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SCADA ALARM ANALYSIS FOR IMPROVING WIND TURBINE RELIABILITY

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Abstract body:

1. Introduction

Current studies of wind turbines (WT) focus on improving reliability [1,2] because good WT reliability will, together with a predictable turbine maintenance schedule, result in a reduced cost of the produced energy, which will determine the success of a wind project. This is even more important for offshore wind farms due to their high initial capital cost and limited accessibility, causing higher operational and maintenance (O&M) costs [3] and prolonging capital payback.

The essence of improving WT cost of energy is to reduce the downtime and increase availability by optimizing WT design and applying a well-organized maintenance schedule. Both these strategies require a full understanding of the WT system and a detailed understanding of its failure mechanisms. WT supervisory control and data acquisition (SCADA) system data provides a rich resource to achieve this, because it archives comprehensive historical signal, alarm and fault log information, as well as the environmental and operational conditions [4, 5]. Research studies on SCADA alarms for detecting WT failures and improving WT reliability through alarm optimization are rare [6].

The aim of this paper is to correct this omission by detecting, locating and diagnosing WT failures by a thorough analysis of WT SCADA alarms to improve WT reliability and realize an efficient alarm system.

2. Wind Turbine Alarm System

Typically, alarms are used to indicate the need for emergency action to protect a WT from running into a risky condition. Whenever the WT is running with a malfunction, corresponding alarms will be triggered by key component signals exceeding threshold reference limits. Alarm occurrences could be described by an event chain or alarm time-sequence, as usually observed when a malfunction occurs, which intuitively could be related to sequence of a failure mechanism. The accuracy of these time-sequences relies on the time resolution of the data collection system. In addition, under some critical WT conditions alarms that need to rapidly activate emergency controls passed through a faster communication channel, which lead to some alarms being triggered appearing earlier than other prior alarms. Therefore, alarm sequences may vary from one malfunction to another or related alarms may appear simultaneously. As a complex and complete system, therefore, WT alarms appear as complex and variable pattern with a rapidly increasing pace as a malfunction progresses and successive alarms are triggered, rather than as a straight time-sequence related to the failure mechanism. In order to deduce the information embedded in the alarms a scientific methodology is needed to extract the correlation between the alarms and associated WT malfunctions. A global investigation of WT alarms based on functional classification will be presented in the full-length paper.

3. Probabilistic Models and Venn Diagrams

3.1 Bayes' theorem

Rather than using a time-sequence analysis for alarms, we proposed a probabilistic method based on Bayes' theorem and Venn Diagrams to investigate the relationship between two or multiple sets of alarms and use them to detect and locate the WT failure. This will have the advantage of avoiding noisy alarms time-sequence and does not require a higher accuracy data collection system than is provided by the WT SCADA.

Based on Bayes' theorem

$$P(B \mid A) = \frac{P(A \mid B) \cdot P(B)}{P(A)} \qquad (3\text{-}1)$$

*P(A|B)*is the conditional probability of the alarm A being triggered given by the alarm B has been triggered.

*P(B)*is the total probability of the alarm B has been triggered.

*P(A)*is the total probability of the alarm A has been triggered.

There are four important derivations based upon this theory:

$$(1)\quad P(B \mid A) \approx 1 \text{ and } P(A \mid B) \approx 1 \Rightarrow A = B$$

This derivation concerns two closely related alarms (*A* and *B*) which always appear together. This may be due to the similar function of these two alarms or a similarity in their triggering logic. Or it may be a direct consequential effect of the failure of the two components.

$$(2)\quad P(B \mid A) \approx 0 \text{ and } P(A \mid B) \approx 0 \Rightarrow A \cap B = 0$$

This derivation concerns the relationship between two independent or weakly related alarms (*A* and *B*) which never appear together.

$$(3)\quad P(B \mid A) \approx 1 \text{ and } P(A \mid B) \neq 1 \Rightarrow A \in B$$

This derivation can be interpreted as alarm *B* triggering whenever alarm *A* appears. In this case, alarm *B* may therefore be a more general alarm than alarm *A* for some specific failure.

$$(4)\quad P(A \mid B) \neq 1 \text{ and } P(B \mid A) \neq 1 \Rightarrow A \cap B \neq 0$$

This derivation concerns the case of two randomly related alarms. The relationship between these two alarms depends upon the control logic as well as the WT's health.

By referring to the mutual conditional probability a Venn diagram to present these four derivations above can be developed as shown in Figure 1.

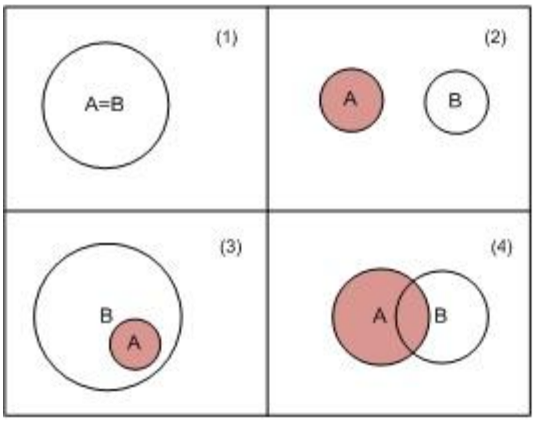


Figure 1: Venn Diagram of four derivations.

3.2 Pitch Failure Case Study

A case of using alarms to detect and locate a failure in a 2 MW variable speed WT's electrical pitch system is presented. The probabilistic calculations were based on 1-2 years historical SCADA alarms data. In a particular fault, 9 alarms were observed when the WT is running as shown in Table 1 below. From historical SCADA alarm records, a Venn diagram was generated to present their relationship as shown in Figure 2.

Table 1: 9 Pitch Alarm IDs and Alarm Names

Alarm ID	**Alarm Name**
369	Pitch
372-374	Blade1-3 Emergency
371	Warning Pitch General Alarm
368	PCP Initiated Emergency Feather Control

384	Blade 1 Saturation Limit
387	Blade 1 Short Circuit
390	Servo Pitch Amplifier Fault

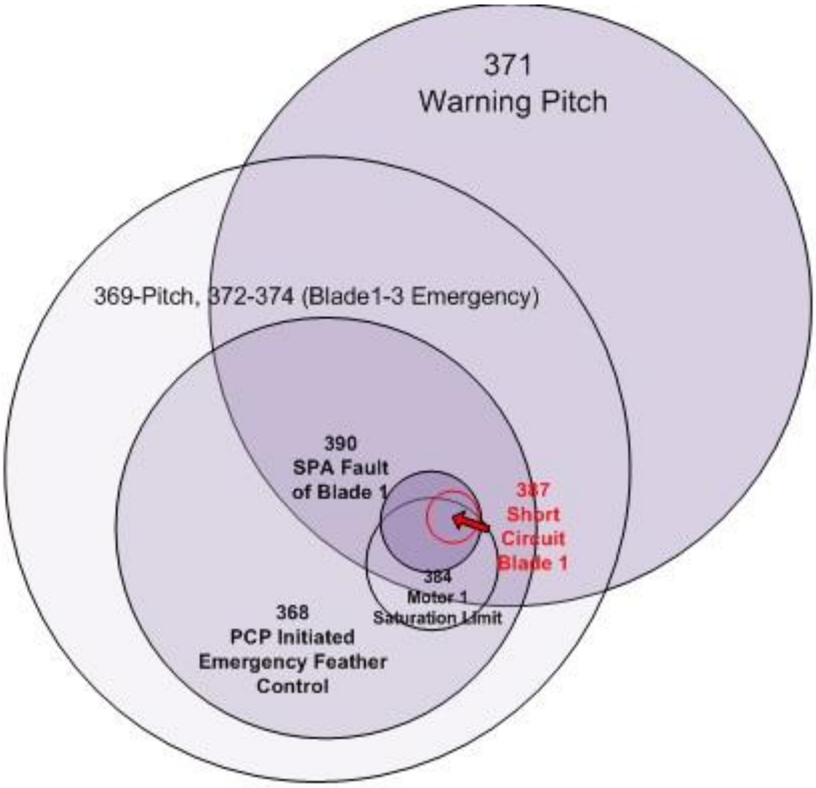
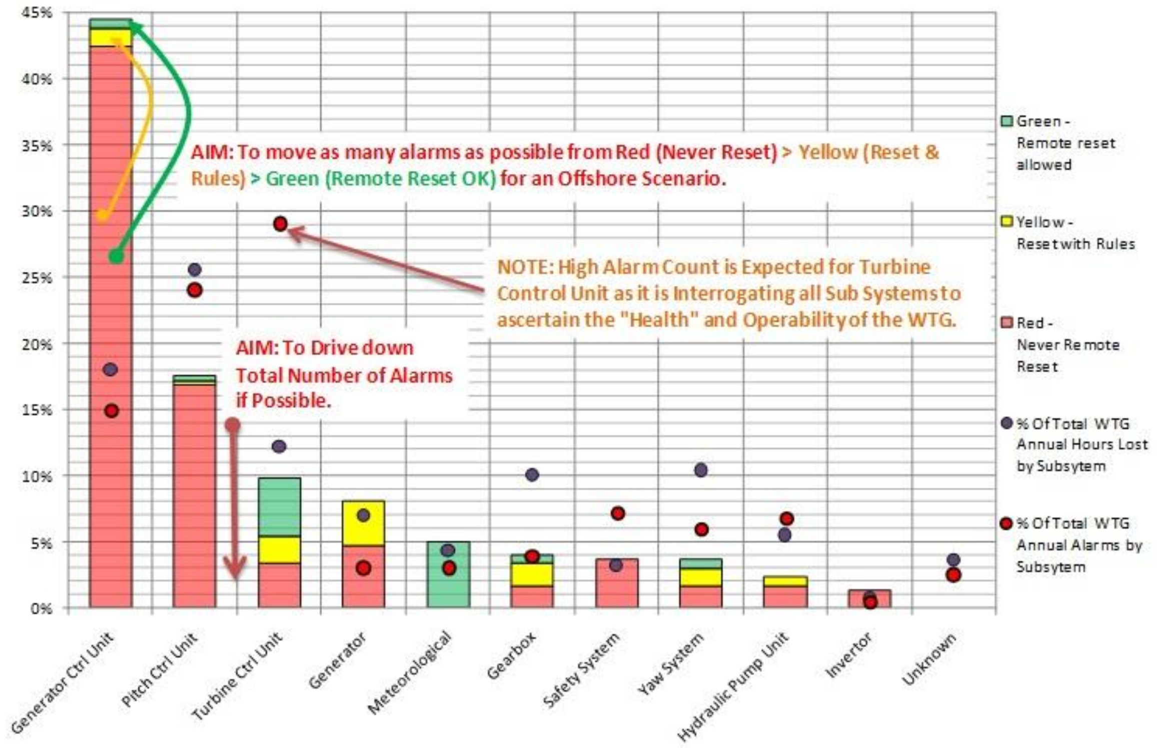


Figure 2: Venn Diagram of Pitch alarms.

Figure 2 above shows the pitch system failure case indicated by a Short Circuit Alarm in the pitch system of blade 1 of the WT. The short circuit detection will have been in the DC pitch motor of blade 1, probably caused by the cumulating of carbon dust in the commutator compartment of the blade motor or a malfunction of pitch system drive circuit components. Once the motor drive circuit is short circuited, the fault will then trigger the Servo Pitch Amplifier Fault alarm as well as the Blade 1 Saturation Limit alarm, defined as an unsatisfied blade angle request to blade 1. Under this situation, the WT enters an emergency state, which means the Pitch Control System will initiate Emergency Feather Control and the alarms consequential upon that condition will then be triggered, such as Blade Emergency Alarms and Warning Alarm. Case studies of other subassemblies will also be presented in the full-length paper.

4. Alarm Systematic Optimization and Wind Turbine Reliability

The purpose of SCADA alarms is to provide early warning of improper operation and ensure a safe state for the WT and its key components. However, there is no assessment of the need for alarms and their value to WT reliability. The lack of this assessment by WT designers results in a noisy alarm environment with overlapping functions which increase WT cost and disturb maintainers' failure judgement. The probabilistic methodology above could be used to calculate alarm redundancy and necessity to optimize WT alarms system. A statistical analysis of alarms from a complete 2.5 MW variable speed WT is shown in Figure 3.



AIM: To move as many alarms as possible from Red (Never Reset) > Yellow (Reset & Rules) > Green (Remote Reset OK) for an Offshore Scenario.

NOTE: High Alarm Count is Expected for Turbine Control Unit as it is Interrogating all Sub Systems to ascertain the "Health" and Operability of the WTG.

AIM: To Drive down Total Number of Alarms if Possible.

Figure 3: Statistical Analysis of Alarms and Cumulative Sub-system Downtime Comparison

Figure 3 shows that:

- The Generator Control Unit (GCU) in this WT accounted for nearly 45% of the total WT alarms, yet only 18% of the annual lost hours are attributed to it.
- The Pitch Control Unit (PCU) has just over 16% of the total WT alarms but just under 26% of the annual lost hours are attributed to this sub system.
- 76.5% of the alarms in total cannot be remotely reset and require intervention by maintainers.
- As few as 12% of the total alarms may be potentially reset if certain rules can be complied with.
- Only 11.5% of the total alarms can be remotely reset without following any rules or requiring any intervention.

The overall purpose of an alarm optimization process for the alarm system of an offshore WT would be to remove as many alarms as possible from:

Red (Never Reset)-> yellow(Reset by rules)->Green(Remote Reset OK).

The alarms that can be removed should focus on the ones that have the probability of derivation (1) as shown in the Bayesian analysis above due to the equivalency of those alarms to another or the ones that have the probability of derivation (3) due to the generality of those alarms. Whether the alarms have properties of derivation (2) and (4) can be reduced depends on their function and priority consideration.

5. Conclusions

From detailed analysis of WT SCADA alarms, a probabilistic method has been developed to detect and locate WT failures. The value of the four derivations from this probabilistic model to clarify the cross-correlation between alarms and to systemize alarm optimization has been discussed. An example has been shown of how WT SCADA alarms can be used to detect and locate a WT pitch mechanism failure. An example has also been given of how alarm analysis could be used to optimize alarm collection. Alarm analysis would improve WT reliability and assist in maintenance scheduling which is especially important for offshore WT application.

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