Condition Monitoring based Maintenance Strategies for Operating Offshore Wind Farms

Heiko Hinrichs, *Projekt GmbH*

Abstract--**With onshore turbines becoming rapidly bigger, producing energy in the multiple mega watt class, the problem with the mechanical drive train has become more and more severe. With new sophisticated control concepts and using power electronics to allow a wide range of rotation speeds and therefore an adaptation to a wide range of wind conditions also the electronic components show expensive failures including burnout.**

Costs are caused by the repair itself and the resulting down time. In the case of offshore wind farms the latter can be much more dominating than onshore. This is caused by the limited access due to adverse sea and weather conditions. Therefore predictive monitoring systems are preferable for both mechanical and electrical components. For the drive train such systems have been in use for several years. In Germany this was mainly driven by the insurance companies, especially by the Allianz [4], which in 2002 came up with the so-called 'Revision Clauses' for turbines without monitoring of the mechanical components. Meanwhile there is a lot of experience existing from successful use of monitoring systems but we are still far away from predicting the time span left until a total breakdown will occur [6,7,10]. In the case of offshore wind turbines this might not be of such an importance because the first indication of a defect will cause an exchange of the component in question at the next possible maintenance interval. Additional unplanned repairs will add extremely high costs to the maintenance budget and therefore have to be avoided.

The discussion will give some detailed examples for successful drive train monitoring and repair strategies for onshore wind turbines. The consequences for offshore wind farming will be shown. A comparison of the costs caused by different strategies on failures on both on- and offshore wind turbines will illustrate the significance of the kind of maintenance concept for the economical success of an offshore wind farm.

Index Terms--bearing failure, drive train monitoring, condition monitoring, gearbox, generator, offshore wind farm, maintenance strategy.

I. Introduction

As a starting point for developing a maintenance concept for offshore wind farms a closer look at the onshore wind farms will be useful. Figure 1 shows statistical data on down time causes for different sizes of turbines. At first glance one can identify three major problems: gearbox failures, generator defects and, in case of the mega watt class turbines, electrical problems. The electrical mal functions arise with the introduction of rectifiers in use with variable speed generators.

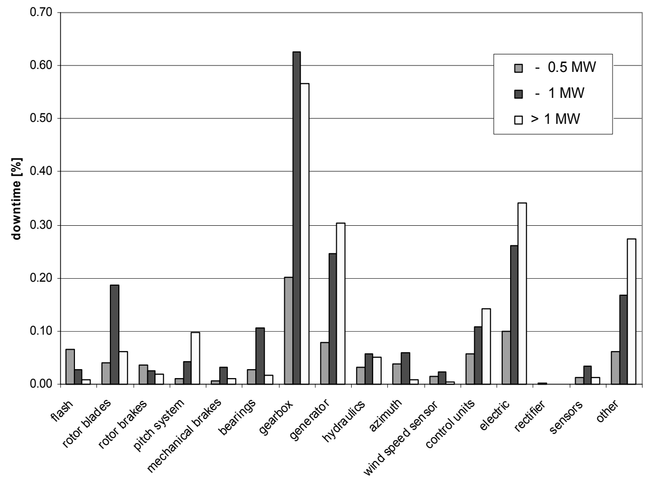

Fig.1: *Main causes for turbine down time are gearbox, generator and electrical failures. The probability of an unexpected defect rises with growing nominal load.*

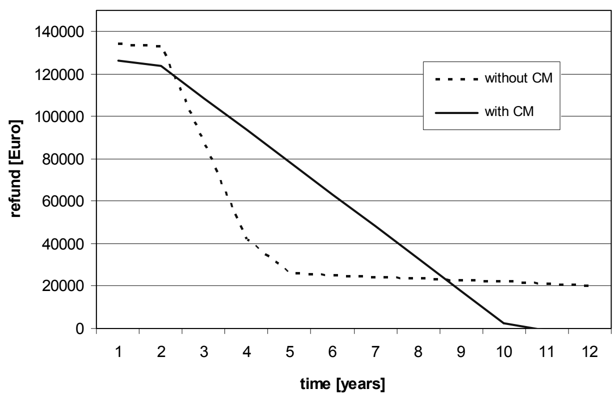

Fig.2: *Effect on the refund in case of applying the Allianz 'Revision Clauses' and the alternative when using a drive train monitoring: A gearbox exchange is expected with a total cost of 140,000€. The costs of a monitoring system (10,000€) and service costs for evaluation on a yearly base (1,200€) are included in the estimate.*

H. Hinrichs is with Projekt GmbH, D-26129 Oldenburg, Marie-Curie-Str. 1 (e-mail: h.hinrichs@projekt-gmbh.de)

Regarding maintenance concepts there can be identified three major approaches. The simplest strategy called reactive is running a machine or a machine element until it breaks down. This can be useful in cases where spare part and repair costs are low and secondary damages can be excluded. Preventative maintenance is scheduled on a regular time basis. This can lead to many unnecessary checks and higher costs. Both concepts are not useful for offshore wind farm services due to the limited access caused by rough sea and foul weather. This can lead to unacceptable long down times.

Predictive maintenance is scheduled when the status of a measured parameter shows anomalies. Such a concept has been used for long in other branches of industry. In wind farming the introduction of predictive maintenance was forced by the insurance companies and is still applied to the drive train only. Techniques for monitoring electric components, the rotor blades and secondary aggregates are available but not in use for economic reasons [8]. Not even fire protection is installed onshore.

A fourth concept called proactive maintenance is not only based on monitoring but on removing the root causes of failures. For large numbers of equal turbines this will be the best concept in the long run. But the analysis of the turbine failures is difficult, time consuming and therefore costly. In most cases the wind farm operator resources will not allow to follow this approach.

II. Condition Monitoring

A condition monitoring system (CMS) for analyzing a drive train in a wind turbine should achieve the requirements appointed by the Allianz [4]. Using a certified CMS is a precondition to obtain an insurance contract that avoids the 'Revision Clauses'. The clause is based on the preventative maintenance concept and enforces the exchange of expensive components like the main bearings, the gearbox and the generator after 5 years of operation. The insurance companies came up with this new clause in 2002 when the claims reached a new maximum in the same year. To avoid the clause a CMS has to check the mentioned machine elements on a daily base. The type of sensor, the minimum number of sensors and the methods to be used are defined. A similar catalog of requirements has been established by the German Lloyd [5].

Figure 3 shows the principle setup. Bearings in gearboxes are difficult to monitor because the gear mesh frequencies and noise from pumps and other sources often hide the defect frequencies of a bearing. The envelope analysis [9] uses resonances of the gear box housing to be excited by pulses caused by passing a defect on the inner or outer race by a roller bearing. The resonance is typically far away from the low frequency noise sources and is periodically exited by the characteristic defect frequency. A demodulation process reveals this frequency. If the rollers pass a defect on the inner race the load will vary during one rotation of the shaft. This causes an amplitude modulation of the pulses with the rotation speed of the shaft and allows distinguishing between defects on the inner and outer race of a bearing.

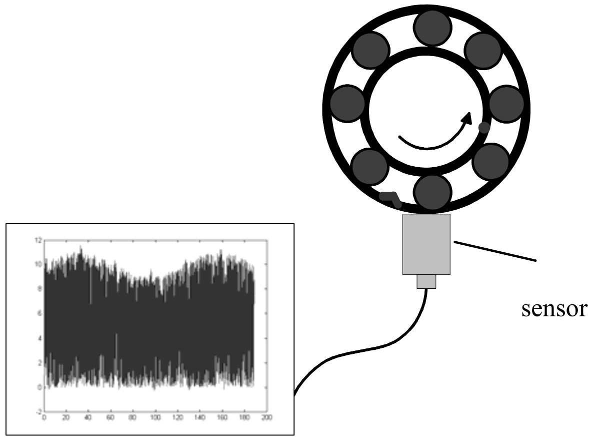

Fig.3: *Setup to monitor a bearing: An acceleration sensor provides a time signal. The signal is analyzed by a signal processor in the nacelle to reduce the amount of data to be sent for detailed analysis to the operators control centre.*

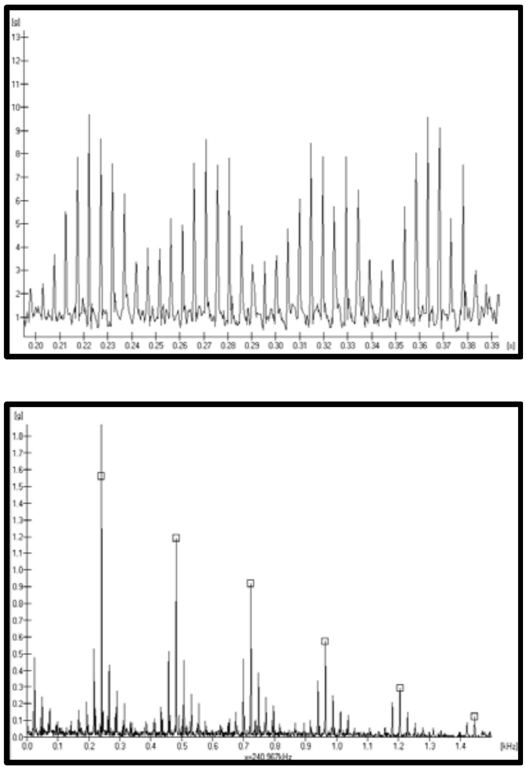

Fig.4: *The upper diagram shows the time signal obtained with an envelope analysis, a highly sensitive algorithm to detect bearing defects. The lower diagram shows the spectrum of the upper signal. A characteristic frequency with harmonics and side lobes form the typical pattern of a defect on the inner race. The difference in frequency between the side lobes is identical with the rotation speed of the shaft.*

Figure 4 shows the time signal of a bearing defect detected by a CMS. The modulation with rotation frequency of the shaft can be observed. The lower part of the diagram shows the corresponding spectrum. The photos made during repair are shown in figure 5.

Fig.5: *On the inner race the expected defects are visible. The repair was carried out in early May. Three month in advance the problem was detected in an early state. The conclusions allowed shifting of the repair into a low wind period.*

The vibration measurements are repeated several times each day triggered by the turbine load and the rotation speed. The amplitudes of the characteristic defect frequencies are used to derive trend information. For the shown example the trend is calculated by two different methods. The grey line shows only the amplitude of a single defect frequency and is very noisy. A better approach sums up all amplitudes belonging to a certain damage pattern. But still it is difficult to estimate how much time has been left for avoiding secondary damages.

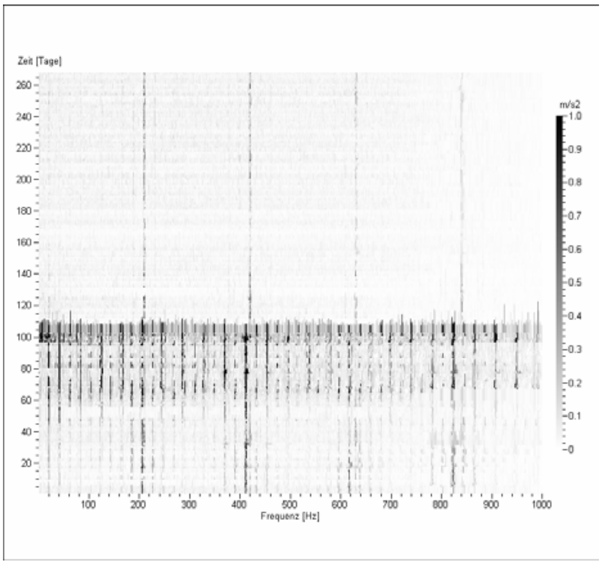

Fig.6: *In this sonogram each horizontal line represents a single measured spectrum as one is shown in figure 4. The amplitude is grey scale coded. Each spectrum is taken at a different rotation speed. Therefore the spectra have to be scaled to a reference frequency. In this case 25 Hz was chosen as a reference. The vertical axis shows the time (270 days). The repair was carried out on day 110*

Assuming only eight sensors per turbine each producing four spectra each day will result in 32 spectra per day. This number has to be multiplied by typically five characteristic patterns to analyze in each signal and the number of turbines. An offshore wind farm with 80 turbines will generate 2560 pattern each day. Without an automatic evaluation it is impossible to manage the huge amount of data. Figure 6 shows a sonogram which allows obtaining a survey for each sensor. It can be used as a tool for observing the development of damages.

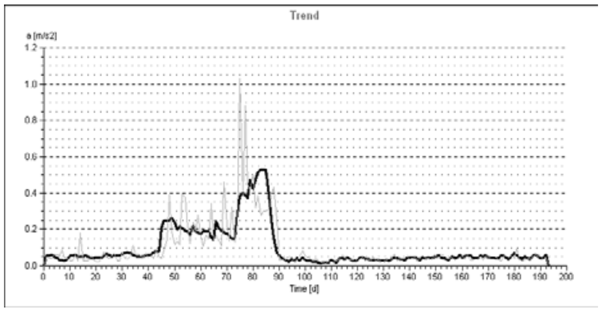

Fig.7*: The grey line shows the development of the amplitude of a single defect frequency line in time (almost 200 days). This line is very noisy. The black line is the sum of all harmonics seen in the spectrum of figure 4 (lower part). The smoother line allows an easier estimation of how the defect evolves.*

III. CONCLUSION

The table in figure 8 shows a cost comparison between the reactive maintenance (left hand side) and the predictive maintenance strategy (right hand side). It is clear from the examples that waiting until a bearing fault leads to a gear mesh damage and therefore to an unavoidable replacement of the whole gearbox is the worst strategy. The same is valid for an undiscovered bearing defect leading to a fatal damage of the generator. Having a look at the first annual report of the offshore wind farm Scroby Sands [2] four generators and 39 gear box bearings had to be replaced already in the first year. Taking into account the much higher costs for a repair done offshore a condition monitoring is indispensable. At the moment a component showing first indications of an ongoing damage has to be replaced within the next regular maintenance interval.

gear box exchange costs V66		bearing exchange in time	
gear box	185,534 €	bearing NJ2326EN	1,500 €
mineral oil	8,075 €	mineral oil	1,346 €
condenser	4,000 €		
crane approach / descent	2,109 €		
crane lump sum 10 Std.	2,876 €		
work schedule (4 pers. 3d per 10h)	6,540 €	work schedule (2 pers. 1d per 10h)	1,353 €
travel costs	554 €	travel costs	554 €
approval for crane transport	300 €		
	209,988 €		**4,753 €**

generator exchange costs		bearing exchange in time	
generator 1650 kW (Weier)	133,506 €	bearing 6330 M C3	1,500 €
crane approach / descent	2,109 €		
crane lump sum 10 Std.	2,876 €		
work schedule (2 pers. 2d per 10h)	2,706 €	work schedule (2 pers. 1d per 10h)	1,353 €
travel costs	554 €	travel costs	554 €
	141,751 €		**3,407 €**

savings:	
gear box	**205,235 €**
generator	**138,344 €**

Fig. 8: *Example for a realized saving using condition monitoring in an onshore wind farm. For offshore the work schedule and crane costs will be much higher resulting in an even higher benefit.*

This is different for onshore, where easier access allows awaiting the evolution of the damage. The trend information of actual condition monitoring products on the market has to be improved to obtain a better estimate of the status of damage. If a high number of similar defects occurs a proactive maintenance concept has to be applied to secure the investment.

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IV. Biography

Heiko Hinrichs was born in Northern Germany on May 4, 1960. After finishing high school he started studying Physics at the Carl-von-Ossietzky University in Oldenburg. In 1993 he received a Ph.D. and worked two more years at the University as a member of the Coherent Optics Group of Prof. Hinsch.

In 1996 he became one of the founders of the Institute for Technical and Applied Physics (itap) where he worked on different research projects until 2003.

Since 2003 he is with the 'Planning Association Energy and Environment Group' and now works on wind turbine monitoring.