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# Indirect detection of ice on wind turbine blades

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## Operating Principle

Wind turbine icing is a significant problem for wind power applications in cold climate conditions. Icing can cause fatigue in turbine components, shortening the lifetime of the turbine and can cause immediate production losses. This work presents one approach to ice detection indirectly, without additional sensors. Ice is detected by monitoring changes in turbine behaviour.

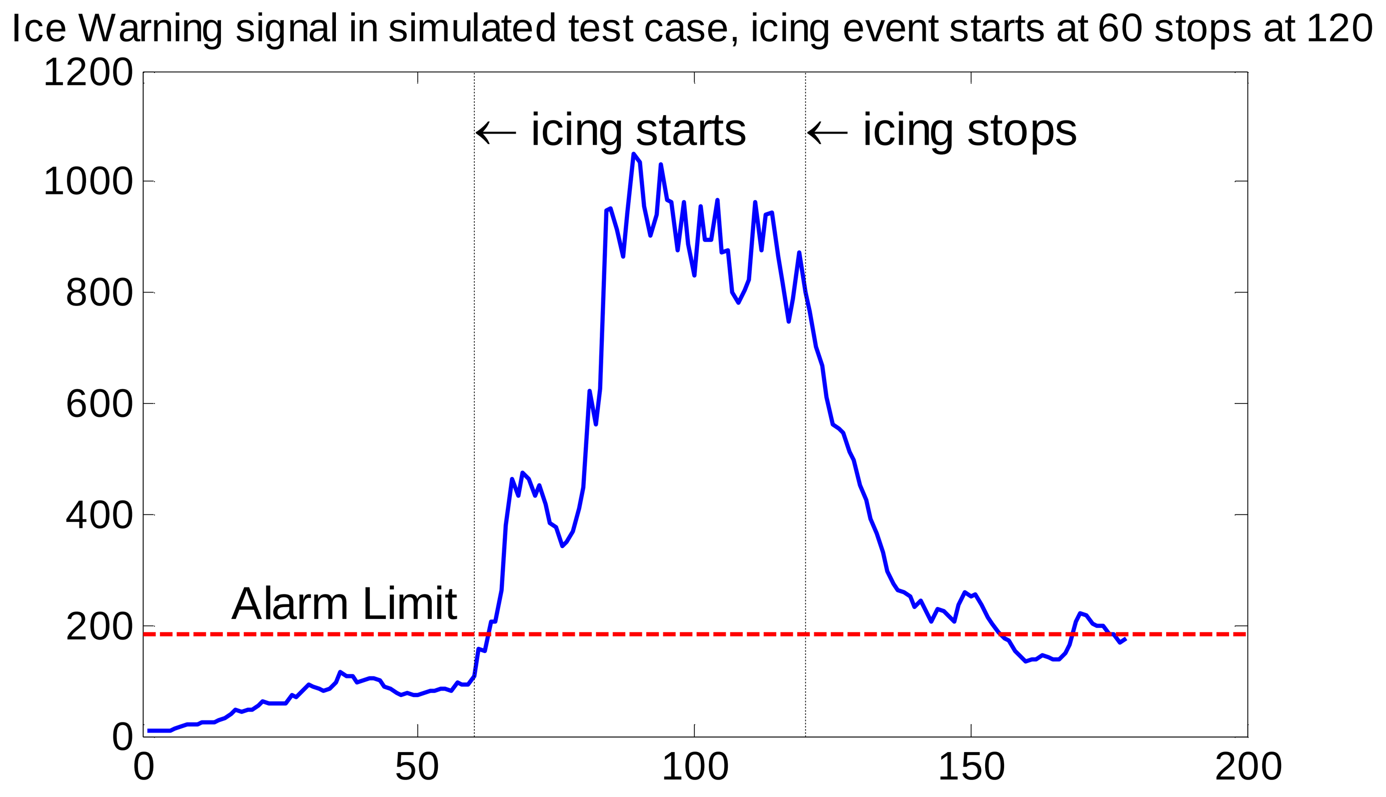
All the methods used here follow a similar two-step approach: First a baseline relationship between wind and different process variables is determined using historical data. Then real-time measurements are compared to the historical baseline. Possible icing events are identified by monitoring the differences between the predetermined baseline and the measurements.

## Ice detection methods

The distance between current measurement and the reference dataset is calculated using five different statistical process control methods. The multivariate methods used make it possible to compare behaviour of multiple variables simultaneously and also take the correlations between different variables into account.

The methods operate solely based on historical data. The same methods can be used on different types of turbines with very minimal changes.

The result is a simple signal representing the state of the wind turbine, higher signal values correspond with higher probability of icing.




*Example of the behaviour of the ice warning signal during an icing incident in a simulated case. The beginning and the end of the ice incident are marked on the graph. An icing alarm is issued for each timestep the value of the signal is above the alarm limit.*

## Simulation tests

The methods were tested against a dataset produced using FAST and the NREL reference 5 MW turbine model. The tests were run in several icing cases in different wind conditions in order to gauge the effectiveness of the approach. Performance was evaluated against different ice cases and different wind scenarios for five different methods.

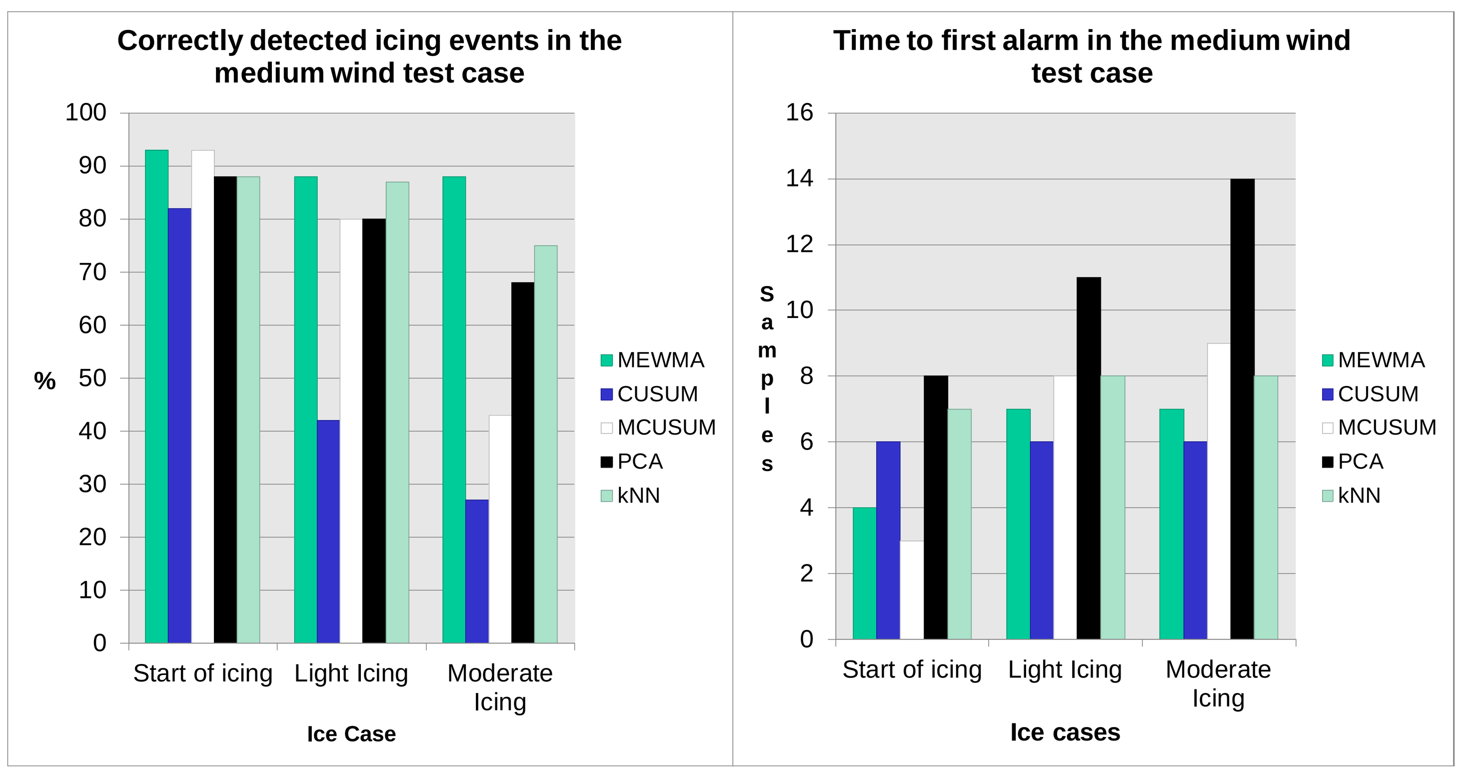
## Detection accuracy

The main metrics used to compare different methods were detection accuracy and speed. In the simulated datasets detection accuracy can be calculated as a percentage of correctly detected iced data points and speed is evaluated as number of steps between the start of an icing event and the first issued alarm.

The detection accuracy and speed depend on the severity of icing and the wind speed during the icing incident. Best accuracy can be achieved at wind speeds at around 50 - 80 % of the rated wind speed.

The drop in accuracy at low and high wind speeds happens because the used process variables have smaller relative deviation from the reference dataset at these wind speeds. Also at lower speeds the signal to noise ratio is high enough to have an effect.

At best, when using simulated data at appropriate wind speed these methods can reach 90% accuracy, but only with simulated data with very little noise.




*Detection statistics of the best case scenario from the simulation study. During these runs, wind speed was between 8 and 11 m/s.*

## Testing with real data

The approach was tested on a real dataset collected from two turbines in northern Finland over two years. The system can spot likely icing events but introduces a number of false positive alarms in the process as well.

When comparing the warnings produced by the methods introduced here to a commercial ice sensor, there does not seem to be a very strong correlation between the two. There are simultaneous warnings but neither method was conclusive.

More work needs to be done to improve the detection accuracy when dealing with real world data, but the preliminary result look useful.