Technical Disclosure[1]

1. Title

Automatic Slipring Encoder Calibration for Wind Turbine Rotor Azimuth Position Determination

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Technical Disclosure

5. Abstract

Disclosed is a method and control-system implementation for automatically calibrating a slipring encoder used to determine rotor azimuth position in a wind turbine. The method combines manual reference capability with automatic recalibration triggered by detection of a keyphasor pulse associated with a known rotor position. Upon a valid trigger event, a controller captures the encoder angle and stores that value as a mechanical zero reference corresponding, for example, to a blade-down orientation. Calibration may be accepted only after validation over a configurable number of consecutive revolutions within a defined angular tolerance. The system may further compute instantaneous drift between the corrected encoder angle and an expected angle derived from the keyphasor event, and may report calibration state, drift, failure causes, and related offsets through operator interfaces and logging systems. The approach reduces manual effort, improves azimuth-reference integrity, and supports phased deployment with fallback to manual calibration logic.

6. Technical field

The present disclosure relates to wind turbine control systems and, more particularly, to calibration and health monitoring of rotor azimuth position sensing using a slipring encoder and an event-based reference signal.

7. Background

Accurate rotor azimuth position is important for wind turbine control, monitoring, and protective functions. In some wind turbines, rotor azimuth is determined using a slipring encoder whose output is referenced to a mechanical zero offset established during factory testing, commissioning, or maintenance.

A conventional approach relies on manual calibration. In such a process, the rotor is placed in a known reference orientation, such as with a designated blade pointing downward, and personnel manually set an encoder offset parameter. Although functional, this process is labor-intensive and prone to human error. Typical failure modes include performing the reference procedure with the wrong blade orientation, losing the configured offset after a controller download or reboot, and failing to detect gradual encoder drift.

As a result, a need exists for a system that reduces dependence on manual intervention while improving confidence in rotor position estimation and providing better visibility into calibration quality and failure conditions.

8. Summary of the disclosure

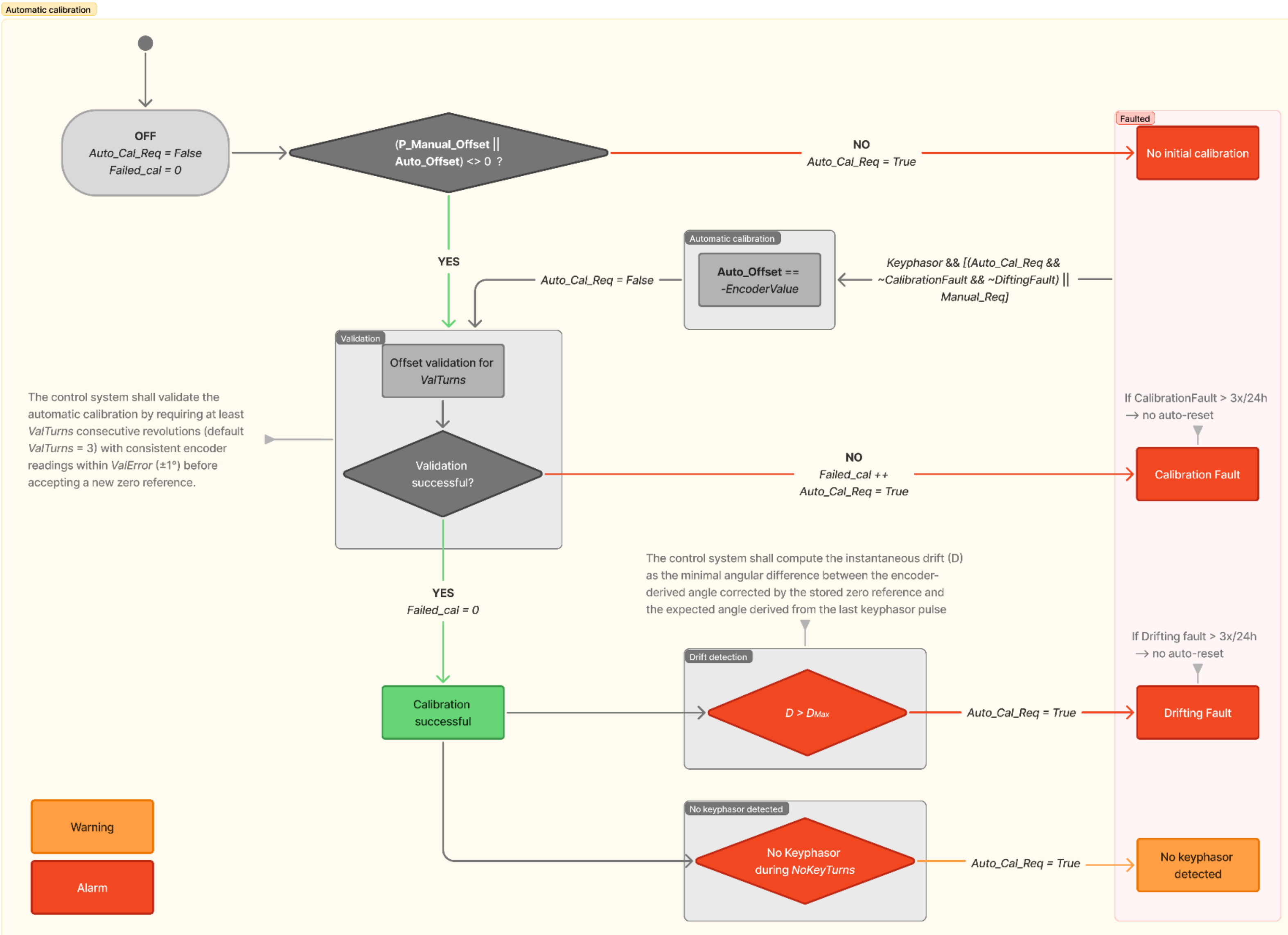
The disclosure provides an automatic calibration architecture for a slipring encoder used in rotor azimuth determination. The architecture may retain manual offset-setting capability while additionally enabling automatic offset capture and validation during turbine operation.

In one implementation, automatic calibration is triggered upon detection of a keyphasor pulse. When triggering conditions are satisfied, the control system captures the encoder angle at a defined pulse edge and stores that value as a mechanical zero reference. The zero reference may correspond to a known rotor orientation, such as a position in which blade 2 is pointing downward.

The control system may validate the calibration by requiring a configurable number of consecutive revolutions, for example three revolutions, during which the observed values remain within a configurable angular error band, for example plus or minus one degree. The system may also continuously calculate a drift value representing the minimum angular difference between a corrected encoder-derived angle and an expected angle derived from the keyphasor reference.

If calibration is missing, repeatedly fails, or if drift exceeds a threshold, the turbine may be prevented from operating or may enter into a protected mode. The system may also track repeated failures over a time window and inhibit automatic reset after repeated events. Operator visibility may be provided through HMI, SCADA, GR, and triplog reporting of raw angle, offsets, drift, state, and failure causes.

9. Brief description of drawings



[FIG. 1] illustrates an example of automatic calibration.

10. Detail description

A wind turbine may include a rotor having multiple blades, a rotor-position sensing subsystem, and a turbine controller configured to use azimuth position information for supervisory, control, and/or protective purposes. The sensing subsystem may include a slipring encoder configured to provide an encoder angle representative of rotor azimuth, and a keyphasor or equivalent event-based reference device configured to produce a pulse at a repeatable mechanical position.

In a baseline operating mode, a user may manually set the rotor mechanical zero reference by entering an offset parameter corresponding to a known orientation, such as a configuration in which a predetermined blade is pointing downward. This manual functionality may be retained as a fallback or commissioning feature.

In an automatic mode, the controller monitors for occurrence of the keyphasor pulse. The automatic calibration routine may be triggered when automatic calibration is requested and no disqualifying fault condition is active, or in response to a manual request for calibration capture. At a specified edge of the pulse, such as a rising edge, the controller acquires the encoder angle and stores that value as the mechanical zero reference.

To avoid accepting erroneous calibration values, the controller may execute a validation process. In one example, the calibration is not accepted immediately after a single capture event. Instead, the controller requires a defined number of consecutive rotor revolutions in which the calibration result remains consistent within a configured angular error tolerance. If the required number of consistent turns is satisfied, the calibration state may transition to a successful or validated state.

The controller may further perform drift supervision during operation. Drift may be computed as the minimal angular difference between: (i) an encoder-derived angle corrected using the stored zero reference, and (ii) an expected angle derived from the most recent keyphasor pulse. This drift value may be compared with a threshold. If the threshold is exceeded, the system may issue a warning, log a fault, inhibit operation, or place the turbine into a protected state.

The control system may also monitor for additional abnormal conditions, including repeated calibration failures within a defined time window and absence of keyphasor detection for a defined number of rotor turns. In some embodiments, if a fault occurs more than a threshold number of times within a designated period, the associated condition becomes non-auto-resettable, thereby avoiding indefinite automatic fault cycling.

The system may report calibration status information to operator and fleet-monitoring interfaces. Example reported values may include manual offset, automatic offset, calibration status, drift magnitude, elapsed time since last successful calibration, raw encoder angle, corrected azimuth angle, and indication of why a calibration routine failed. These values may be made accessible through web-based HMI systems, supervisory interfaces, GR records, trip logs, or other fleet analytics channels.

In some embodiments, deployment is carried out in phases. A first phase may use the automatic routine for monitoring and validation only while continuing to rely on manual calibration for operation. A subsequent phase may activate the automatic offset for operational use while also enabling faults and notifications associated with validation and drift supervision. The architecture may further support reversion to the prior manual-only approach before full field validation is complete.

The approach may be applied without requiring active validation maneuvers such as forced motorizing or pitching. In some implementations, other sensors, such as a wheel encoder, are not used in the active algorithm but may be incorporated in future variants to further improve robustness.

11. Advantages

The disclosed approach may provide one or more of the following advantages:

- reduced commissioning and maintenance labor associated with manual azimuth offset setting;
- lower risk of human error in establishing rotor mechanical zero reference;
- improved integrity of azimuth estimation through event-synchronous recalibration;

- earlier detection of drift, missed pulses, incorrect assembly, or other sensing anomalies;
- improved diagnostic transparency through explicit state and failure reporting;
- configurable validation, thresholds, delays, and reset behavior suitable for different fleets or maturity levels;
- safer rollout through phased activation and reversion capability; and
- improved fleet analytics through logging of raw angle, corrected angle, offsets, drift, and calibration outcomes.

12. Example Embodiments

In one embodiment, a wind turbine controller automatically captures a slipring encoder angle at a rising edge of a keyphasor pulse and stores the captured angle as a zero-reference offset corresponding to a blade-down mechanical reference.

In another embodiment, the controller accepts a newly captured offset only after three consecutive revolutions show consistency within an angular tolerance of plus or minus one degree.

In another embodiment, the controller computes a drift value for each relevant event by comparing the corrected encoder angle with an expected angle inferred from the last keyphasor pulse and issues a fault if the drift exceeds a threshold.

In another embodiment, the turbine is inhibited from operation if calibration has not been established, if calibration fails repeatedly within a defined time period, or if drift faults exceed a defined limit.

In another embodiment, a user interface presents manual offset, automatic offset, calibration status, drift value, time since last successful calibration, and a cause associated with routine failure.

In another embodiment, the automatic calibration routine is introduced in stages, including a monitoring-only phase and a later activation phase in which the calculated offset is used in operation.

13. Industrial Applicability

The disclosed system is applicable to utility-scale wind turbines and other rotating machinery in which a sensed rotational position must be referenced accurately to a known mechanical orientation. In wind turbines, the method is particularly useful for improving rotor azimuth estimation quality while reducing field-service dependency. The method may be implemented in turbine controllers, retrofit control software, supervisory monitoring systems, and fleet-level diagnostics platforms.

14. Variations and Alternatives

Various modifications may be made without departing from the scope of the disclosure. For example, the triggering reference may be generated by a keyphasor or by another event source associated with a repeatable mechanical position. The pulse edge used for capture may be rising, falling, or otherwise defined. Validation criteria may use a different number of turns, tolerances, persistence rules, or confidence scoring.

Drift monitoring may be performed continuously, periodically, or event-synchronously. Fault handling may include warnings, derates, protected modes, start inhibition, or advisory-only notifications. Reset logic may be tailored to different operating environments.

In other alternatives, additional sensors may be incorporated for cross-checking, including wheel encoders, redundant encoders, or model-based observers. In still other implementations, the system may retain manual calibration as a primary mode and use automatic functionality only for diagnostics or recommendation purposes.

15. Conclusion

This disclosure describes a practical and scalable method for automatic calibration and supervision of a slipring encoder used for rotor azimuth determination in a wind turbine. By combining manual fallback capability with event-based offset capture, multi-turn validation, drift detection, and operator-visible diagnostics, the system can improve reliability and observability while reducing manual intervention. The architecture further supports phased introduction and alternative implementations, making it suitable for deployment across a turbine fleet.

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