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From Detection to Action: Improving Wind Turbine Efficiency in Cold Climate

A joint case study by Icetek and FT Technologies

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Ice formation on wind turbines is a critical issue that impacts both the performance and safety of these installations. For example, icing can lead to energy losses of up to 20% of annual production. To mitigate these effects, wind farm operators are looking for solutions, such as blade heating systems. However, these systems are typically activated based on turbine performance data alone, which can lead to inefficiencies (delays in activation, unnecessary heating). A more precise approach would involve direct measurement of icing conditions, though accurately gauging these conditions on a wind turbine presents significant challenges.

Icetek has introduced an innovative ice sensor, a culmination of over 14 years of academic research. The IC-1 ice sensor measures multiple meteorological data, including wind speed and direction, which is crucial for detecting ice. Initially, the sensor was equipped with a cup anemometer, but it soon became apparent that this type of instrument was unsuitable for the harsh conditions found on wind turbine nacelles. After testing various anemometers, the FT sensor was selected for its robustness and precision. Since 2016, all IC-1 sensors are equipped with FT sensors, enabling them to operate effectively in some of the world's iciest climates. To demonstrate the importance of effective ice detection and the advantages of informed intervention, two case studies are presented.

Case Study 1: Powering Through a Severe Icing Event

The IC-1 was installed on a turbine in a region of Eastern Canada known for severe icing conditions. The intensity of the icing necessitated the retrofitting of heating systems onto the blades. Additionally, a heated pan-tilt-zoom camera was installed on the turbine's nacelle to provide visual evidence of ice accumulation. This case study covers the first 30 hours of a five-day icing event, during which a significant shell of ice formed around the camera from the 30th hour onwards. Figure 1 displays images captured by the IC-1 at six-hour intervals from the onset of the event up to the 30-hour mark.

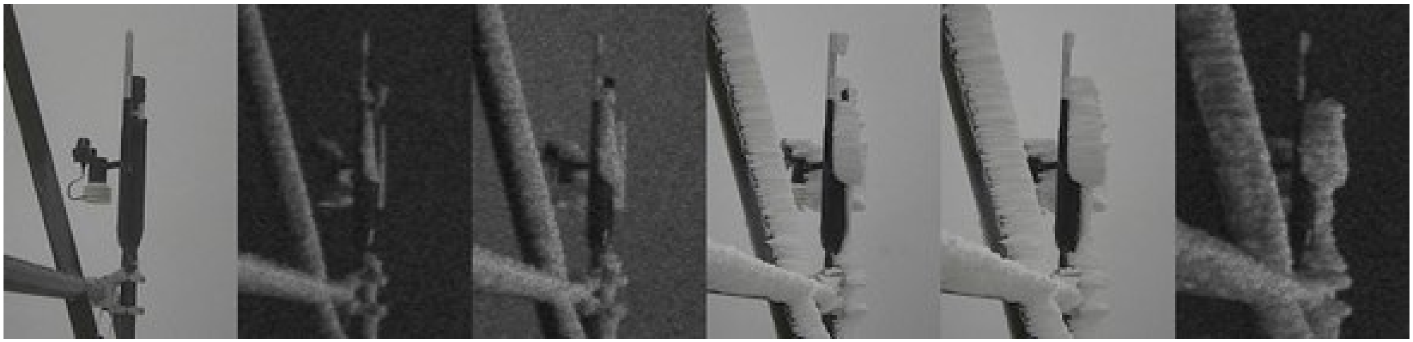

Figure 1: Picture of the IC-1 sensor taken at six-hours intervals during the 30-hour icing event.

The combination of the ice detection probes and the FT sensor allowed to collect valuable data during this harsh icing event. Figure 2 presents the ice thickness estimated from the IC-1 sensor throughout the event.

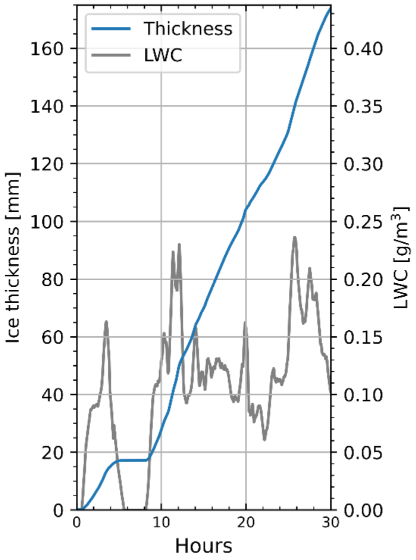

Figure 2: Ice thickness signal from the MCMS during the icing event of the first case study.

With over 160 mm of accumulated ice on the blades and nacelle, the IC-1 was still able to collect data and perform as planned, including the Liquid Water Content (LWC), critical to Icetek in predicting the accretion of ice on the blades. The key to the sensor success lies in its ability to remain ice-free during the full event, achieved by a sophisticated design of the heating systems and including the wind sensor. The fact that the IC-1 was able to function allowed the operator to make informed interventions, maximising safety and protecting its assets.

Both Icetek and FT'S equipment are strong and robust enough to power thru extreme conditions. The FT722-D-PM wind sensor is equipped with an integrated three-element distributed heater, which is automatically controlled by the sensor and employs a dynamic control scheme that adjusts the electric current supplied to each heater element, ensuring the set point temperature is consistently maintained. The heater circuit is thermostatically controlled, meaning that the actual power drawn from the supply varies based on the set temperature and environmental conditions, such as ambient temperature, wind speed, and precipitation.

Case Study 2: Leveraging the data from the ice sensor to improve turbine performance

On another wind farm, also situated in Eastern Canada, an IC-1 sensor was installed on a wind turbine nacelle, controlling heating systems across a cluster of turbines. However, during a 48-hour icing event, a communication network outage disrupted the IC-1's ability to trigger the blade heating systems. In this scenario, only the turbine icing status codes, determined by deviations from the power curve, were relied upon to activate the heating systems for the turbines in the cluster. The behavior of two turbines within this cluster was closely monitored.

Figure 3 depicts the performance of the first turbine. The green area represents the actual power produced by the turbine, while the red area indicates the expected power output based on wind speed and the power curve. The overlapping green and red areas signify the visible red areas represent production losses attributable to icing. Additionally, yellow zones in the background denote activation periods for the blade heating system, while purple areas atop the figure indicate active turbine icing status codes. The dark blue areas highlight instances where icing conditions were detected by the IC-1 sensor.

Observing this figure reveals cycles of icing-related power losses as the turbine's output diminishes due to ice accumulation. The cycles start with a power degradation until an icing status code is triggered, prompting the activation of the heating system. It takes slightly over an hour for the blades to reach a temperature sufficient for ice removal, after which the power output increases until the turbine's underproduction becomes small enough and the heating system deactivates. However, as the icing event persists, power output subsequently declines until another icing status code prompts the heating system's reactivation. These cycles persist until the icing event concludes. With intelligent triggering based on meteorological conditions, the power represented by the dark green zones could have been reclaimed, mitigating losses caused by icing.

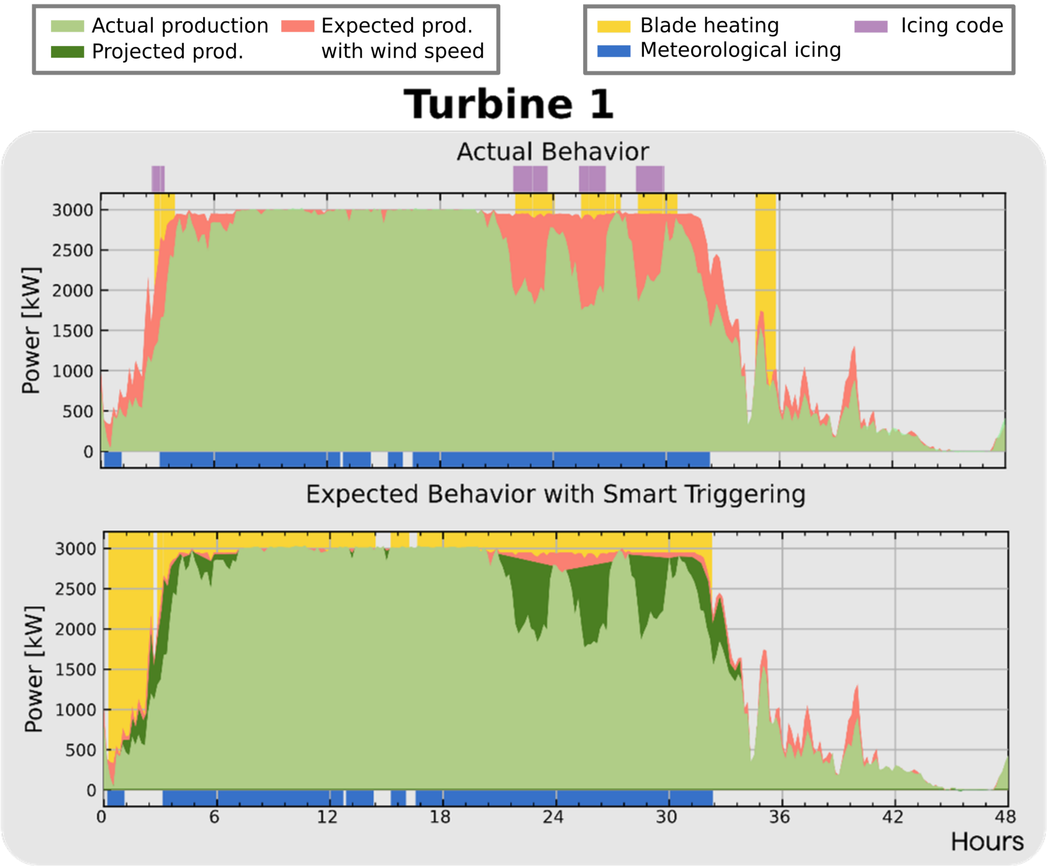

Figure 3: Comparison between the actual performance of Turbine 1 which heating was only activated with power curve deviation to a projection of the performance of the turbine if it had heated based on the IC-1 signal.

A comparable pattern emerges with the second turbine, cycles of icing-related power losses are observed due to the reactive approach of the heating strategy. Notably, a significant portion of ice accumulation occurred while the turbine was operating at its rated power. This doesn't necessarily imply that the blades remained ice-free; rather, the high wind speeds allowed the turbine to maintain its rated power without adjusting the blade pitch angle. However, around the 20th hour, the ice buildup reached a point where, despite the strong winds, the turbine's power output decreased. During this phase, the heating system should have been active to prevent ice formation as it occurred.

In both instances, the additional cost of heating amounted to approximately 1 MWh. However, had a proactive approach based on meteorological conditions been adopted, Turbine 1 and 2 could have generated an additional 11 and 12 MWh, respectively. This would have resulted in a net gain of 10-11 MWh over the course of the 48-hour event.

Conclusion

In conclusion, the observations from the two case studies underscore the critical role of effective ice detection and proactive measures in mitigating the adverse effects of icing on wind turbine performance. The deployment of IC-1 sensors equipped with FT anemometers has provided valuable insights into icing conditions, enabling more precise activation of blade heating systems. The detailed analysis of turbine performance during icing events revealed distinct patterns, emphasizing the importance of timely intervention. Notably, a proactive approach based on meteorological conditions could have significantly reduced production losses associated with icing. Moreover, the economic implications are substantial, with potential gains of 10-11 MWh over a 48-hour event through optimized heating strategies. This underscores the importance of investing in advanced sensing technologies and implementing smarter control systems to maximize energy production and ensure the long-term viability of wind energy installations, particularly in regions prone to icing.

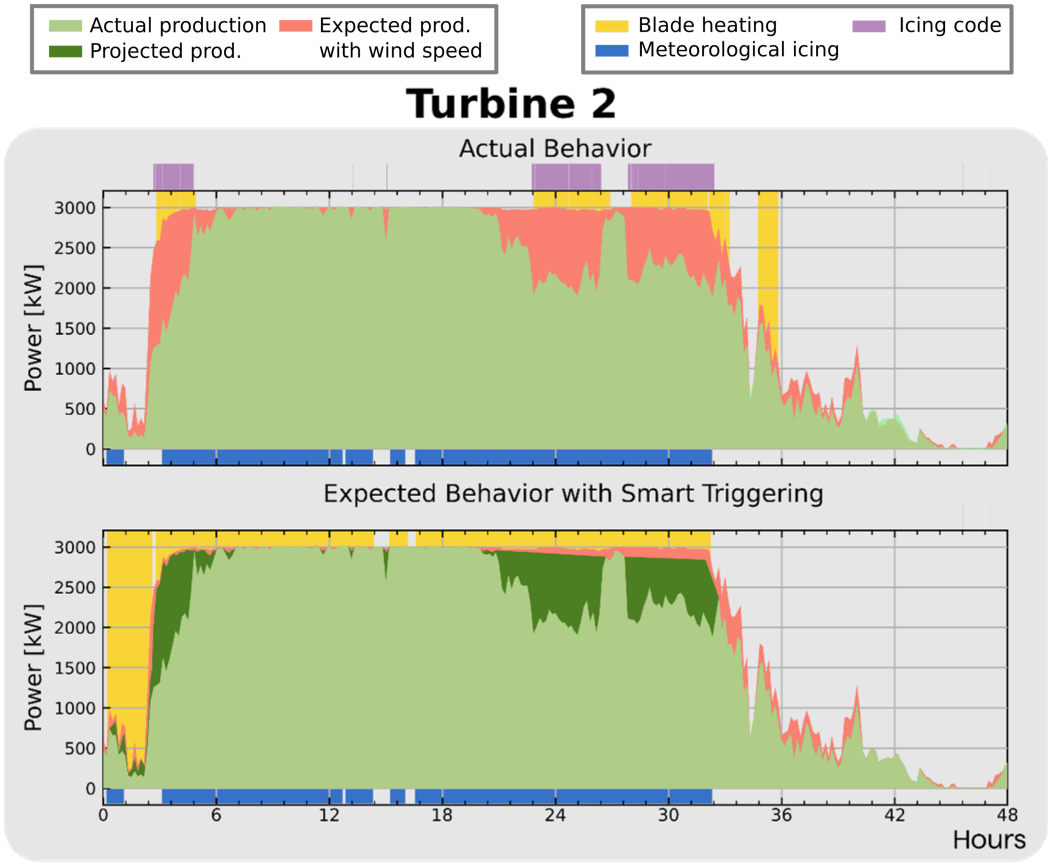

Figure 4: Comparison between the actual performance of Turbine 2 which heating was only activated with power curve deviation to a projection of the performance of the turbine if it had heated for based on the IC-1 signal.

Table 1: Historic of versions

Date	Revision	Author	Changes
April 2024	0	Patrice Roberge	initial version
April 2024	1	Dave Tremblay	corrections
May 2024	2	Philippe Guay	formatting