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Technical Disclosure [1]

## 1. Title

Checking Neighboring Conditions for a Buddy Wind Turbine Used in Sensor-Fault Substitution Control

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## 5. Abstract

A control method is disclosed for validating whether a selected "buddy" wind turbine generator (WTG) is sufficiently near, or otherwise subject to similar wind conditions, to provide substitute operating signals when sensors on a primary wind turbine fail. In existing practice, a buddy turbine may be selected, for example, via IP address, and its wind-related values may be used as substitutes during local sensor or communication faults. The present disclosure adds a validation process that compares operating data from the primary and buddy turbines during periods when both turbines have healthy sensing systems. The comparison may include trend analysis, average-value comparison over extended durations, and detection of constant offsets between measured wind signals. Based on the similarity assessment, the system determines whether buddy-turbine values may be used for an extended duration, used with offset compensation, or limited to only a predefined substitution interval. The disclosed approach improves reliability of fallback control operation and reduces the risk of using substitute values from turbines exposed to materially different wind conditions.

## 6. Technical field

This disclosure relates generally to wind turbine controls, and more particularly to fault-tolerant sensor substitution methods using data from a neighboring or buddy wind turbine.

## 7. Background

Wind turbines rely on measured environmental and operational signals, including wind speed and related wind-condition values, for safe and efficient control. In some wind turbine control systems, when a local sensor fails or communication with that sensor is lost, substitute values may be obtained from another wind turbine, sometimes referred to as a "buddy" turbine.

Existing approaches may allow the buddy turbine to be selected through a network identifier such as an IP address. However, the fact that a turbine is selectable on the network does not ensure that it is physically nearby or exposed to sufficiently similar wind conditions. If substitute values are taken

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from a turbine experiencing materially different wind behavior, the primary turbine may operate with degraded control quality or increased risk. Accordingly, there is a need for a method that verifies whether the selected buddy turbine is truly suitable for sensor-fault substitution, particularly for prolonged use of substitute wind signals.

## 8. Summary of the disclosure

The disclosure introduces methods for checking whether a selected buddy wind turbine is genuinely near the primary wind turbine, or otherwise operating under similar wind conditions, before relying on the buddy turbine's signals during sensor failure.

In one approach, when both turbines' wind measuring systems, such as anemometers, are operating normally and without sensor or communication faults, wind speeds from the two turbines are compared over time. The comparison may include:

- trend comparison over an extended and ongoing duration;
- average-value comparison over an extended duration; and
- determination of whether a substantially constant offset exists between the two turbines' measurements.

Based on the outcome of these checks, one of multiple fallback actions may be taken when the primary turbine experiences a sensor fault:

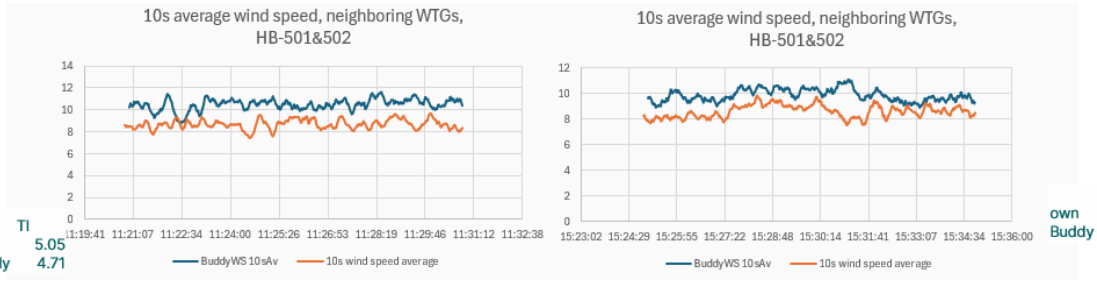
1. **Similarity confirmed**: buddy turbine values are used for a duration longer than a predefined substitution interval.
2. **Partial similarity confirmed with offset**: buddy turbine values are used for an extended duration, with compensation for a detected constant offset.
3. **Similarity not confirmed**: buddy turbine values are used only for a predefined limited duration.

The disclosure therefore provides a more robust decision process for determining when and how substitute signals from another turbine may be used and postpone a shut-down of the WTG due to the sensor fault which increases the availability.

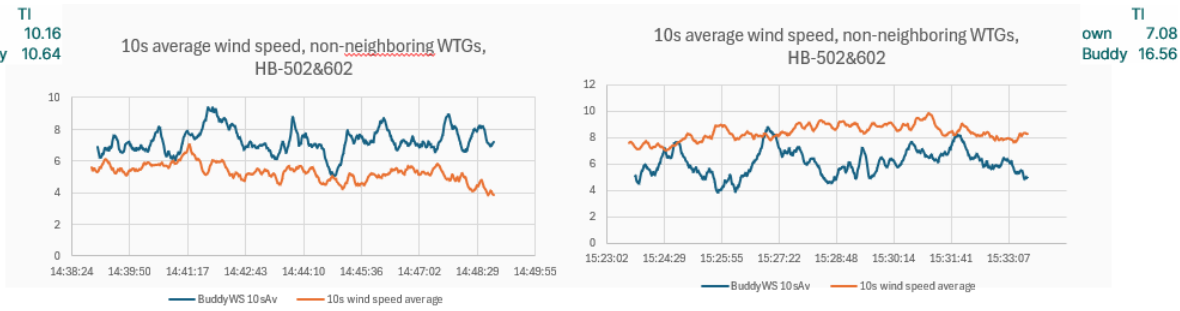
## 9. Brief description of drawings

Graphical representations below include example comparisons and related illustrations showing:

- Comparisons of 10-second average wind speed between neighboring wind turbine generators;



- comparisons of 10-second average wind speed between non-neighboring wind turbine generators; and




These drawings illustrate that neighboring turbines can exhibit similar wind-speed trends and averages, whereas non-neighboring turbines may show substantially different signal behavior, and/or very different turbulence intensity (TI) supporting the disclosed suitability-check methodology.

## 10. Detail description

In existing fault-handling controls, a wind turbine may substitute values from a selected buddy WTG when its own sensor signals fail. The present disclosure supplements that functionality with a validation layer to determine whether the buddy turbine is an appropriate substitute source.

### Buddy turbine suitability check

A selected buddy turbine is evaluated during periods when both the primary turbine and the buddy turbine have healthy measurement systems. In at least one embodiment, both anemometer-derived wind speed signals are monitored continuously or periodically over a relatively long duration. The system analyzes the relationship between the two signals to determine whether the turbines are experiencing sufficiently similar wind conditions.

The analysis may include one or more of the following:

- comparison of signal trends over time;
- comparison of rolling, windowed, or long-duration averages;
- comparison of turbulence intensity for a certain time period, e.g. 10min;
- assessment of degree of correlation or similarity;
- identification of persistent bias or offset between the signals; and
- classification of the buddy turbine as suitable, partially suitable, or unsuitable.

### Similarity outcomes

The disclosed method may classify the buddy turbine relationship in several ways.

#### 1. Similarity fulfilled

If the comparison indicates that the buddy turbine is sufficiently near and the wind-speed behavior

is sufficiently similar, then the buddy turbine is considered a reliable substitute source. In such a case, if the primary turbine later suffers a sensor or communication fault, buddy values may be used for longer than a predefined normal fallback duration.

2. Similarity partially fulfilled

If the signal trends are very similar but a substantially constant offset is detected, then the buddy turbine may still be considered usable. In that case, when the buddy turbine's wind speed is substituted for the primary turbine's failed signal, the control system may compensate for the offset before using the value. This allows extended use of buddy-turbine data despite calibration or location-related bias. This offset could also be dependent on wind direction, so not really constant for all directions.

3. Similarity not fulfilled

If the comparison fails to establish sufficient similarity, then the buddy turbine is not considered a reliable long-duration substitute. In that event, buddy values may be used only for a predefined short interval, if at all, after which other fallback, derating, or protective actions may be invoked.

Timing and duration

The assessment of suitability may be performed on an ongoing basis, intermittently, or as part of a background validation process during normal turbine operation. The purpose is to ensure that a prior, data-based basis exists for deciding whether substitute values may be trusted during a subsequent fault event.

Inputs and signals

Although the disclosure particularly emphasizes wind signals and wind speed from anemometers, the same framework may be applied to other signals exchanged between turbines. The buddy relationship may be selected initially through network information, but the disclosed method adds physical-condition validation rather than assuming suitability based only on network selection.

Example technical rationale

The example materials indicate that neighboring WTGs can exhibit closely matched 10-second average wind-speed behavior, while non-neighboring WTGs may show larger divergence in average value and variability (TI). Such evidence supports the use of a similarity check before extending the duration of substitute-signal use.

11. Advantages

The disclosed approach provides several advantages, including:

- improved confidence that substitute signals originate from a turbine under similar environmental conditions;
- safer and more reliable operation during local sensor or communication faults;
- ability to extend substitute-value usage when prior validation supports such use;
- optional compensation for constant offset between turbines, improving substitution accuracy;

- reduced risk of inappropriate fallback control decisions based on dissimilar turbines; and
- broader applicability to additional buddy-sourced values beyond wind speed.

## 12. Example Embodiments

### Embodiment 1: Long-duration substitution after confirmed similarity

A primary wind turbine and a selected buddy turbine both operate with healthy anemometers. Their wind-speed trends and long-duration averages are continuously compared. The control system determines that the two turbines show highly similar wind behavior. Later, when the primary turbine's anemometer fails, the system substitutes buddy wind-speed values for a duration longer than the normal predefined fallback interval.

### Embodiment 2: Offset-compensated substitution

A primary turbine and buddy turbine exhibit similar wind-speed trends, but the buddy turbine consistently measures a fixed offset relative to the primary turbine. The system records this offset during healthy operation (wind direction dependent). After a sensor fault on the primary turbine, the buddy turbine's wind-speed value is adjusted by the detected offset and then used as the substitute signal for an extended duration.

### Embodiment 3: Limited substitution when similarity fails

A selected buddy turbine is compared with the primary turbine during healthy operation, but the measured trends and averages do not sufficiently match. The system classifies the buddy turbine as unsuitable for extended substitution. If the primary turbine later experiences a sensor fault, buddy values are used, if at all, only for a predefined limited interval before additional control restrictions are applied.

### Embodiment 4: Use with other buddy-derived values

The same suitability-check framework is applied not only to wind speed but also to other values received from a buddy WTG. The system determines whether those values may be safely used based on the degree to which the turbines are exposed to similar operating conditions.

## 13. Industrial Applicability

This disclosure is applicable to utility-scale wind turbines, wind farms, and distributed fleets in which inter-turbine communications permit sharing of operating values. It is particularly useful in:

- fault-tolerant wind turbine control systems;
- wind farm supervisory and turbine-level control architectures;
- retrofit upgrades to existing buddy-turbine substitution logic; and
- systems requiring increased availability despite intermittent sensor failures.
- WTGs which are difficult to reach and exchange the sensor if necessary (e.g. in offshore sites)

The method may be implemented in turbine controllers, farm-level control platforms, or software modules integrated into existing control infrastructure.

## 14. Variations and Alternatives

Various modifications may be made without departing from the substance of the disclosure. For example:

- the suitability check may use wind speed, turbulence intensity, direction, or other measured or derived variables;
- similarity determination may be based on trends, averages, correlation, statistical thresholds, machine learning models, or combinations thereof;
- the offset compensation may be fixed, adaptive, filtered, or conditional;
- the predefined substitution duration may vary based on operating state, turbine type, site conditions, or confidence score;
- buddy-turbine selection may consider physical distance, network topology, wake interaction, terrain, historical similarity, or combinations thereof; and
- the method may be extended to other applications and other values obtained from the buddy WTG.

It is indicated that the methods of checking wind conditions can be further improved, and that the concept may be extended to additional applications.

## 15. Conclusion

This disclosure improves wind turbine fault-tolerant control by validating whether a selected buddy wind turbine is sufficiently near or otherwise subject to similar wind conditions before using its signals as substitutes for failed local sensors. By comparing signal trends and averages during healthy operation, and by optionally compensating for constant offsets, the system can distinguish between suitable and unsuitable buddy turbines. This enables more accurate and reliable substitute-signal use, including extended substitution where justified, while reducing the risks associated with using data from non-comparable turbines.

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