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A Proposed Maintenance Strategy for a Wind Turbine Gearbox Using Condition Monitoring Techniques

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Abstract: Renewable energy sources such as wind are available without limitations, but reliability is critical if pay back periods and power generation requirements are to be met. With recent developments in the field of wind engineering, in particular the expansion of installed capacity globally, the need for reliable and intelligent diagnostic tools is increasingly important. The number of offshore wind turbines installed around the UK coast is likely to increase from just fewer than 150 to 7,500 over the next ten years at a

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potential cost of £10 billion. Operation and Maintenance activities are estimated to be 35% of the cost of electricity. However, the wind industry is lagging behind in the development of appropriate and efficient maintenance strategies. The current reliability and failure modes of offshore wind turbines are known and have been used to develop preventive and corrective maintenance strategies but these have done little to improve reliability. In addition, the failure of one minor component can cause escalated damage to a major component, which can increase repair and/or replacement costs. Unplanned maintenance levels can be reduced by increasing the reliability of key components. One such component is the gearbox and its individual subcomponent gears. Through the analysis of gear lubricants, it is possible to detect early signs of failure and determine potential mean time to failure, in addition to developing correct maintenance tasks.

A Reliability Centred Maintenance (RCM) approach offers considerable benefit to the management of wind turbine operation, as it includes an appreciation of the impact of faults on operation. Given the high cost of performing maintenance and the even higher cost associated with failures and subsequent downtime and repair, it is critical to consider the impacts when maintenance is planned. Condition Based Maintenance (CBM) is becoming more wide-spread in wind turbine maintenance. The factors driving an increased use of CBM include the need for reduced maintenance and logistics costs, improved equipment availability, and protection against failure of critical equipment. A complete condition monitoring system comprises a number of functional capabilities, including sensing and data acquisition, signal processing, condition and health assessment, prognostics, and decision aiding.

This paper provides an overview of the application of RCM and condition monitoring tools and techniques, to support the development of a maintenance strategy for offshore wind turbine maintenance management. It discusses the development of a complete sensor-based processing unit that can continuously monitor the wind turbines' lubricated systems and provide, via wireless technology, real time data enabling onshore staff to predict degradation, anticipate problems and take remedial action before damage and failure occur.

Keywords: Reliability Centred Maintenance, Wind Turbines Gearboxes, Oil Analysis

1 Introduction

Wind power is an increasingly important source of energy for countries aiming to reduce the emission of greenhouse gases and mitigate the effects of global warming. Accordingly, the wind power industry has experienced rapid growth, with offshore wind farms promising to become a particularly important source of energy in the near future [Bilgili 2011]. GWEC [2012] estimates the cumulative wind power capacity could reach 587 GW by 2020, and 918 GW by 2030. Another scenario predicts growth will continue throughout the 2020s, with annual market size approaching 100 GW per year and a total installed capacity of about 1,600 GW by 2030. In addition, the regional projection of wind power generation around the world seems encouraging (Figure 1).

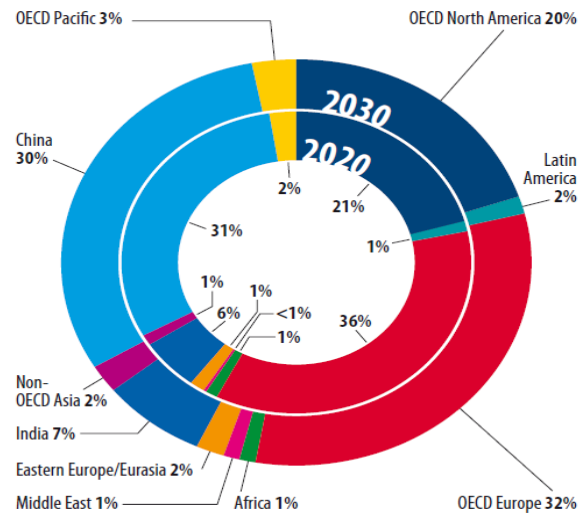


Figure 1 Regional projection of wind power around the world [GWEC 2012]

Modern wind turbines are designed to work for approximately 100000 hours throughout an estimated life-span of 20 years. This means a turbine will operate approximately 66% of the time for two decades [Botsaris 2010, Puigcorbe 2010]. Every machine has a set lifetime based on how long the parts are expected to last. Generally, a moving part, especially an exposed part i.e. gearbox, will wear faster. Onshore turbine gearbox failure rates are in the range of 1.5 to 4 per year while offshore turbines can need approximately 5 service/repair visits per year [Botsaris 2010, Puigcorbe

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2010]. The harsh offshore conditions not only make the access to sites difficult but also significantly increase operation and maintenance costs.

Available data show operation and maintenance costs are usually in the range of 25-30% of the kWh cost for offshore wind turbines and 10%-15% for onshore wind turbines [Rademakers 2003]. Having suitably trained personnel visit turbine installations is a costly enterprise, especially when large and heavy parts need to be replaced. Such problems are exacerbated in offshore installations. Operational costs can be significantly reduced by developing an appropriate asset management strategy using one or a number of modern maintenance technologies. Recent research has examined both modern maintenance technologies and condition based maintenance tools and systems [Márquez 2015, Wang 2012, Carter 2011]. For improved maintenance management and increased reliability, Reliability Centred Maintenance (RCM) and Condition Monitoring (CM) techniques should be combined.

RCM has been recognised as an essential part of world-class maintenance [Mishra 2014]. RCM takes a structured approach to determining the appropriate maintenance tasks and requirements of assets in specific operating contexts. This makes RCM particularly effective for identifying the maintenance requirements of equipment in unique and demanding environments [Baglee 2006], such as offshore wind turbines. With RCM, there is a reduced need for installation accessibility, fewer failure events, less installation downtime and the retention of power output until the next maintenance visit.

Condition monitoring (CM) systems cover a range of functions, from data collection to the recommendation of specific maintenance actions. Key functions include:

- Sensing and data acquisition
- Signal processing and feature extraction
- Production of alarms or alerts
- Failure or fault diagnosis and health assessment
- Prognostics: projection of health profiles to future health or estimation of RUL (remaining useful life)
- Decision making: assist in maintenance recommendations or evaluation of asset readiness for a particular operational scenario

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The combined use of RCM and CM for equipment maintenance is not widespread for wind turbines because of the difficulties in data transfer associated with their remote locations. Further, it becomes nearly impossible to deal with cases where, during the occurrence of a fault, there is no possible economical way of accessing the site. It is, however, a crucial aspect in ensuring environmentally and financially expensive maintenance visits are performed to maximum benefit and occur only when necessary. Maintenance of offshore wind turbines for generating electricity is always complex, given site inaccessibility, exposure to adverse weather conditions, transportation difficulties, and lack of maintenance records. The costs and logistical implications of visiting turbines means decision making and planning of maintenance activities are critical for economic viability; the goal is to reduce sudden, unscheduled visits of service engineers, as this greatly affects maintenance costs.

In this paper, we propose the identification of critical equipment using RCM and the analysis of data gathered from sensors can be used to develop a structured maintenance methodology to provide optimal cost savings, looking specifically at wind turbines. The paper provides a brief overview of the technologies involved in wind turbines, notes some reliability issues related to the various components and suggests new approaches to wind turbine maintenance using RCM and CM maintenance solutions.

1.1 Wind Turbine Technology

The drive to reduce costs has led to rapid increases in turbine size, as small turbines are less economical in terms of land usage, maintenance requirements and installed capacity (Figure 2). The link between average production cost and turbine size is indicated in Figure 3. Large-scale systems use asynchronous machines to generate electrical power, with a gearbox used to match the rotational speed of the machine to the frequency required by the power grid. Smaller domestic and commercial installations convert the generated alternating current to direct current before using an inverter to produce AC at the required frequency. The mechanical components are common bearings and gearing systems.

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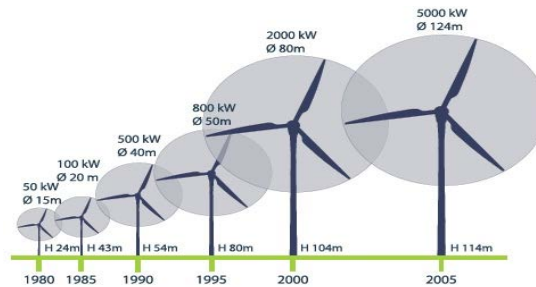


Figure 2 Trend in increased wind turbine size (Source [Botsaris 2010])

Various types of generators are used in wind turbines, but a major problem across the industry is the reliability of the gearbox. The majority of turbines currently in operation use indirect drive where the turbine is coupled to the generator via a gearbox (Figure 4). A gearbox permits the use of a high speed generator; in general, this is more cost effective in terms of manufacturing [Polinder 2006]. By way of contrast, direct drive systems involve low speed electrical machines which are more expensive to produce but offer greater overall system availability because there is no gearbox. Wind turbines do not have a direct drive configuration and, thus, require a gearbox. The design of wind turbine gearboxes is based on well-developed and mature technologies involving gears, shafts and bearings.

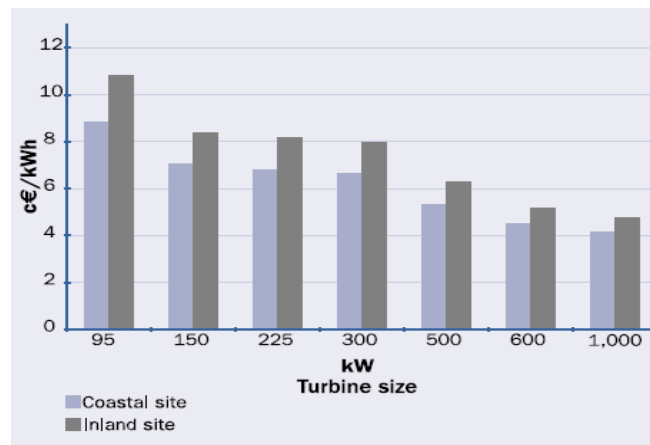


Figure 3. Overall cost of generation for different turbine sizes [Poley 2012]

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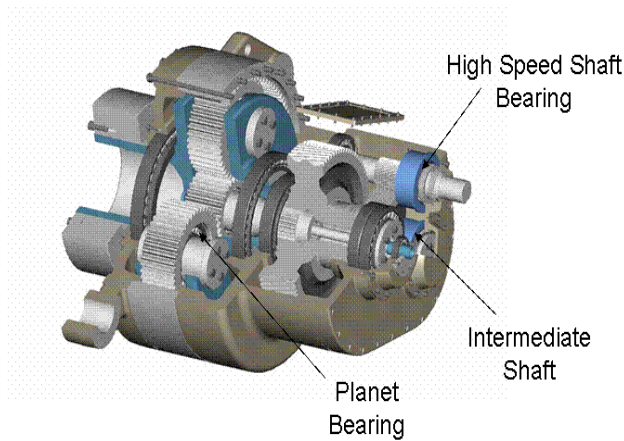


Figure 4 Typical gearbox components [Puigcorbe 2010]

Turbine gearboxes are quite large and can cost in the region of \$250,000 [Barber 2010]. A number of studies have examined the failure rates and criticality of the various gearbox components, as a major source of wind turbine downtime is the gearbox [Fischer 2012], Puigcorbe 2010, Tavner 2006, Tavner 2007]. However, developing a cost-effective strategy to mitigate gearbox failures remains difficult because of variable failure rates and a lack of accepted benchmarks [McMillan 2008a, McMillan 2008b].

Gearboxes are considered a mature technology; therefore, improving design reliability is viewed as difficult. This means detecting faults before they lead to a failure and taking steps to mitigate them is crucial. Despite their technological maturity, gearboxes continue to be a major issue because of the costs involved in repairs and the reduced lifespan of 7-11 years for a gearbox compared to a design life of 20 years for a turbine as a whole [Puigcorbe 2010]. The gearbox is one of the most expensive components of the wind turbine system, and the higher than expected failure rates are increasing the cost of wind energy. In short, a new approach to the gearbox must be developed to increase gearbox reliability and reduce the cost of wind energy.

2. RCM to Determine Critical Equipment

Reliability Centred Maintenance (RCM) is a method for determining the maintenance needs of a particular asset, asset component and asset sub-component. RCM can be applied in many different industries to achieve multiple objectives, including improved operating performance, cost-

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effectiveness and safety [Márquez 2015, Belak 2013, Yuan 2012, Wang 2012, Carter 2011]. RCM allows the maintenance ‘team’ to identify the critical components, their function and failure modes; this, in turn, permits the team to identify failure patterns and possible maintenance tasks to maintain operation. Fischer [2012] recently used RCM to determine the critical equipment of wind turbines. The focus of RCM is on maintaining system function rather than restoring equipment to an ideal condition, and according to Daya [2000], RCM is characterised by the following features:

- Greater safety and environmental protection, because of improved maintenance;
- Improved operating performance, because of more emphasis on the maintenance requirements of critical components;
- Greater maintenance cost-effectiveness, because of less unnecessary maintenance;
- A comprehensive maintenance database, which reduces the effects of staff turnover with its attendant loss of experience and expertise.

Condition monitoring techniques permit those critical components identified through RCM analysis to be monitored for changes in condition. Continuous monitoring using sensors, often wireless, allows early detection of abnormalities; with such detection, corrective tasks can be introduced to the maintenance strategy. Modern condition monitoring techniques, using, for example, real-time data, have been discussed in recent literature [Yuan 2012, Wang 2012]. A number of techniques can be used to monitor the condition of a particular component, such as simulation based diagnostics, vibration analysis, computational fluid dynamics (CFD), Oil analysis, Thermography, Strain measurement, Acoustic measurements, Electrical effects, Visual inspection, Performance monitoring, Self-diagnostic sensors. Incorrect data collection ‘architecture’ may limit the flexibility and performance of system implementation if it does not take data flow requirements into account. To support the full range of CM data flow requirements, the architecture should support both time-based and event-based data reporting and processing. Time-based data reporting can be further categorised as periodic. An event-based approach supports data reporting and processing based upon the occurrence of events (limits exceeded, state changes, etc.). It is important to understand, develop and implement the correct system for the collection and analysis of data to suit the particular environment and operating parameters.

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A condition monitoring technique critical for determining the state of health of a key component of a wind turbine, the gearbox, is oil analysis. This technique can isolate the following three basic conditions related to the gearbox's lubrication or lubrication system [Baglee 2006, Barber 2010, and McMillan 2008a]:

1. Ability of current condition to lubricate as designed: Testing is performed to determine lubricant viscosity, acidity, etc., as along with other chemical analysis to quantify the condition of oil additives like corrosion inhibitors.
2. Condition of lubrication system condition (i.e., have any physical boundaries been violated causing lubricant contamination?): Lubrication system integrity can be evaluated by testing for water content, silicon, or other contaminants (depending on the system design).
3. Gearbox condition: Machine wear can be evaluated and quantified by analysing wear particles in the lubricant.

For wind turbines, oil analysis is typically applied to the gearbox with the objective [Sheng 2011] of detecting oil contamination and degradation. Contamination can be caused by dirt, wear debris, water, incorrect oil etc. Degradation can result from depletion of additives, oxidation, base stock breakdown, and so on. Oil analysis is a significant factor in attaining maximum service life for wind turbine gearboxes [Graf 2009]. In addition to system degradation, oil analysis performed and trended over time can provide indication of improperly performed maintenance or operational practices. The arrival of dependable, effective online sensors has changed oil analysis, leading to a three -tiered system of oil analysis, Online, Onsite, Offsite, each with its own advantages [EWEA 2009]. A system able to measure the chemical composition of oil continuously and send data via wireless sensors to a central 'server' would help reduce unplanned stoppages which could be extensive, costly and, in severe cases, have an impact on the environment.

2.1 Application of Oil Analysis

To monitor the overall condition of an engine, the analysis of the lubricating oil is vitally important. Degradation of the oil's performance can lead to rapid deterioration in engine lubrication and cause mechanical wear, chemical corrosion and overheating [Baglee 2010]. The lubricating oil can also act as a condition indicator of other aspects of operation. For example,

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monitoring the presence of wear particles and their characteristics, contaminant levels and soot levels can indicate a variety of problems, such as bearing degradation.

Monitoring lubricant oil condition is currently achieved in two ways:

- Samples are drawn off and checked using portable equipment and test kits. This allows many parameters to be measured but has the drawback of requiring manual sample taking and checking in the hostile environment of an offshore wind turbine. Furthermore, great care is required to ensure samples are handled correctly and not contaminated between the time they are drawn off and the time they are tested to ensure that an accurate assessment is made.
- Samples are drawn off and dispatched for onshore laboratory assessment. This allows much more extensive analysis using high precision instruments. However, in addition to the need to take samples and correctly handle them, there is a substantial time delay because of the need to send samples to the laboratory. The process has been accelerated by new technologies such as email, but any delay can lead to further degradation before the fault is isolated and attended to.

Clearly, both approaches are flawed. The Progressive Oil Sensor System for Extended Identification On-Line (Posseidon) project aims to address these flaws by developing an online oil condition monitoring system which will allow oil to be analysed while still in service. This has the following advantages:

- The need for operator intervention in the sample preparation process is removed.
- The possibility of sample contamination is reduced.
- There is no delay in obtaining results so further fault development can be limited.

Automated, remote monitoring and analysis has become an area of interest for marine and offshore wind turbines [Knowles 2010, Baldwin 2010]. Oil analysis involves a variety of measurements which can detect a wide range of fault modes. Table 1 shows a number (not exhaustive) of oil analysis tests and their significance.

The principal application of this type of monitoring in a gearbox is the detection of wear particles. In addition to providing an early warning of

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failure, automated measurement of wear particles conveys the need for the replacement of lubricant before further damage is caused. In recent years, a variety of systems has been developed for counting and characterising wear particles optically [Gorritxategi 2006]. Such analysis provides a wealth of raw data. To ensure maximum benefit, however, it is necessary to condense and interpret the data to provide operatives with appropriate diagnostic information and guidance on corrective actions.

Table 1. Selection of oil analysis techniques

Test Type	Significance
Particle Count	Measures the size and quantity of particles in a lubricant. <u>Significance:</u> Oil cleanliness and performance.
ICP Spectroscopy	Measures the concentration of wear metals, contaminant metals, and additive metals in a lubricant. <u>Significance:</u> Measures and quantifies the elements associated with wear, contamination, and additives.
Karl Fischer Test	Quantifies the amount of water in the lubricant. <u>Significance:</u> Water seriously damages the lubricating properties of oil and promotes component corrosion. Increased water concentrations indicate possible condensation, coolant leaks.
Viscosity Test	Measures a lubricant's resistance to flow at a specific temperature. <u>Significance:</u> Viscosity determination provides a specific number to compare to the recommended oil in service.
FT-IR Spectroscopy	Measures the chemical composition of a lubricant. <u>Significance:</u> Molecular analysis of lubricants and hydraulic fluids by FT-IR spectroscopy produces direct information on molecular species of interest, including additives, fluid breakdown products, and external contamination.

CM techniques require data fusion and techniques which can measure and display the oil properties, as well as indicating faults and suggesting the appropriate planning and scheduling of maintenance. Data transmission is a key issue in the installation of remote wind turbines. The selected standards and protocols must ensure data are securely and reliably

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transmitted and can be verified upon reception. Distributed system architecture can be a better option for remote locations. This architecture consists of a collection of independent computers connected through a network, thereby enabling users to experience a single integrated system instead of several independent systems. Distributed systems have higher reliability than centralised systems as data are stored in number of machines; in conditions of failure, only one element will be lost, leaving the rest intact.

In critical systems, a distributed system could be a better choice from a reliability perspective. The microprocessors in distributed systems have better performance, price and computation power than mainframe centralised systems. The distributed system architecture allows continuous access to data, alarms, alerts and history across a cluster of systems. It is worth mentioning that a distributed architecture system offers the best solution for multiple units or distributed locations, such as offshore wind turbines. In situations with changing users and application demands, the distributed system architecture can vigorously regulate the changes. Thus, it is exceptionally effective when used in a network, allowing even low bandwidth networking possibilities. Furthermore, maintenance personnel need to have access to data and documentation when working in remote environments where data connectivity may be limited.

It is necessary to engage with industry experts and maintenance personnel to ensure the design of data presentation is optimal and tailored to the requirements of the industry. A number of questions require attention before condition monitoring solutions become a viable reality:

- Which oil condition parameters allow detection and diagnosis of likely failure modes?
- How frequently must data be transmitted?
- How can condition monitoring limits be managed to optimise maintenance patterns?
- How can data security and integrity be managed?
- How can data best be presented to the appropriate personnel?

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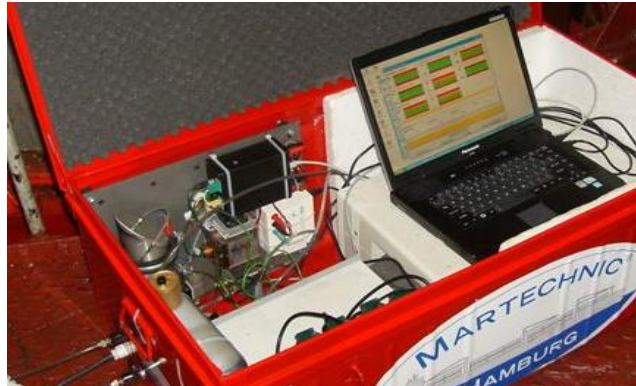


Figure 5. Poseidon Sensor Unit

2.2 Proposed Test System

To investigate these and other important questions, a test setup has been devised at the University of Sunderland. It builds on the work of the Progressive Oil Sensor System with extended Identification On-Line (Poseidon) [Knowles 2010, Gorritxategi 2007]. The Poseidon Sensor Unit (Figure 5) addresses the flaws inherent in current oil analysis practice by developing an online oil condition monitoring system which allows oil to be analysed while still in service.

In the proposed system, four sensors collect parameter data from the lubricant oil. These sensors have been developed specifically to measure the desired parameters in lubricating oil and are listed in Table 2.

Table 2. Sensors and measurements

Sensor	Output	Measurement Technology
IR sensor	Water concentration	Optical Infra-Red Spectroscopy
	Soot concentration	
	TBN	
Viscosity sensor	Viscosity	Vibrating Pin
FTIR sensor	TBN	Infra-Red Spectroscopy
	Water content	
	Insoluble content	
Optical Particle detector	Particles	Image processing to characterise particle shape and size

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A Bayesian Network [Knowles 2010] is used to make the diagnosis. Many practical tasks can be reduced to classification, including fault diagnosis. Bayesian Networks have many desirable properties which, when applied to classification, help overcome problems of other methods. These properties include:

- Ability to mix previous knowledge with data/experimental knowledge;
- Explanatory abilities;
- Ability to deal with uncertainty and causality management;
- Ability to learn both parametric and structural attributes of the classification problem.

For data display, we envisage a robust unit with an easy to read and changeable (to suit application) industrial display (Figure 6), featuring a minimum of controls and intelligently laid out user interfaces designed in conjunction with industry to provide a suitable means for presenting data.



Figure 6. Industrial display unit

To ensure representative usage is applied to the gearbox under test, it is turned by a motor with a power spectrum which represents the speed of the wind in a realistic fashion, such as the Van der Hoven spectrum (Figure 7) used by Neammanee [2007] and Nichita [2002].

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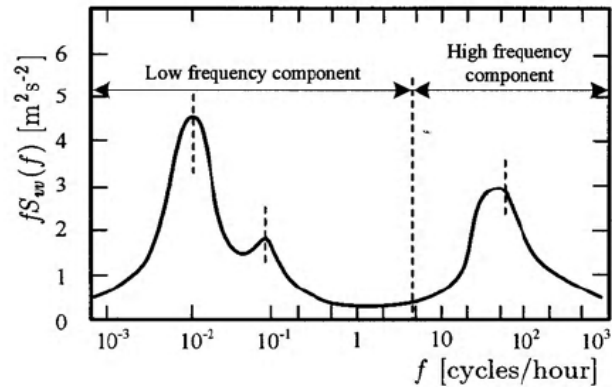


Figure 7. Van der Hoven Power Spectrum of wind speed

The load placed on the output of the gearbox is dependent on the generator and the characteristics of the electrical grid to which it is connected. This can be modelled and has formed the basis of other test systems [Moore 2010, Wu2010, Hong 2009]. In order to supply such a load to the gearbox under test a dynamometer can be used, as illustrated in Figure 8.

Once data are collected, a new maintenance strategy can be developed by combining up-to-date data and productivity measures such as availability and uptime. This can further be used to support decision making based on the RCM framework described previously.

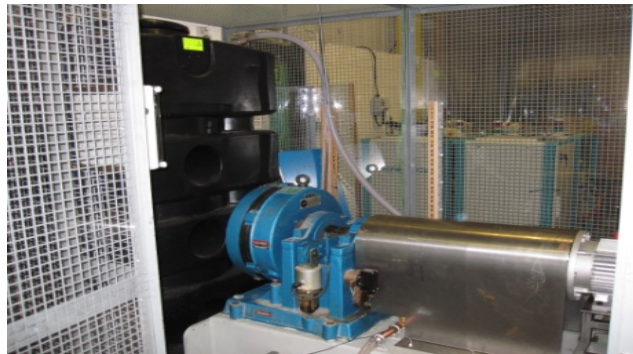


Figure 8. Dynamometer for gearbox load testing

3. Cost Benefits of Using the System

With data collected by the proposed online oil condition monitoring system, we can develop a cost effective maintenance strategy and reduce the high

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maintenance costs typical in offshore wind turbines. Operation and maintenance costs for wind turbines include the costs of scheduled and unscheduled maintenance. The unscheduled maintenance costs turn out to be surprisingly high, as much as 75% of the total wind turbine maintenance costs [Barber 2010]. Unscheduled costs may comprise repair costs, replacement costs, subsequent downtime costs, and other costs such as logistics costs. These can skyrocket if a major component breaks down, making it vital to minimise the cost of failure. The key is to increase reliability and, thus, to ensure availability. Availability has a significant impact on production or revenue losses [Scheu 2012]. Modern condition monitoring techniques are often considered the way to improve reliability. Condition based maintenance, i.e. predictive maintenance, is said to have remarkable cost benefits over corrective and preventive maintenance [Barber 2010, El-Thalji 2012, and Wiggelinkhuizen 2007]. A condition monitoring system can help to minimise unscheduled maintenance costs; it will help create a better maintenance strategy, leading to fewer unplanned visits.

Barber & Golbeck [Barber 2010] use a case example to explain the costs that can be avoided by using modern condition monitoring techniques. In their worst case scenario, a minor component causes a gearbox failure. The costs and possible savings are gathered in Table 3. A new gearbox incurs a huge cost, but crane rental and revenue loss due to subsequent downtime (revenue loss = downtime*electricity price) also have a major impact on total cost. If an oil condition monitoring system is not in use and a gear causes a gearbox failure, the results are similar. Table 3 compares costs between the worst case scenario, where a gearbox fails and extra delay is caused by inadequate maintenance planning, and the best case scenario, where an online oil condition monitoring system is used and the fault is caught and overhauled in time. As the table shows, costs are not only caused by spare parts and repair actions; in fact, a remarkable amount is caused by revenue losses due to downtime. Unplanned downtime is composed of (1) identification time, (2) time for maintenance planning, (3) time for service, (4) time for accessibility, and (5) time for maintenance (repair or replace) [El-Thalji 2009]. For offshore wind turbines, the accessibility of a turbine in the case of failure is another aspect affecting downtime [Scheu 2012]. However, the use of RCM and the proposed online oil monitoring system can minimise the total downtime and reduce costs.

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When the oil condition is monitored online, several costs can be avoided. In traditional lubricating oil condition monitoring techniques, sample contamination and time delay are critical flaws, as previously mentioned (2.1). In the proposed online method, the costs related to sampling (to access offshore turbines and work on them) and the costs of contamination if a new sample is needed can both be avoided. Arguably, the most critical cause of increased cost is a time delay. For example, a minor component may cause the failure of a major component, such as a gearbox. The ensuing time delay may result in greatly increased expenditures, including repair costs, replacement costs, and revenue loss caused by downtime. It is vital to reduce major component failures as they greatly affect the total maintenance costs. All these costs can be reduced by using the proposed online oil condition monitoring system.

Table 3. Comparison of gearbox failure costs (Adapted [Barber 2010])

	Gearbox failure costs	Costs if using online oil condition monitoring	Cost benefits/savings
Repair and replacement costs	A new gearbox and work cost \$250,000	Gearbox bearing, main shaft and work cost \$30,000	\$220,000
Revenue loss caused subsequent downtime	\$26,000	\$2,000	\$24,000
Other costs	Crane \$150,000	Crane \$75,000	\$75,000
Total	\$426,000	\$107,000	\$319,000

As Table 3 shows, significant costs savings, as much as \$319,000, can be achieved through the use of an online oil condition monitoring system. Unplanned corrective maintenance costs could be reduced significantly by using accurate real-time data, as this would allow maintenance personnel to schedule maintenance based on condition. Collected data can also help to adjust scheduled maintenance intervals to strike an optimum balance

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between the cost of maintenance and the cost of unscheduled repairs [Milborrow 2010]. Because modern condition based maintenance techniques improve reliability, their use in the wind energy sector can ensure wind turbines reach their expected lifetime. More specifically, the system proposed here can prevent gearbox failures and limit unscheduled maintenance visits which are costly, especially for offshore wind turbines.

4. Conclusions

Wind turbine maintenance is predominantly a combination of time-based tasks, undertaken at predetermined and regular intervals, and failure-based tasks which can be costly and have an impact on other components. Little attention is paid to whether these maintenance strategies or their tasks are appropriate, cost effective and necessary, making it important to develop a complete maintenance strategy using modern maintenance practices. The paper suggests combining Reliability-Centred Maintenance (RCM) techniques with Condition Based Maintenance (CBM). The former is a technique used to select appropriate maintenance strategies for physical assets, to identify possible failure modes, and to determine failure causes and effects on system operation. With this knowledge, the correct Condition Based Maintenance activities can be identified and applied to complement the technology and maximise the return on investment.

The strength of RCM is its systematic approach to consider all system functions, and set up appropriate maintenance task for these functions. A major advantage of the RCM methodology is a structured, and traceable approach to determine type of preventive maintenance. This is achieved through an explicit consideration of failure modes and failure causes. A major challenge in an RCM analysis is to limit the scope of the analysis so that it is possible to carry out the analysis within the limits of time and budget. Most implementations of RCM put main focus on the identification of maintenance tasks, but do not carry out explicit optimization of maintenance intervals. Although RCM cannot be claimed to be an approach for maintenance optimization, it may form the basis for maintenance optimization.

For most of the components within wind turbines a large number of condition monitoring techniques exist. Therefore condition based maintenance is a mix of logic maintenance intervals as a consequence of risk assessment by RCM together with expert knowledge on the basis of the selected CM technology. However the failures are so seldom in wind energy

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that a data driven approach is not an option and lab test must be performed in order to validate the technologies selected even creating syntetic data sets for further real use in the field.

This paper introduces the development of an oil analysis system which, once fully tested in (1) laboratory conditions and (2) installed in an offshore wind turbine, will show that gearbox oil analysis using a range of oil sensors provides accurate data in real time using the latest technologies. Use of the system will indicate the optimal maintenance strategy to minimise costs and unnecessary downtime. It will lead to improved fault detection and better scheduling of maintenance, allowing repair activities to take place when maintenance is required.

In summary, RCM way of thinking leads towards a reduction of the components and subsystems monitored in complex assets for further maintenance planning and scheduling. This reduction identifies the components which may kill the capacity of the system or compromise vital functions. Moreover condition monitoring techniques, like oil analysis are suitable since they are especially tailored for these components where the degradation knowledge relies on well-known physics and big amount of acquired data is not a must. This combination allows the user to design a rational maintenance opening windows just when needed based on real remaining life.

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