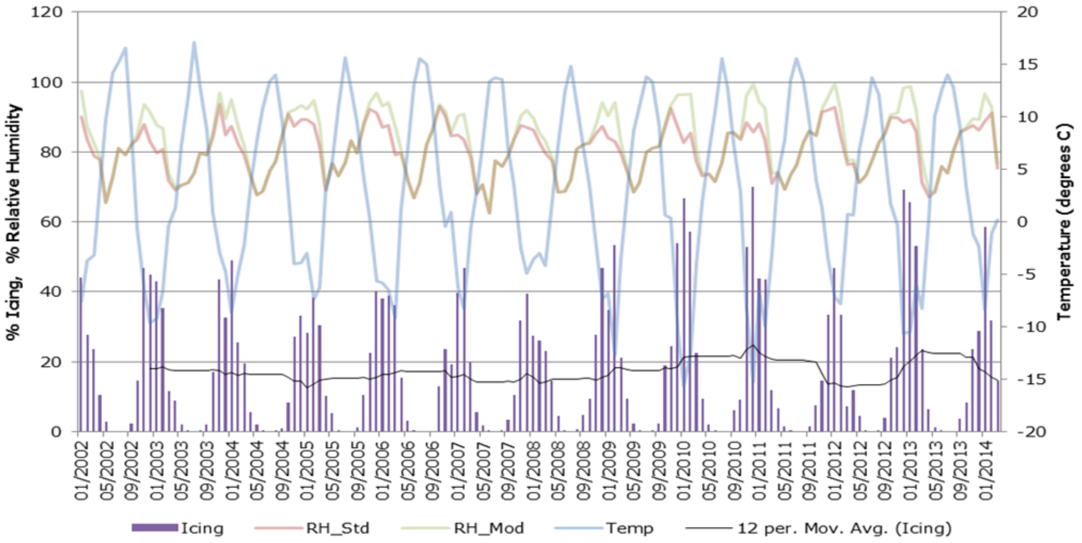

Figure 3 - Long term mean icing levels derived from long-term temperature and relative humidity data

Control strategy of the turbine

The control strategy of shutting down only under severe ice loading was found to minimise the icing losses and potentially decrease them by up to half at sites with annual losses of approximately 8% or less. However, the impacts on safety, noise or turbine lifetime should be considered when implementing a strategy to operate during icing events. Preliminary analysis on impact of loads in turbine lifetime suggests impact to be manageable.

Summary and final comments

The results above demonstrate that the magnitude of icing losses in the Nordic region is probably higher than initially expected by the industry and, depending on the site altitude and geographic location, can amount to more than 10% of the annual production of the wind farm. These losses have been observed at wind farms that typically remain operational during icing conditions; higher losses would therefore be expected should the turbines be immediately shut down as soon as ice is detected on the blades. Such a control strategy may, however, need to be considered in terms of turbine lifetime and other issues such as noise and safety.

For sites located in Sweden, altitude has been found to be the main driver and can be used to estimate icing losses, together with the level of icing observed in pre-construction onsite meteorological data. Based on anemometer icing, a different relationship between altitude and energy loss appears to exist in the north of Sweden, Norway and Finland where the icing climate seems to increase in severity eastwardly. For sites in those locations, the estimate can rely on the correlation between icing in pre-construction meteorological data and observed icing energy losses at the operational stage.

Results also show high inter-annual variability in the magnitude of the icing losses. This highlights the need for long measurement periods, and shows that even over long periods, future energy losses may differ significantly from the historical mean. Inter-annual variability in anemometer icing was found to mirror this result. A method to put icing losses into a long-term context has been developed and is still being validated. This is based on temperature and relative humidity data from long-term meteorological station or reanalysis datasets, and matrices of frequency of icing occurrences by temperature and relative humidity.