Technical Disclosure[1]

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Generator Airgap Sensor Configuration and Turbine Operation

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Technical Disclosure

5. Abstract

A control and monitoring approach is disclosed for operating a direct drive wind turbine generator when the active airgap sensor configuration differs from a default sensor configuration. The generator includes multiple airgap sensors, such as stator-mounted and rotor-mounted sensors, used for monitoring generator airgap conditions and triggering protection actions. A default mandatory sensor configuration is defined, and a different running configuration may be selected, for example after inspection or service assessment. The disclosed approach evaluates the difference between the default configuration and the running configuration and automatically adapts turbine operation so that the resulting operating risk remains at or near the risk level associated with the default configuration. Example adaptations include lowering rotor speed, increasing sampling density from remaining sensors, and performing periodic low-speed full airgap scans.

6. Technical field

This disclosure relates to wind turbine generator monitoring and control. More specifically, it relates to airgap sensing configuration management for direct drive generators and to adaptive turbine operation based on the availability, health, or mandatory status of airgap sensors.

7. Background

Direct drive generators may include multiple airgap sensors for monitoring and protection, such as four sensors arranged with two stator sensors and two rotor sensors. In conventional operation, airgap closure detection may trigger turbine shutdown. Certain sensor failure combinations may also trigger shutdown.

However, practical operating situations can arise in which a turbine continues to operate with fewer than the full set of sensors, such as after inspection, maintenance review, or sensor failure. In at least some cases, operation without a subset of sensors can increase the risk of unmonitored or insufficiently monitored airgap-related events. For example, operations without rotor sensor coverage may leave certain failure modes inadequately protected, including events associated with pole shoe loss or impact-related sensor failure. Conventional static sensor logic does not adequately

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account for such changing configurations and may therefore permit operation at an elevated risk level or require unnecessarily conservative stoppage.

8. Summary of the disclosure

The present disclosure provides a configurable airgap supervision scheme in which a turbine control system distinguishes between a default sensor configuration and an actual running sensor configuration. The system supports designation of mandatory sensors, while permitting one or more sensors to be treated as non-mandatory based on configuration parameters.

When the running configuration differs from the default configuration, the control system assesses the resulting change in monitoring capability and automatically modifies turbine operation to maintain a risk profile substantially equivalent to that of the default configuration. In representative implementations, the system may:

- ignore a disabled or non-mandatory sensor for protection logic;

- continue operation when a failed sensor is non-mandatory;

- stop the turbine when a failed sensor is mandatory;

- lower rotor speed to increase effective data density from remaining sensors;

- increase sampling frequency or sampling density for remaining sensors; and/or

- execute periodic full airgap scans at very low speed to identify developing issues.

9. Detail description

In one embodiment, a wind turbine includes a direct drive generator, an airgap monitoring system, and a turbine controller. The airgap monitoring system receives signals from multiple airgap sensors positioned to monitor generator airgap conditions. In a representative arrangement, the generator includes four sensors, with two associated with the stator and two associated with the rotor.

A default configuration is stored in the controller or supervisory logic. The default configuration may define which sensors are required for ordinary operation and protection. In one example, the default configuration is a four-out-of-four configuration in which all four sensors are active and mandatory.

The system also permits a running configuration to differ from the default configuration. This may occur when a service team, inspection result, or operating assessment determines that temporary operation with a different sensor set is acceptable. For example, the running configuration may be a three-out-of-four configuration in which one sensor is disabled or deemed non-mandatory.

The controller evaluates the difference between the default configuration and the running configuration. This evaluation may consider the number of active sensors, the location of the unavailable sensor, whether the missing sensor is rotor-based or stator-based, and the resulting reduction in coverage for particular failure modes.

Based on that evaluation, the controller automatically adjusts turbine operation so that the effective monitoring risk remains comparable to the risk level under the default configuration. In one example, when operating without one rotor sensor, the controller lowers rotor speed while maintaining or improving the information quality available from the remaining sensors. Lower speed may increase the density of airgap observations relative to machine position or event progression.

In another example, the controller increases sampling from the remaining sensors, such as by changing a sampling interval from about 40 milliseconds to about 10 milliseconds. This increased sampling can improve the ability to detect transient or developing airgap anomalies despite the reduced sensor count.

In a further example, the controller initiates periodic full airgap scans at very low rotational speed. Such scans may be scheduled, event-triggered, or condition-based, and may provide additional diagnostic coverage for conditions that would otherwise be less observable when one or more sensors are unavailable.

The disclosed logic may also include fault handling rules tied to mandatory status. If a failed sensor is designated non-mandatory in the current running configuration, the turbine may continue operating with adaptive restrictions. If a failed sensor is designated mandatory, the turbine may transition to a stopped or protected state.

The system therefore introduces configurable mandatory sensor capability together with adaptive operational response, rather than relying solely on fixed static protection assumptions.

10. Advantages

The disclosed approach provides several technical and operational advantages, including:

- reduced likelihood of catastrophic airgap-related generator failures;

- improved protection when operating with fewer than the full set of sensors;

- risk-aware operation tailored to actual sensor availability;

- reduced exposure to unmonitored rotor-related failure modes;

- improved flexibility after inspection or service actions;

- more efficient use of remaining healthy sensors through higher sampling density or slower operation; and

- potential avoidance of prolonged turbine outages and costly generator repair, including in offshore environments.

11. Example Embodiments

In one example embodiment, a direct drive wind turbine generator operates with four airgap sensors in a default four-out-of-four mandatory configuration.

In another example embodiment, after inspection indicates acceptable generator condition, one rotor sensor is designated non-mandatory and excluded from active protection logic, thereby allowing temporary operation in a three-out-of-four running configuration.

In a further embodiment, upon identifying that the running configuration has lower monitoring capability than the default configuration, the controller automatically reduces rotor speed and increases the sampling rate of the remaining sensors.

In yet another embodiment, the system periodically performs a low-speed full airgap scan to supplement reduced real-time sensor coverage.

In still another embodiment, configuration logic distinguishes between mandatory and non-mandatory sensor failures, continuing operation for non-mandatory sensor faults while stopping the turbine for mandatory sensor faults.

12. Industrial Applicability

The disclosed subject matter is applicable to utility-scale wind turbines, particularly turbines employing direct drive generators with multiple airgap sensors. It may be used in onshore and offshore wind installations, including fleets in which service teams require temporary operating flexibility after inspection, maintenance, or partial sensor degradation. The approach is particularly useful where prevention of severe generator damage and reduction of downtime are important commercial and operational objectives.

13. Variations and Alternatives

Numerous variations are possible. The number and placement of airgap sensors may differ from the four-sensor arrangement described above. The default and running configurations may be defined using different voting, enablement, or health-status schemes. The operational adaptations may include one or more speed reduction, torque limitation, derating, modified shutdown thresholds, modified alarm logic, increased sampling frequency, changed data-processing rules, or additional diagnostic routines.

The comparison between default and running configurations may be rule-based, model-based, or risk-score-based. The adaptive response may depend on sensor type, sensor location, failure history, turbine operating state, inspection recency, or environmental conditions. The disclosed concepts may also be extended to other rotating electrical machines or other multi-sensor protection systems in which reduced sensing capability can be compensated through adaptive operation.

14. Conclusion

This disclosure describes a configurable generator airgap monitoring and turbine control approach in which turbine operation is automatically adapted when the running airgap sensor configuration differs from a default mandatory configuration. By compensating for reduced sensing capability through adjusted operating behavior and enhanced use of remaining sensors, the system maintains a protection level closer to the intended baseline risk while improving operational flexibility and reducing the likelihood of severe generator damage.

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