Estimates of wind farm icing events using preconstruction instrumentation

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***Abstract*—Estimation of the losses expected at a wind farm due to icing is of high importance in wind farm planning and is typically done through detection of ice at preconstruction meteorological masts. This paper examines the relationship between the frequency and timing of icing events at seven masts and one ice detector in operation near and coincident to operating wind farms in Canada. In most cases, there is a clear relationship between the periods of ice detected using preconstruction instruments and on the turbines, with closer correlation at temperatures near zero or where the expected ice type is glaze. The sensitivity and specificity of ice detection range between 27% to 87%**

I. Introduction

Ice-related losses at a wind farm include degraded airfoil performance, faulting due to blade imbalance or excess loads, safety shutdown, access disruption, and turbines failing to start up due to anemometer icing. In some climates, these comprise the majority of energy losses at a wind farm. Therefore it is important to accurately estimate the magnitude of ice-related losses at a potential wind farm site.

Typically icing losses are estimated by counting the frequency of icing on the instruments of the preconstruction measurement mast and assuming the wind farm losses will be directly related. There is normally no ice detector in a preconstruction measurement campaign and therefore icing is inferred from anemometer and wind vane signals.

The assumption that the icing frequency on the instruments on a meteorological mast is representative of the frequency on proposed wind turbines is tenuous as the structures differ in size, elevation, and velocity. The assumption is also difficult to test as preconstruction masts are generally replaced with a permanent mast with different instrumentation on construction of a wind farm, and there are rarely periods of concurrent data.

In this paper we examine data from seven preconstruction meteorological masts and an ice detector in operation near to and concurrent with an operating wind farm in Canada.

II. Ice detection at preconstruction masts and wind turbines

Bespoke ice detectors are not standard equipment at a preconstruction measuring campaign or wind farm in Canada, so ice at both sites must be inferred from other signals.

A. *Ice detection on preconstruction meteorological masts*

The instruments used for a wind measurement campaign typically include unheated anemometers and vanes, heated anemometers and vanes, and a temperature sensor mounted on meteorological masts of 30 m to 80m in height.

Icing is typically inferred at the measurement mast by identifying any of the following events at temperatures near or below zero:

a) The wind speed at one or more anemometers deteriorates relative to the others or to a heated anemometer;

b) The direction signal at one or more wind vanes becomes "stuck" and does not vary over a set period of time;

c) Any signals display a zero or flat line behaviour for unusual periods.

Once the frequency of icing is estimated at the proposed wind farm site, the associated losses are predicted to be linearly related.

All data from the meteorological masts used in this study were analyzed for icing events in this way.

B. *Wind turbines*

Blade and nacelle anemometer icing is detected at a wind farm using ten-minute SCADA data in the following ways:

- Blade icing is identified as deviations to the normal wind speed power curve during winter conditions in the absence other performance problems.
- Anemometer icing is detected through inspection of the power curves and correlation of nacelle anemometer signals with the wind farm average. If a turbine displays implausibly high power for the recorded nacelle anemometer wind speed, or if its nacelle anemometer wind speed signal became significantly low relative to the wind farm average during icing conditions, this is considered an anemometer icing event.

When icing events are detected, the production loss due to power curve deterioration can be calculated at the iced turbines by constructing a density-corrected nacelle anemometer power curve for each turbine during non-icing conditions, then comparing the power produced during the icing event to that expected given the nacelle anemometer power curve. Losses due to anemometer icing, when it was suspected the turbine was shut down due to low wind speeds measured by the iced anemometer, are estimated by calculating the expected energy which would have been produced at the turbine given the average nacelle anemometer wind speed of the other turbines at the wind farm.

C. Ice detector

A time series of an ice detector frequency signal was obtained which coincided with the operation of a nearby wind farm. Icing events were identified as negative trends in the ice detector resonant frequency as a result of ice accumulation on the detector.

D. Sensitivity and specificity

The sensitivity of a meteorological mast or ice detector for prediction of ice at the nearby wind turbines is calculated as the percentage of time when ice detected on the turbines is also detected on the mast. The specificity is calculated as the percentage of time where ice, detected on the met mast or ice detector during times when the wind speed is above a wind turbine's cut-in speed, is also detected on the turbine.

III. RESULTS

A. 2 Masts near wind farm, glaze icing regime

The first two preconstruction masts analyzed lay 3 km and 125 km from a modern wind farm in a region of Canada characterized by infrequent but occasionally severe ice rain and glaze icing. Ice was only detected at the masts and turbines during two months out of the nine months where the data were coincident. One of the events was a major ice storm.

The turbines and masts show very well-correlated frequency of ice detection. The sensitivity of both masts together in detecting ice at the turbines was calculated to be 87% and the specificity was 43%. The icing losses due to this type of glaze ice, when present, are severe, as the ice is heavy and either causes an average of 70% reduction of the power production capabilities of the turbine blades or causes the turbines to be shut down for safety or excessive blade loading.

B. 1 Mast near wind farm, light icing regime

A mast was located within 5 km of a wind farm in a region of Canada characterized by dry mild winters with low levels of mixed rime and glaze icing. At this wind farm the icing-related loss was estimated to be very low. Two 1-day periods of icing were detected on the meteorological mast during the 10 months of concurrent operation of the mast and wind farm. During the first icing event at the mast, two nacelle anemometers were seen to be iced but no blade degradation was identified at the turbines. During the second mast icing event, the wind was calm. However, when the turbines began operation after the calm, three hours of ice were detected on three turbines. The sensitivity and specificity of this met mast for detecting turbine icing are calculated to be 35% and 27%. However, approximately the same small number of hours of icing was detected on the mast and the turbines, and they occurred over the same 3-day period.

C. 3 Masts near wind farm, heavy icing regime

Three masts were analyzed located on site at a wind farm in northern Canada characterized by heavy losses due to a mixture of glaze and rime ice. The overlap of data between the masts and the wind farm SCADA data was one year. For events during this period where the majority of the turbines display icing, there is close correlation between the timing and length of the mast and turbine icing events. But there are significant periods where ice is detected on the turbines and not on the meteorological mast. It was noted that the mast most successfully indicated turbine icing when the icing event began at temperatures of -5 deg C or higher, suggesting glaze ice. The net sensitivity of the masts for detecting turbine icing was 28% and the specificity was 76%.

D. 1 Mast near wind farm, moderate ice, coastal

One preconstruction mast identified was located near two small wind turbines in the Atlantic region of Canada. Very little ice was detected on the turbines during operation. However, the turbines were automatically shut down by the SCADA system during periods of suspected icing detected by the turbine controller in much the same way that it is detected in this paper.

Examination of the mast and turbine icing events does not show any correlation between mast and turbine-detected icing at this site.

E. Ice detector near wind farm, heavy icing, inland

Time series data were obtained from an ice detector located 3 km away from and 350 m lower than a wind farm in an inland region characterized by heavy rime icing.

Good correlation was shown between the ice detector signal and the turbines for events with many turbines reporting ice, with some time shift between the start of the turbine and ice detector events, and therefore the sensitivity and specificity of the ice detector for prediction of icing events on site is not calculated.

IV. CONCLUSIONS

Of the four meteorological mast / wind farm combinations analyzed, three showed reasonable correspondence between the frequency and timing of icing events at the meteorological mast and the turbines. An ice detector signal also corresponds well with wind farm icing events.

From the small data set considered, it appears that the relationship between ice detected on the preconstruction instruments and at a wind farm is strongest in glaze icing conditions. Consequently, wind farm planned in heavy rime icing regions may need to rely on alternative means such as additional meteorological indicators for estimating energy loss due to icing.