Fault Analysis of Wind Turbines Based on Error Messages and Work Orders ⋆

Anders Bech Borchersen * **Jesper Abildgaard Larsen** ** **Jakob Stoustrup** ***

* *Institute of Electronic Systems, Aalborg University, Denmark Vattenfall R&D, Fredericia, Denmark (e-mail: anb@es.aau.dk).*
** *Institute of Electronic Systems, Aalborg University, Denmark (e-mail: jal@es.aau.dk).*
*** *Institute of Electronic Systems, Aalborg University, Denmark (e-mail: jakob@es.aau.dk).*

Abstract: In this paper data describing the operation and maintenance of an offshore wind farm is presented and analysed. Two different sets of data is presented; the first is auto generated error messages from the Supervisory Control and Data Acquisition (SCADA) system, the other is the work orders describing the service performed at the individual turbines. The auto generated alarms are analysed by applying a cleaning procedure to identify the alarms related to components. A severity, occurrence, and detection analysis is performed on the work orders. The outcome of the two analyses are then compared to identify common fault types and areas where further data analysis would be beneficial for improving the operation and maintenance of wind turbines in the future.

1. INTRODUCTION

The Operation and Maintenance (O&M) cost of offshore wind turbines is estimated to be 30% of the total turbine cost, see Blanco [2009]. Thus to get offshore wind energy to be a competitive alternative to fossil fuel energy, the cost of O&M should be reduced. A step towards this reduction is to gain knowledge about which faults that are contributing most to the O&M costs in offshore wind turbines. This knowledge could then be used to guide the design of further fault detection system for offshore wind turbines.

There exists several studies of faults in wind turbines Ribrant and Bertling [2007] using many onshore wind turbines, Qiu et al. [2011], Arabian-Hoseynabadi et al. [2010]. Since these studies mainly has been looking at the faults in onshore turbines where the accessibility to the turbines are higher and cheaper compared to offshore turbines, there might be a difference between which faults there are crucial in onshore- compared to offshore-turbines, since the cost of getting to the turbines is not accounted for in the previous studies. Furthermore the type of faults might also differ between the two turbine types due to their different operating condition. The reason for the missing information regarding faults in offshore wind turbines come from the fact that offshore wind energy is a relatively new area and therefore fewer experiences regarding faults and O&M of offshore wind farms are available. To close this gap in information, fault specific data concerning offshore wind farms should be analysed, which is also stated in Rademakers et al. [2003].

To get the required knowledge about which faults are the most crucial in offshore wind turbines, it is necessary to get data from a operational offshore wind farm which has been operating for a longer time period. This is to ensure that early infant mortality failures is not affecting the analysis. This is not easy since most offshore wind farms only have been operating for a few years, EWEA [2009]. In this study, data fulfilling these requirements are available. Therefor this data will be analysed to get some figures for what sets of faults that occurs in offshore wind turbines, and to identify if these faults are already predicted by the current Supervisory Control and Data Acquisition (SCADA) systems or if there is a need for improving the fault detection and prediction of offshore turbines.

It has previously been tried to use the SCADA alarms for fault isolation using a probabilistic method, see Ribrant and Bertling [2007]. Instead of using the alarms directly for fault isolation this study will focus on identifying the most severe faults which then can be detected trough fault detection methods using all the available SCADA data.

In this article the available alarms and work orders from an offshore wind farm are presented in Section 2. The two types of data are analysed in Section 3 and Section 4 separately. The results from the two analyse are then discussed and compared in Section 5. Based on the discussion a final conclusion about which faults there are of greatest interest for future studies is draw in Section 6.

2. THE DATA

In this study two sets of data concerning the faults in the offshore wind turbines are studied. The first data set is the SCADA alarms which are automatically generated by the turbines and sent to the SCADA system. These alarms are handled remotely from the O&M center. The second data set used in this study is the work orders. These are descriptions written by the service team describing the

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maintenances performed at the turbine. In this section the specification and overview of these data sets are presented. All the data is collected from the same offshore wind farm.

2.1 SCADA Alarms

It is known that the alarms from wind turbines needs improvements since they often give alarm flooding Qiu et al. [2011]. An overview of the SCADA alarms is shown in Table 1. It should be noted that the alarms used in this study are the alarms stored in the database, thus only a fraction of these alarms are shown to the operator.

Start day:	2006-11-07
Stop day:	2012-01-01
Different alarm types:	173

Table 1. Overview of parameters for the SCADA alarms.

The most common SCADA alarms are listed in Table 2. It is seen that the most common alarm type is Turbine OK and the other alarms with high occurrences is mainly noise which is also known from other studies of SCADA alarms Qiu et al. [2011].

Alarm Description	% of all entries
Turbine OK	61.0 %
Communication Fail	20.6 %
Bad data	7.5 %
Paused	3.5 %
High wind speed	1.4 %
Stopped	0.8 %
Emergency stop	0.7 %
Timeout	0.5 %
High gear temperature	0.3 %

Table 2. The most common SCADA alarms in the database.

In Figure 1 the distribution of SCADA alarms are shown. From the figure it is clearly seen that the number of SCADA alarms is much higher in 2007 than the other years. This is probably caused by a start up tuning of the SCADA alarm system. Thus the number of alarms are reduced for the other years.

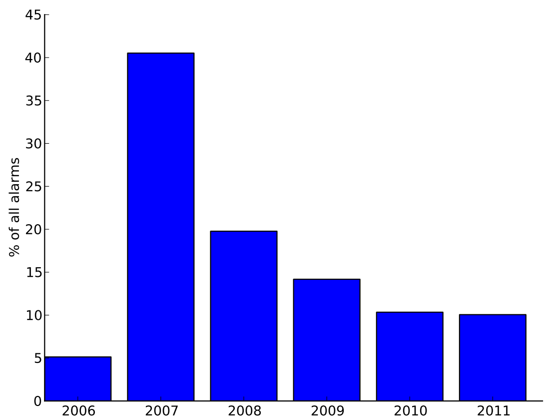

Fig. 1. Distribution of the SCADA alarms over the years.

2.2 Work Orders

The work orders analysed in this study are from February 2008 to May 2011, the distribution of the work orders over the years are listed in Table 3.

Year	2008	2009	2010	2011
Orders	26.5%	32.0%	29.7%	11.8%

Table 3. Distribution of work orders over the years.

Each work order is given one of four different priorities based on estimates on how long the turbine could have been running before it would have been stopped (urgent means it was stopped). The priorities and their numbers are listed in Table 4, it is seen that a majority of the reports are either categorized as urgent or to be done within a week.

The distribution of the priorities over the years are plotted in Figure 2. The figure reveals a clear change in how the priorities are given from 2009 to 2010. But the general tendency for the work is the same over all four years, that most of the work is done as reactive maintenance.

Priority	% of all work orders
Urgent	54.0 %
Week	34.7 %
Month	3.6 %
Planned	7.7 %

Table 4. Distribution of reports at the different priority levels.

According to Walford [2006] 30-60% maintenance will be unscheduled. Unscheduled corresponds to urgent in this study, thus the hypothesis seems to be confirmed by the available work orders. This only amplify the need for improving the current fault detection systems and thereby changing to a more scheduled maintenance.

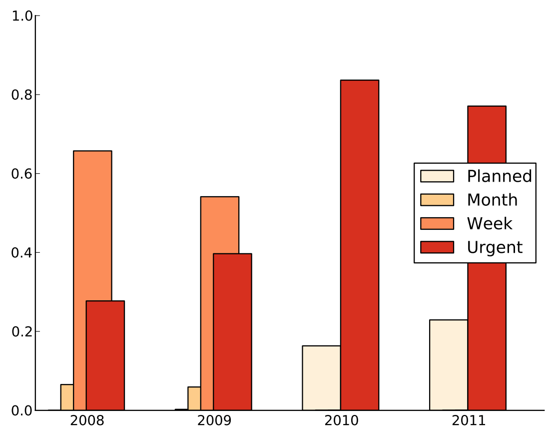

Fig. 2. How the priorities are given over the years.

3. ANALYSIS OF SCADA ALARMS

In Section 2 the SCADA alarms contains a lot of noise, thus to avoid looking at non specific alarms a cleaning procedure of the alarms has been performed before any further analyse of the alarms are conducted. The outcome of the cleaning procedure is shown in Table 5. Most of the alarms has been remove since they mainly described external parameters or other parameters not directly related to a fault in the turbine. Thus the number of alarm groups can be reduced to nine.

Cleaned Alarm Group	Occurrence
Temperature	30.7 %
Controller	16.2 %
Gear	11.0 %
Yaw	10.9 %
Generator	9.9 %
Breaker	7.3 %
Pitch	5.7 %
Others	4.1 %
Hydraulic	4.0 %
Cleaned alarms out of all SCADA alarms	2.6 %

Table 5. The different alarm groups and their occurrence after the cleaning procedure. It should be noted that it is only a small fraction of the total numbers of alarms are in the cleaned alarms.

It is also seen that the cleaning procedure performs a great reduction in the number of interesting alarms, this was expected since an alarm as "Turbine OK" can not be used for determine what types of faults there often occurs in wind turbines. Furthermore the cleaning procedure gives a more equally distribution of alarms over the years shown in Figure 3 compared to Figure 1, but still with lowest numbers for 2011.

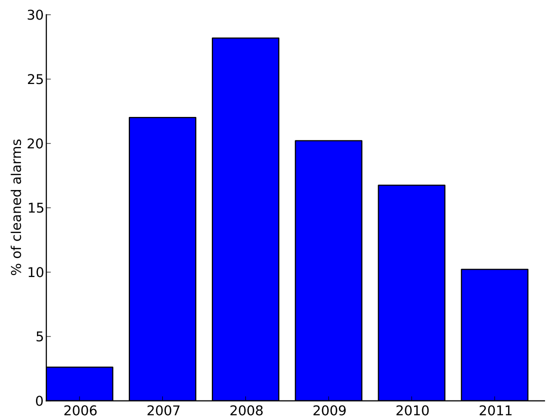

Fig. 3. Distribution of SCADA alarms after the cleaning procedure has been performed.

4. SEVERITY, OCCURRENCE, AND DETECTION ANALYSIS

In this section a severity, occurrence, and detection (SOD) analysis is conducted using the work orders from Section 2.2. These are used since they includes information about the cost and the priority of each order.

The first step in the SOD analysis is to find the different indices for each fault, which is done by using the conversion factors shown in Table 6.

To have a standardized way of determining the severity and the occurrence indices a data driven approach is proposed and used, since no logic way for selecting the indices are given directly from the data. The intervals are therefore found by dividing the data into four sets these are found using (1) to (4). The subsets are found for both the cost set S and the occurrence set O. This gives severity and occurrence indices which are depending on the available data, and thereby ensures that some faults will have the highest severity index and some the highest occurrence index (not necessarily the same fault).

$$S_1 \subseteq Q_3\{S\} \tag{1}$$
$$S_2 \subseteq Q_2\{S \setminus S_1\} \tag{2}$$
$$S_3 \subseteq Q_2\{S \setminus (S_1 \cup S_2)\} \tag{3}$$
$$S_4 \subseteq \{S \setminus (S_1 \cup S_2 \cup S_3)\} \tag{4}$$

where $Q_n\{A\}$ is the n^{th} quartile of the data set A.

The detection index is determined by the priority in the work order (the four priority levels are listed in Table 4), and this is also the reason for using four different indices for the severity and occurrence indices. Which is also used in Arabian-Hoseynabadi et al. [2010] where faults in wind turbines are investigated as well.

The Risk Priority Numbers (RPN) are omitted in this article, see Wheeler [2011]. Thus instead of calculating the RPN, the indices are used relatively to each other and thereby the need for having different scales for severity, occurrence, or detection is unnecessary.

Since the occurrence indices only exists for a group of work orders, the severity and detection index for a group is found by the median of the severity and the detection index of the work orders in each group.

Index	Cost (severity)	Occurrence (occurrence)	Priority (detection)
4	S_4	O_4	Urgent
3	S_3	O_3	Week
2	S_2	O_2	Month
1	S_1	O_1	Planned

Table 6. The relationship between the SOD indices and the data.

For the rest of the analysis only work order groups with a detection index of 3 or 4 are used, since if the detection index is less than 3, the order was either planned or there were more than a month of normal run time before expected failure. The number of work order groups with their different combination of the severity and occurrences indices are shown in Figure 4.

Since this study is on offshore wind turbines and the severity index does not include transport cost to the wind turbine, the occurrence index is weighted higher than the severity. By using the weighting illustrated in Figure 4, 8 typesare consider especially interesting for further studies since they have a high occurrence index while at the same time being relatively severe.

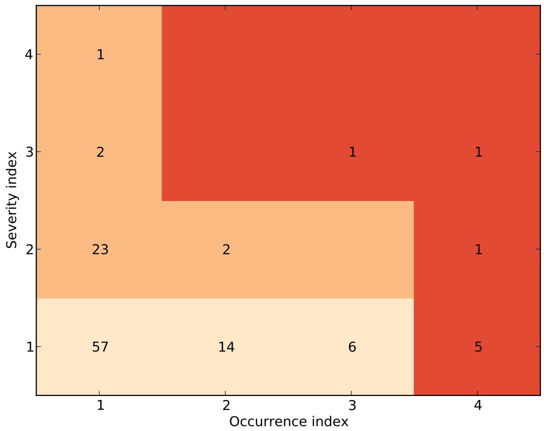

Fig. 4. Number of work order groups at the different severity and occurrence indices for detection indices above or equally to 3.

The outcome of the SOD analysis is listed in Table 7. It is seen that the gear is the main component where work is being performed in different aspects.

Fault type
Gear inspection
Gearbox exchange
Electrical breaker
Gear adjustment
Ventilation error
Gear oil
Relay
High speed gear

Table 7. The most severe faults based on the SOD analysis(sorted by occurrence).

5. LOCATING SEVERE FAULTS

In this section the results from the SOD analysis with the SCADA alarms are combined to identify which faults that are severe. From the SOD analysis the gear related faults are identified as the most severe, since four of the severe fault types were connected to the gear. Furthermore two of the severe faults were connected to the electronic components (Electrical breaker, relay). Some of the same tendencies can be seen in the SCADA alarms but generally the SCADA alarms are more general than the work orders, and less focused on the gear. In the SCADA alarms 30% of the alarms were temperature related, but since a temperature fault can come from both a hot component or a failing sensor, they are difficult to connect to a specific fault without further analysis of the data.

The yaw alarm and the controller alarm does not show up in the SOD analysis even tough they account for 25% of the cleaned alarms combined. The reason for this is that some of these faults can be handled remotely, thus not showing up in the work orders. But generally there is consistency between the cleaned SCADA alarms and the work orders, but it should be noted that a fault might tricker several alarms but only the first to tricker will show up in the SCADA data.

6. CONCLUSION

In this study two types of data describing the faults in a wind farm have been presented and analyzed. The overall conclusion is that the data is confirming that most of the maintenances is performed as reactive maintenance. Furthermore several severe faults are located trough a SOD analysis, based on the work orders. The analysis of the connection between the actual work performed at the turbines and the alarms given by the SCADA systems showed that there is some connection, but there are still a lot of the work orders that could benefit from a improved fault detection systems, which would allow more of the maintenance be scheduled instead of the current unscheduled.

From the large amount of temperature related SCADA alarms, better detection and diagnosis of temperature related faults might be an area where further investigation could lead to an improvement of the current alarm system. From the analysis of the SCADA alarms it was also clear that a large amount of the alarms where impossible to connect to specific components or parts, based on their current description. To improve this a connection between SCADA alarms and the actual SCADA data might be an area of further investigations.

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