Technical Disclosure[1]

1. Title

Ice Detection in Spinning and Run Up Through Generator Speed and Pitch Angle

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Technical Disclosure

5. Abstract

Ice accumulation on wind turbine blades during operation reduces turbine power output at a given wind speed and can increase fatigue loading due to asymmetric ice mass and altered aerodynamic blade profiles. Conventional solutions rely on dedicated ice sensors or redundant heated and unheated anemometers, and, after shutdown, often require manual visual inspection before restart. The present disclosure provides a sensor-minimized technique for detecting ice before power production begins by using the wind turbine rotor as a virtual wind-sensing element. In non-producing states, rotor speed is related to wind speed and blade pitch angle. By holding either pitch angle or rotor speed substantially constant during spinning or start-up, the controller estimates wind speed from rotor behavior and compares that estimate to measured wind speed from an available anemometer. If the deviation exceeds a threshold, the system determines that ice is present and aborts start-up. This approach improves restart decision-making, reduces fatigue damage, and increases energy yield without requiring additional physical sensors.

6. Technical field

The present disclosure relates generally to wind turbine control systems and condition detection methods. More particularly, the disclosure relates to detecting ice accumulation on wind turbine blades during spinning and start-up conditions using rotor speed and blade pitch behavior without requiring dedicated ice sensors or redundant anemometer hardware.

7. Background

Ice accumulation on rotating wind turbine blades adversely affect aerodynamic performance and reduces the electrical power that a turbine can deliver at a given wind speed. Ice also introduces non-uniform blade mass distribution and altered blade surface geometry, which may result in increased structural fatigue loading.

Reliable detection of blade icing is therefore important both for protecting the turbine and for maximizing energy production. Existing ice detection methods often depend on specialized ice

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sensors or on comparing readings from heated and unheated anemometers. These approaches may increase system cost and complexity, and they may not be available on all turbines.

Following an icing event, a turbine may be stopped and prevented from restarting until operators determine that the blades are free of ice. In many installations, customers without dedicated ice-detection equipment must perform visual inspection before restart. This process delays return to service and reduces energy capture. Existing controller-based indicators, such as failed start-up logs, are imprecise and do not provide a robust pre-production icing decision. Accordingly, there is a need for an improved technique to detect icing before the turbine enters power production, while reducing dependence on added hardware and manual inspection. Additionally, this method can be used to start a blade heating system to remove ice from the blades.

8. Summary of the disclosure

The disclosure provides a method and associated control strategy for detecting ice on wind turbine blades by using rotor dynamics and blade pitch angle as a virtual wind-sensing mechanism. When the turbine is not producing power and is properly aligned with the wind, rotor speed is a function of wind speed and blade pitch angle. A controller uses a predefined or learned relationship between these parameters to estimate wind speed based on rotor behavior.

To improve estimation accuracy, the control system intentionally constrains one variable during a pre-production operating state. In one implementation, the blade pitch angle is maintained substantially constant, such that estimated wind speed becomes a function primarily of rotor speed. In another implementation, rotor speed is maintained substantially constant using closed-loop pitch control, such that estimated wind speed becomes a function primarily of blade pitch angle. These conditions may be created or extended during spinning or run-up sequences.

The estimated wind speed is compared with actual wind speed measured by an available anemometer, such as a heated anemometer already present on the turbine. If the deviation between measured and estimated wind speed exceeds a threshold, the controller infers that blade icing is present because the aerodynamic state no longer corresponds to the ice-free model. The turbine start-up is then interrupted or aborted until icing is no longer detected.

9. Brief description of drawings

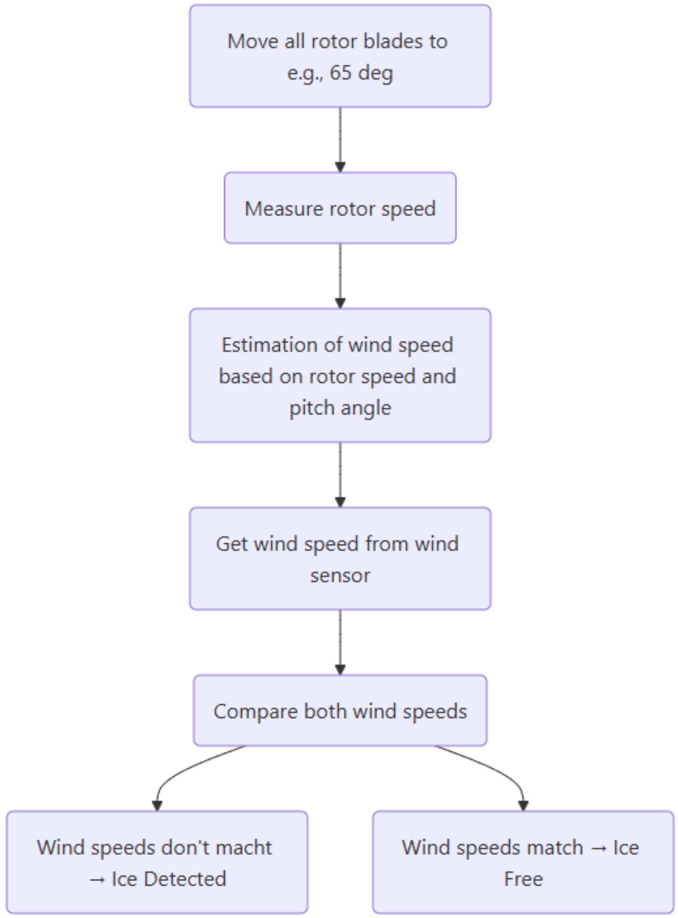

Figure 1 Ice detection via constant pitch

10. Detail description

A wind turbine typically includes a rotor having one or more blades, a nacelle, a generator, one or more pitch actuators for adjusting blade pitch angles, at least one wind speed sensor, and a controller configured to manage turbine operating states. In non-power-producing conditions, such as spinning, idling, or early run-up, the rotor is driven primarily by aerodynamic forces rather than by torque conversion for grid-connected power production.

Under ice-free conditions and assuming proper yaw alignment, rotor speed is determined by the incident wind speed and the blade pitch angle. The disclosure exploits this physical relationship to create a virtual wind-speed estimate. A transfer function, lookup table, model, or learned relationship may be established between wind speed and rotor speed and/or pitch angle. This relationship may be derived from simulation, field data, historical operational records, calibration procedures, or combinations thereof, using known ice-free operating periods.

In one implementation, the controller maintains blade pitch angle substantially fixed during a selected interval of a spinning or start-up state. Because pitch remains fixed, estimated wind speed can be inferred substantially as a function of rotor speed. In another implementation, rotor speed is regulated to a target value using a closed-loop controller with blade pitch angle as the manipulated variable. In that case, estimated wind speed can be inferred substantially as a function of pitch angle.

The selected operating interval may correspond to an existing start-up sequence or a modified sequence designed to improve detection fidelity. For example, the controller may extend a fixed-pitch period, select a specific pitch setpoint, or hold rotor speed below cut-in while monitoring pitch response. These engineered operating conditions create a more reliable basis for comparing expected aerodynamic behavior with measured behavior.

The controller receives measured wind speed from an available anemometer, such as a heated anemometer already installed on the turbine. The controller also determines estimated wind speed from the rotor-speed/pitch-angle relationship under the constrained operating state. A deviation metric is then computed, which may be expressed as an absolute difference, relative difference, filtered residual, statistical confidence value, or other suitable comparison measure.

If the deviation exceeds a predefined threshold, the controller determines that the turbine aerodynamic response is inconsistent with the ice-free reference behavior. This inconsistency is interpreted as the presence of blade icing. In response, the controller may abort start-up, prevent grid connection, maintain the rotor at a lower speed, log the event, issue an alarm, and/or continue monitoring until the deviation falls within acceptable limits.

Because the technique operates before full power production begins, it enables improved restart decisions after an icing shutdown. The approach reduces reliance on manual visual inspection and avoids the need for a second anemometer or dedicated ice-specific sensors in some implementations.

This ice detection method can also be used to trigger a blade heating system to remove ice from the blades.

11. Advantages

The disclosed technique provides several technical and operational advantages. First, it enables blade ice detection without requiring additional dedicated sensors or a redundant unheated anemometer. Second, it reduces the likelihood of operating a turbine with iced blades, thereby reducing excess fatigue damage associated with mass imbalance and aerodynamic asymmetry. Third, it can improve energy production by reducing the need for manual visual inspections before restarting a turbine following an icing event. Fourth, by preventing or limiting operation while icing is present, the technique can also reduce the risk of ice throwing and related safety concerns. Fifth, the method leverages existing turbine hardware and control states, which can simplify implementation and lower system cost. Sixth, the method can be used to start a blade heating system to remove ice.

12. Example Embodiments

In a first example embodiment, a wind turbine controller holds blade pitch angle substantially constant during a spinning state prior to grid connection. Rotor speed is measured during that interval and used to estimate wind speed based on an ice-free model. The estimated wind speed is compared with wind speed from a turbine anemometer, and the turbine start-up is aborted if the deviation exceeds a threshold.

In a second example embodiment, the controller regulates rotor speed to a substantially constant setpoint below cut-in speed using blade pitch control. During this controlled state, blade pitch angle is used to estimate wind speed according to an ice-free aerodynamic relationship. The estimated wind speed is then compared with measured wind speed to determine whether icing persists.

In a third example embodiment, the turbine controller selectively applies both methods during different phases of a start-up routine. A first phase uses fixed pitch to derive a rotor-based estimate, and a second phase uses fixed rotor speed to derive a pitch-based estimate. A combined decision logic may increase detection confidence.

In a further embodiment, the model used for estimation is developed from field data collected during verified ice-free operation. In another embodiment, the model is derived from aerodynamic simulations and subsequently updated based on operational history.

13. Industrial Applicability

The disclosed method is applicable to utility-scale and distributed wind turbines operating in cold-weather or icing-prone environments. It is especially useful for turbines that do not include dedicated ice sensors or redundant anemometer arrangements. The method may be implemented through controller software, control logic updates, or supervisory control modifications using existing turbine instrumentation. The technique is suitable for fleets where reduced downtime, improved automated restart decisions, and lower hardware complexity are commercially valuable.

14. Variations and Alternatives

Various modifications may be made without departing from the scope of the disclosure. For example, the estimation model may take the form of a transfer function, multidimensional lookup table, machine-learned model, or hybrid physical-data-driven model. The comparison threshold may be fixed, adaptive, wind-speed-dependent, temperature-dependent, or confidence-weighted. Filtering, averaging, or statistical validation may be used to reduce false positives.

In some implementations, the turbine may use one constrained variable only, while in others it may alternate between constrained-pitch and constrained-speed states. Additional existing signals, such as temperature, nacelle orientation, vibration indicators, or start-up history, may be incorporated into the final icing decision. A design-around approach could use external ice sensors or an additional unheated anemometer; however, such alternatives may increase cost and hardware dependency relative to the disclosed approach.

15. Conclusion

The present disclosure provides an effective and practical approach for detecting ice on wind turbine blades during spinning and run-up conditions by using generator or rotor speed and blade pitch angle as part of a virtual wind-sensing framework. By comparing estimated wind speed derived from turbine behavior with measured wind speed from an existing anemometer, the system can identify icing before power production begins and can prevent start-up when icing remains present. The method improves turbine protection, reduces fatigue exposure, increases potential energy capture, and minimizes dependence on additional hardware and manual inspection.

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