Technical Disclosure[1]

1. Title

Detection of Pitch Angle Measurement Fault

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Technical Disclosure

5. Abstract

Disclosed is a system and method for detecting faults in wind turbine rotor blade pitch angle measurement by generating an independent estimate of blade pitch angle using blade-based sensors and comparing that estimate to a conventional pitch measurement derived from a pitch motor encoder. In modern wind turbines, pitch angles are typically calculated using an encoder associated with the pitch motor, scaled by a gearbox ratio, and periodically reset using limit switches. This conventional approach may provide inaccurate pitch angle information under a variety of failure conditions, including pitch pinion failure, incorrect gearbox ratio parameters, improper limit switch placement, pitch motor resolver faults, and severe pitch gear damage. To improve fault detection, the proposed approach uses one or more sensors mounted in or on the wind turbine rotor blades, such as strain gauges, accelerometers, or other rotor blade-based sensors, to determine the orientation of the individual wind turbine rotor blade relative to gravity and, in combination with rotor azimuth information, derive an independent estimate of individual blade pitch angle. The independent estimate is then compared with the encoder-based pitch angle measurement, and discrepancies beyond a threshold are used to identify potential pitch measurement faults. The approach can support protective turbine actions, diagnostic routines, and more effective return-to-service decisions.

6. Technical field

The present disclosure relates generally to wind turbine control, monitoring, and fault detection systems. More particularly, the disclosure relates to detection of faults in wind turbine rotor blade pitch angle measurement using blade-mounted sensors that provide an independent estimate of blade orientation.

7. Background

Modern wind turbines use pitch systems to control and adjust the angle of each rotor blade relative to the wind. Pitch control is used to optimize energy capture, balance turbine loads, and limit loading at excessive wind speeds. The pitch system also functions as a primary braking system in modern wind turbine generators.

In case of an electrical pitch system, major components commonly include a pitch bearing, a pitch gearbox, and a pitch motor. Limit switches may be installed at defined blade positions to stop pitch rotation or reset position references. In many existing systems, blade pitch angle is measured indirectly using a pitch position encoder associated with the pitch motor, with the resulting value scaled by a pitch gearbox ratio and reset or referenced using the limit switches. A pitch encoder could alternatively be associated with the pitch bearing.

This indirect measurement approach can become inaccurate or misleading under certain conditions. For example, if a pitch pinion of a pitch gearbox fails, the pitch motor may become mechanically decoupled from the rotor blade while the encoder continues to indicate apparent motion. Similarly, incorrect pitch gearbox ratio parameters, incorrect limit switch locations, pitch motor resolver faults, or severe damage to pitch gears can all lead to incorrect rotor blade pitch angle estimation. In some cases, such conditions may remain undetected until a limit switch check or maintenance inspection occurs.

At the same time, additional sensors are increasingly being installed in wind turbine rotor blades for other operational purposes. Examples include strain gauges used for blade moment measurement or rotor imbalance calculations, and accelerometers used for ice detection, blade condition monitoring, or related monitoring functions. These sensors create an opportunity to derive a diverse and independent pitch angle estimate for diagnostic purposes.

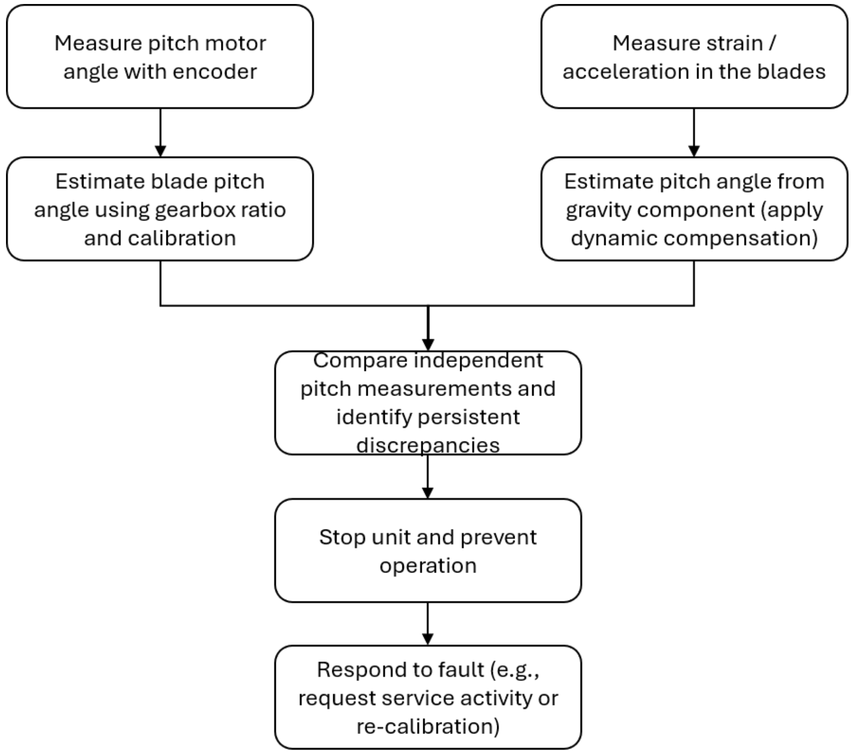
8. Summary of the disclosure

The disclosure provides a method and system for identifying wind turbine rotor blade pitch angle measurement faults by using blade-based measurements to derive an independent estimate of rotor blade pitch angle and comparing that estimate to a pitch angle value obtained from the conventional pitch motor encoder path or alike.

In one aspect, one or more rotor blade-mounted sensors, such as strain gauges, accelerometers, or functionally similar sensors, are used to determine the angle that gravity makes relative to the rotor blade or sensor orientation. Rotor azimuth information is incorporated into the calculation to resolve rotor blade position within the rotating frame. In some implementations, rotor speed or related operating parameters may additionally be used to compensate for centripetal or dynamic effects.

The resulting independently derived rotor blade pitch angle estimate is compared with the encoder-based pitch angle measurement. If the discrepancy exceeds a threshold, persists for a prescribed duration, or matches a fault signature, the system may flag a suspected pitch measurement fault. Such a fault may be indicative of pitch pinion failure, incorrect gearbox ratio configuration, incorrect limit switch placement, resolver fault, or gear damage. The system may then initiate one or more responses, such as preventing turbine operation, preventing or modifying a braking capability test, issuing an alarm, or supporting troubleshooting and return-to-service decisions.

9. Flow diagram



10. Detail description

In a representative wind turbine implementation, each blade is mounted to a hub through a pitch bearing and is rotated by a pitch drive system that includes a pitch motor and a pitch gearbox. A conventional pitch angle signal is obtained from an encoder associated with the pitch motor. The encoder output is converted to blade pitch angle using a known gearbox ratio and may be reset, referenced, or validated using one or more limit switches positioned at defined blade orientations.

The present disclosure supplements this conventional arrangement with an independent pitch angle estimation path based on blade-mounted sensing. In one embodiment, one or more sensors installed in or on the blade generate signals indicative of blade orientation relative to gravity. Suitable sensors may include accelerometers, strain gauges, or other sensors capable of supporting estimation of blade orientation. These sensors may already be present on the blade for functions such as blade load measurement, rotor imbalance calculation, ice detection, or crack detection.

The blade-based sensor signals are processed to determine the angle between gravity and the sensor or blade reference frame. Because the blade rotates with the rotor, rotor azimuth information is incorporated into the calculation to properly interpret the measured orientation. In some embodiments, rotor azimuth may be obtained from an existing rotor position sensing system. In further embodiments, rotor speed or other dynamic parameters may be used to compensate for centripetal acceleration, vibration, or related rotating-frame effects that could otherwise influence the estimate.

Once the independent estimate of blade pitch angle is calculated, it is compared to the pitch angle measurement obtained from the pitch motor encoder path. A discrepancy metric may be computed as an absolute difference, filtered difference, statistical deviation, or another suitable comparison parameter. The system may apply thresholds, persistence criteria, contextual logic, or confidence metrics to reduce false positives.

If the discrepancy indicates a probable fault, the system may generate an alert, store diagnostic data, trigger a maintenance notification, restrict turbine operation, inhibit selected control functions, or prevent execution of an online braking capability test until the issue is resolved. The system may also support fault isolation and return-to-service workflows by identifying likely root causes associated with the mismatch.

This arrangement can help detect failure modes that are difficult to identify using the conventional encoder-based measurement alone. For example, pitch pinion failure may mechanically decouple the pitch motor from the blade, causing the encoder to report motion that does not correspond to actual blade position. Similarly, an incorrect gearbox ratio parameter may produce systematic pitch angle error. Incorrect limit switch placement may create erroneous reset points. Resolver faults or severe gear damage may also cause position estimation errors that may remain undetected for extended periods if only the conventional measurement path is used. By comparing the conventional pitch estimate to an independent and diverse estimate based on blade-mounted sensing, these faults can be detected earlier and more reliably.

11. Advantages

The disclosed approach provides several technical and commercial advantages.

First, it improves detection of pitch angle measurement errors that may not otherwise be identified promptly using encoder-based estimation alone.

Second, it provides a diverse and independent diagnostic path, increasing confidence in fault detection and helping reveal root causes such as pinion failure, gearbox ratio misconfiguration, resolver faults, limit switch errors, or gear damage.

Third, it leverages sensors that may already be installed in the blade for other monitoring purposes, thereby reducing the need for dedicated additional pitch angle hardware.

Fourth, it enables more effective turbine responses, including protective action, improved diagnostics, and more informed return-to-service decisions.

Fifth, it may avoid or reduce the need for placing additional sensors in dirty, harsh, or mechanically challenging locations near the pinion or bearing gear interface.

12. Example Embodiments

In one example embodiment, an accelerometer installed in a wind turbine blade is used to determine blade orientation relative to gravity. Rotor azimuth is combined with the accelerometer data to calculate an estimated blade pitch angle. That estimate is compared to the pitch angle reported by the pitch motor encoder. If the difference exceeds a threshold, the system flags a possible pitch measurement fault.

In another example embodiment, one or more strain gauges mounted in the blade are used to infer blade orientation and thereby contribute to an independent pitch angle estimate. The strain gauge-based estimate is compared with the encoder-based estimate to identify discrepancies associated with incorrect position measurement.

In a further embodiment, both accelerometer data and strain gauge data are combined to improve robustness of the independent pitch angle estimate. The system may further use rotor speed information to compensate for centripetal effects and improve performance during turbine rotation.

In yet another embodiment, the system responds to a detected discrepancy by preventing continued turbine operation until the issue is investigated. In other embodiments, the system may allow limited operation, trigger an alarm, schedule inspection, or inhibit an online test of braking capability.

13. Industrial Applicability

The disclosure is applicable to utility-scale wind turbines and other rotor-based systems employing blade pitch control. It is particularly useful in wind turbine generators having electrical pitch systems in which pitch angles are derived from a motor encoder and associated reference parameters. The disclosed techniques may be implemented in new turbine designs or retrofitted into existing fleets where blade-based sensors are already present or can be added. The approach is relevant to turbine health monitoring, predictive maintenance, operational safety, and service optimization.

14. Variations and Alternatives

Various modifications may be made without departing from the scope of the disclosure. For example, blade-based sensors other than strain gauges and accelerometers may be used, provided they support derivation of an independent pitch angle estimate or equivalent blade orientation estimate.

In some alternatives, comparison logic may use adaptive thresholds, operating-state-dependent thresholds, machine learning models, or fault classifiers. In other implementations, the independent estimate may be used only for diagnostics and fault confirmation rather than for closed-loop pitch control.

A possible alternative approach is to measure pitch angle mechanically on the blade side of the pinion, such as by using an additional encoder meshing with the pitch bearing gear. However, such approaches may be exposed to harsher environments, increased contamination risk, higher cost, backlash-related precision limitations, or inability to address certain parameter-related issues such as gearbox ratio or limit switch location errors. The present disclosure can therefore provide benefits beyond such alternatives.

15. Conclusion

The present disclosure describes a practical and effective technique for detecting pitch angle measurement faults in wind turbines by comparing a conventional encoder-based pitch angle measurement with an independently derived estimate obtained from blade-based sensors. By using blade orientation relative to gravity, together with rotor azimuth and optionally other operating parameters, the system can identify discrepancies associated with otherwise difficult-to-detect failure modes. The disclosed approach improves fault detection capability, supports protective turbine responses, and can enhance diagnostic efficiency and return-to-service decision-making in wind turbine pitch systems.

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