Offshore Wind Power at Rough Sea

The need for new Maintenance Models

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Offshore Wind Power at Rough Sea
- The need for new Maintenance Models

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Abstract
This study compare the current operations and maintenance issues of one offshore wind park at very rough sea conditions and two onshore wind parks. Through a detailed data analysis and case studies this study identifies how improvements have been made in maintenance of large wind turbines. However, the study has also revealed the need for new maintenance models including a shift from breakdown and preventive maintenances and towards more predictive maintenance to reduce the cost of energy for offshore wind energy installations in the future.

Keywords: Maintenance, Maintenance Models, Offshore Wind Energy,

Introduction
Wind energy has become an increasingly attractive choice, as it is a clean alternative to fossil fuels and nuclear power. However, space has quickly become scarce for installation of onshore wind turbines, and the fact that wind turbines are getting higher and higher is e.g. in Denmark resulting in protests from the public while some citizens do not like to live close to large wind turbines, caused by different reasons, which often give political debates. Offshore wind energy has therefore become increasingly attractive and because of stronger and more stable winds, offshore installations have shown a much higher potential. Although, when moving offshore, the level of complexity is increasing dramatically as logistics for installations, operations and maintenance (O&M) are much more difficult and expensive.
Wind energy is believed to play a crucial role in the future energy supply of both the European Union (EU) and of the rest of the world. The European Commission and The European Wind Energy Association (EWEA) estimate that a total of 230GW of wind energy will have been installed in the EU by 2020 (EWEA, 2010). Today, a total of 106GW is installed in this area (EWEA, 2013). For more than a decade, large energy companies have increased their installation of new turbines and in 2012 almost 12 GW

(EWEA, 2012) of wind energy (corresponding to 6.000 2MW wind turbines) was installed within the EU.

For the last 10 years, the wind turbine industry has been almost solely focused on the development of new and larger wind turbines for wind parks. Focus on O&M of wind parks has been very limited and is currently in its early phases (Utne, 2010). Existing literature on maintenance and service within the wind energy sector is therefore scattered within various subjects like development of sensors for oscillation (Caselitz & Giebhardt, 2005), decision theory (Dalsgaard Sørensen, 2009), or mathematical models for planning of maintenance (Besnard et al., 2009; Besnard et al., 2011). Some studies (e.g. Fischer et al., 2012 and Nielsen & Sørensen, 2011) have sought to introduce well-accepted maintenance concepts like the Reliability-Centred Maintenance (Moubray, 1997; Nowlan & Heap, 1978) into the wind energy sector. However, so far the success of these implementations has been modest, mainly because the concept has been developed for more stable environments than of those for wind turbines; especially for offshore turbines where the environment is very stochastic and harsh.

The purpose of this paper is therefore to investigate the main issues in relation to O&M for the offshore wind energy sector.

After this introduction we will in the second section of this paper describe maintenance from a general perspective, which also will include two different maintenance concepts. In section three we will introduce the current literature concerning maintenance of offshore wind turbines. Section four explains our case studies and the methodology used in this paper and forms the background of our findings and discussion in section five. Finally, in section six, we will conclude and look into the implications of O&M of large offshore wind parks.

Maintenance and maintenance concepts

The purpose of maintenance is to "ensure that physical assets continue to do what their users want them to do" (Moubray, 1997, p. 7). Today, companies contain a large numbers of physical assets which are all interacting to achieve the company's pursued business objectives. Therefore, maintenance has become extremely important to contribute to the achievement of these objectives (Waeyenbergh & Pintelon, 2002).

Different types of Maintenance

In general there is three different ways to perform maintenance: (1) Predictive Maintenance, (2) Preventive Maintenance, and (3) Corrective Maintenance (Moubray, 1997). Whenever a system is in operation, maintenance has to be *planned* and *scheduled*. When planning maintenance, the execution of major maintenance activities (e.g. shutdowns) has to be planned in accordance with other plans. Maintenance jobs can be relatively complex and calls for careful preparation. However, scheduling of maintenance tasks often occurs over a shorter horizon of time and it consists of determining the order of execution of the activities needed (Dekker & Scarf, 1998). Figure 1 illustrates a typical P-F-curve (Moubray, 1997) and shows the three types of maintenance in relation to time and the condition of the equipment. In this figure we have shown an example of a gearbox from a wind turbine and along the time-line different condition detection methods are illustrated. Future gearbox failures may for instance be predicted by ultrasonic measurements or by vibration detection (Dalsgaard Sørensen, 2009). However, maintenance within the wind turbine sector is mainly carried out as preventive and as corrective maintenance but more focus is put on moving backwards towards a more predictive and preventive strategy.

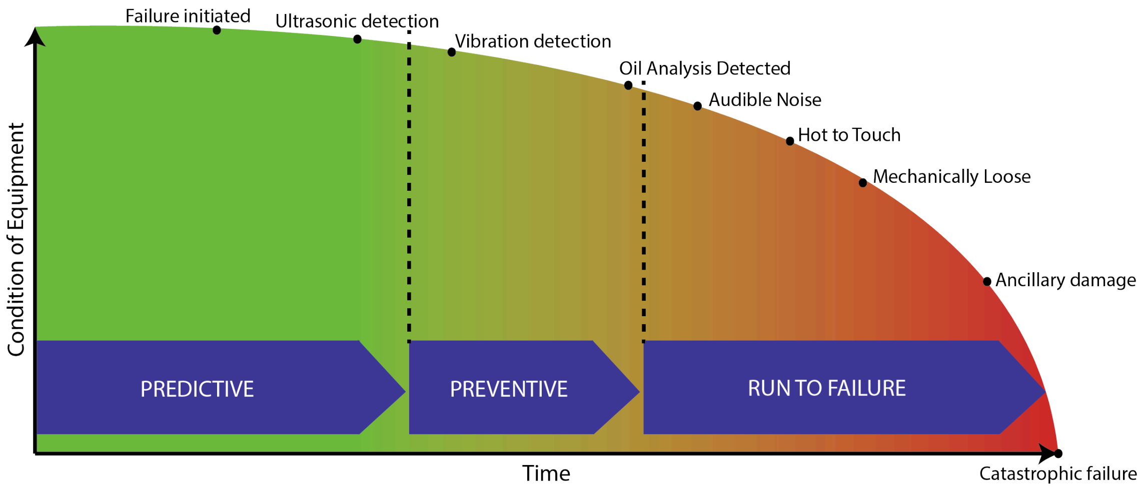

Figure 1 – Condition of equipment over time. In this example a gearbox is presented (inspired by Moubray (1997) and Kittiwake (2013))

Maintenance concepts

A maintenance concept is used to govern which types of maintenance actions that should be used for what equipment. The current literature on maintenance includes a number of different concepts. However, most of the concepts are either very time-consuming to implement or are only valid for special classes of equipment or for a specific industry (Waeyenbergh & Pintelon, 2002).

Reliability-Centred Maintenance

The concept of Reliability-Centred Maintenance (RCM) originate from the aircraft industry (Nowlan & Heap, 1978) and has been applied with considerable success in various industries (e.g. railways (Márquez, Schmid, & Collado, 2003), offshore oil & gas (Arthur & Dunn, 2001), the manufacturing sector (Deshpande & Modak, 2003), etc.). RCM identifies ways in which components or systems may fail to perform their intended functions, and these considerations can be used in the phase of design stage or in a maintenance strategy. The RCM concept focuses on the function of the equipment by predicting failure modes and the consequences. From this, suitable maintenance actions can then be determined. (Andrawus et al., 2006; Nowlan & Heap, 1978; Waeyenbergh & Pintelon, 2002)

Total Productive Maintenance

The concept of Total Productive Maintenance (TPM) is based on Productive Maintenance, which was introduced in General Electric in the 1950'ies. Later, it was developed further in Japan and then re-imported to the West (Waeyenbergh & Pintelon, 2002). The concept evaluates potential causes of asset failure by focusing on the equipment, on methods of operation, on measurement styles, on manpower error, and on materials. In short, the TPM concept is used to continuously improve performance of certain industrial activities; in the first place of maintenance. (Andrawus et al., 2006; Dekker, 1996; Waeyenbergh & Pintelon, 2002)

The Costs of Maintenance of Offshore Wind Turbines

There is a huge difference in the installation and operation of wind turbines when comparing onshore with offshore turbines. Installation of onshore wind energy cost between €1,5-1,9 million per megawatt of capacity, while offshore the costs are around €3,8 million per megawatt of capacity (Haluzan, 2011). O&M costs are also substantially higher for offshore wind parks than for onshore wind parks. The higher cost of transport, as well as the reduced site access, constitutes a large part of this. Onshore, O&M costs are estimated to be between 4,5-8,7 €cent/kWh, while offshore it is 6-11,1 €cent/kWh (Blanco, 2009). This is backed up by earlier studies that showed that O&M is 1,5-2 times more expensive when performed offshore than onshore (Massachusetts Technology Collaborative, 2005). Actually, O&M costs for offshore wind parks can constitute up to 30% of the overall costs for a wind farm (Blanco, 2009) and it is estimated that repairs cost 5-10 times more when performed offshore than onshore, mainly due to the need for expensive vessels (Bussel & Zaaijer, 2001). Even though it is more expensive to perform O&M offshore, there are still advantages to offshore wind energy; the stronger wind offshore imply a greater productivity that in the end may offset the higher installation and O&M costs. Furthermore, when moving wind turbines offshore, it is possible to build the turbines even larger than onshore without neighbours to complain about noise or visual impacts.

Case and Methodology

The study has been carried out in one of Europe's leading energy companies as case studies. The company operates over 900 wind turbines of which about 1/3 is located offshore. The company has been operating and maintaining wind turbines for almost two decades. The wind turbine sector is still a rather immature field where the wind turbine manufacturers (OEMs) during the last decades constantly have launched new and larger wind turbine models and new versions on the market. The general manager of the company where we have conducted our study explains it this way: "if a wind turbine manufacturer has developed a type or a version of a wind turbine during the last decades - we have got it". In this study we have therefore been challenged to identify identical wind turbines to be able to compare the different operational conditions of operation. Thus, a 2MW wind turbine was chosen, as it is installed in three different parks located in the Northern Europe both offshore and onshore under strong wind conditions. Further details on the three parks can be found in table 1 below.

Although the three wind parks have been in operation for several years, it has been impossible to gather data from before year 2010, while explicit data was stored unstructured and thus impossible to systemise. This seems to be a general problem within the wind sector and the data issues are currently studied through another research program in the company.

Table 1 – The wind parks used in the analysis

Park	Location	No. of turbines	Max. Output [MW]	Year of Commission
Park 1	Offshore	80	2	2002
Park 2	Onshore	7	2	2004
Park 3	Onshore	2	2	1996

In our survey of data we have been inspired by quantitative methods (Brandon-Jones & Slack, 2008) and to be able to have a more in depth understanding of the challenges of O&M of wind parks we have also made qualitative studies based on case methods (Eisenhardt & Graebner, 2007; Voss et al., 2002; Yin, 2003) where we have interviewed key personnel within the company. The interviewed employees include O&M managers, site managers for wind parks, business controllers, an analyst, a support engineer and service-technicians. In addition, informal conversations have taken place during lunches and observations have been made during meetings and seminars. All the interviews have been carried out as semi-structured interviews (Kvale & Brinkmann, 2009) where the questions have been based on our literature review and on our survey of data. Summaries have been made of each interview and some of the interviews have been confirmed by the interviewed. All interviews have been analysed to identify the different challenges for operation and maintenance of wind turbines installed offshore and onshore.

Furthermore, our survey have included O&M costs per year, production per year and reported errors per year. All data is gathered in relation to the one single type of wind turbine in order to identify if the same error types are faced onshore and offshore. In addition, this makes the comparison of the Cost of Energy more relevant as there is a difference in types and versions of wind turbines.

Findings and Discussion

Cost of Energy – Onshore vs. offshore

The first finding of the research is that in 2012, offshore O&M were 18% more expensive than onshore O&M. This was found by calculating the costs of the three wind parks in the case study and dividing these numbers with the parks total production. In the calculations, the initial investment and O&M costs (i.e. transport, parts, internal and external man hours, etc.) are included. Before 2012, the offshore O&M costs were even higher, as can be seen in Table 2.

Table 2 – Cost of Energy – the difference between onshore and offshore

Year	Onshore	Offshore
2012	100%	118%
2011	100%	128%
2010	100%	131%

Research from 2005 (Massachusetts Technology Collaborative, 2005) suggested that offshore O&M would be 1,5 to 2 times higher than onshore O&M. However, our study illustrates the difference to be lower. This points in the direction that initiatives taken by the operators and manufactures in the industry has been successful, although it is still necessary to bring investments and O&M costs even further down.

The reason why offshore O&M costs at are higher than onshore is, that there is a vast difference between the O&M processes in the two environments. The main reason for the higher installation costs and O&M costs at offshore locations lies in the level of complexity. One aspect of this regards the transportation which at offshore installations is carried out either by helicopter or by boat whereas transportation onshore is simple meaning that service technicians are able to drive to the turbine and access the turbine directly from the ground. At offshore installations technicians, tools and spare parts needs to be transferred from the boat to the foundation of the wind turbine and this process is rather complex as safety has to be regarded at all times. Our findings have also revealed how offshore wind parks are located far from shore, resulting in high waves and high winds and therefore often leading to sea sickness among the involved technicians. By accessing an offshore wind turbine from a helicopter, the technicians need to be either lowered down from the hovering helicopter or the helicopter has to land on the top of the wind turbine. However, our findings have illustrated extreme costs by using helicopters and we have found that not all offshore wind turbines are accessible by helicopter either because a helipad is not always installed or due to heavy weather conditions. In relation to other studies (Breton & Moe, 2009) we have found that due to heavy weather conditions, access to an offshore wind farm is only possible 50-70% of the year.

Failures

The second finding of this research is a better understanding of the actual O&M tasks that are carried out by the wind turbine operators. To attain this understanding, it was necessary to systemise the generated errors from the wind turbines in the three parks. Error reports from the different parks were generated from the energy company's internal system and summed up in errors per year. A lot of noise and faulty alarms (e.g. an error message stating that the turbine was ok) was found. After interviewing service technician it was found that some alarm types were send whenever the turbine was restarted, meaning that it could be excluded from this analysis. A small piece of software was therefore developed to clean out alarms that were not an actual error. After cleaning the data (up to 70% was excluded because it was noise), the software categorised the errors in to a relevant category by searching for keywords. For example the category of errors related to temperature could include the keywords thermo, thermo error, heat and warm. Every error code for the turbine was analysed manually, as some errors could be addressed to several categories. The categorisation of the alarms can be found in Table 3, which shows the occurrences of each alarm group for both the onshore and offshore parks.

Most alarm types do not differ in relation to onshore and offshore installations. However, gear-, controller-, generator- and pitch alarms showed a vast difference between the parks. Gears appear to be much more exposed in the harsh and stochastic offshore environment. Offshore wind speeds are much higher and more constant than onshore, which means that the wind turbines are operating on a higher stress level than their onshore counterparts. At offshore installations this seems to lead to much more wear on gears in relation to onshore installations.

Table 3 – Onshore and offshore occurrences for every alarm group

	Occurrence	
Alarm Group	**Offshore**	**Onshore**
Temperature	20	21
Gear	17	8
Generator	14	19
Others	14	11
Electrical	13	12
Controller	8	1
Pitch	5	22
Breaker	4	2
Hydraulic	3	4
Yaw	1	1
Blades	0	0

Van Horenbeek et al. (2012) found in their study that three major components constitute more than 75% of the total maintenance costs. These components were the gear, the generator and the blades. This corresponds to our findings, as repairing or exchanging gears or the generators were identified to be two of the most frequent errors. The exchange of a gearbox of a generator is a very costly process at offshore installations while a special crane vessel is needed and charters are typically around €135.000 per day to hire. As illustrated in table 3, blade errors do not seem to be of any specific concern but an interview with the responsible manager identified that blade errors do occur and that they constitute a large part of the total O&M spending (up to a third). However, new methods for maintenance and rebuild of blades have recently been improved and now only the leading edge of the blades is repaired. It is important to note that blade errors are not present in table 3 as this kind of error has to be found by visual inspections and not by the monitoring system and thus they are not part of the alarm reports.

Our analysis shows that offshore, alarms regarding the controller are much more frequent than onshore. As our study can be considered as an early study, we have not been able to compare this pattern yet but this will be investigated in our future studies.

Gathering Data from a developing sector

During our study of the challenges of operating and maintaining the wind parks, we identified how difficult it was to gather data concerning failures and costs. The intention was to use data from the full lifetime of the three parks and to compare these data to gain a deep insight. However, it turned out that data from before 2010 was either impossible to locate or showed to be inconsistent. Through our investigation of this instance we identified that data systems had changed several times throughout the lifetime of the wind turbines and every time the data system was changed some data was lost.

Our study has also revealed that there is no real standard for storing data from wind turbines. In addition the OEMs are using different controllers in their turbines and thus data is stored in various formats and with various error codes and related text which makes it difficult to gather and analyse longitudinal data from different wind parks.

In line with other studies (e.g. Utne, 2010) our study has therefore revealed how the offshore wind energy sector is a rather immature field, and further it has identified the need for a more structured focus on data gathering within the wind energy sector. The company has realised this instance and is currently participating in research about data gathering through another research-project. However, in the future the wind energy sector may develop into a more mature field and in this development the wind energy sector could benefit from the ship- and oilrig building industry and their SFI-structure (Erikstad, 2009) or develop a similar structure for design, maintenance and cost structure.

The Need for a Customised Maintenance Concept for Offshore Wind Energy

When focusing on the offshore part of the wind energy sector the general understanding is that the current maintenance strategy needs to change. Currently, the maintenance strategy is mainly focusing on preventive maintenance to prevent failures and when this does not succeed, corrective maintenance is used. Some of the larger operators are going in the direction of more condition-based maintenance; though, this is mainly done in relation to gearboxes by use of vibration analysis. The strategy needs to be shifted even more into this direction, in order to gain substantial savings and more reliable equipment, which in turn give a more reliable production.

In order to back up a new strategy, where the focus is predictive instead of preventive, a new maintenance model or concept for the offshore wind energy sector is needed. Through our study we have briefly investigated two existing maintenance concepts, namely RCM and TPM. Both concepts seem promising, though they are not a perfect match for this type of industry. RCM is a very complex maintenance concept and as a consequence a very expensive concept (Waeyenbergh & Pintelon, 2002), which can be difficult to introduce in a rather immature field like the offshore wind energy sector.

The other maintenance concept studied is TPM. Actually, TPM is not only a maintenance concept, but goes much further. As a maintenance concept, TPM seems to be incomplete since it does not provide clear guidelines or rules that decides which basic maintenance policy should be used (Waeyenbergh & Pintelon, 2002). In some occasions, TPM is regarded more like a management strategy than a maintenance concept. Thus, a further development of TPM seems needed to be adapted to the settings that are present in offshore wind parks.

More maintenance concepts can be found, but they can be difficult to transfer directly to the harsh and stochastic environment where offshore wind parks are located. This means that a new maintenance model for offshore wind parks needs to be customised to work in the stochastic environment, where planning and re-planning needs to be done all the time, because the heavy weather conditions are having a huge impact on the planning and execution of offshore O&M (e.g. Byon, 2010; Orosa, Oliveira, & Costa, 2010; Tracht & Seuguep, 2011). However, studies of how to handle planning and execution of wind energy maintenance at rough offshore sites seems to be lacking in existing literature. Hofmann (2011) has made a comparative literature study of existing life cycle analyses of offshore wind parks, and found that the majority of these analyses do not include a maintenance aspect in their calculations. This fact clearly indicates a lack of focus on maintenance in the offshore wind energy sector, which opens up for further research in this area.

Conclusion and Implications

In this study we have compared a large offshore wind park with two smaller onshore wind parks. The comparison showed that the offshore wind turbines are operating in a much harsher and more stochastic environment, resulting in a much higher load on the turbines. Together with the logistical and environmental complexity of accessing the offshore wind turbines, the costs for operating and maintaining these are very high. Our studies have shown that even though the prices for offshore O&M are high compared to onshore O&M, it seems that the difference is decreasing (from 31% higher in 2010 to 18% higher in 2012). Furthermore our study has identified a need for much more focus on a systemisation and structuring of data from alarms, malfunctions and breakdowns from offshore wind turbines to have a solid foundation for maintenance planning within the offshore wind energy sector.

In this paper we have also investigated the two maintenance concepts, RCM and TPM, but our study point in the direction that a direct implementation of either of them would not be beneficial in this rather immature field. Instead, a more customised concept should be developed that exploits the predictive maintenance strategy together with the preventive instead of the current preventive/corrective strategy.

Our study shall be regarded as an early study in the field of O&M of offshore wind energy and we have limited our study to three wind parks and only one single type of wind turbine. However, we have access to much more data and in future studies we will go much deeper in our investigations and development of maintenance models for planning and execution of maintenance in the offshore wind energy sector at very rough sea conditions.

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