breeze

Lifetime Analysis of a Wind Turbine Component

An investigation of how to use physics-based models and general OEM documentation to estimate the remaining lifetime of a wind turbine component.

Contributors

This E-Book is the result of a master thesis carried out at Breeze and Chalmers University of Technology at the Swedish Wind Power Technology Center.

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Executive Summary

The main findings in this E-Book can be broken down into two parts:

- Part 1: Lifetime estimation of a wind turbines main bearing using measurement data and physics based models
- Part 2: Information available to wind farm owners in OEM design documentation to make internal component lifetime calculations using physics based models

First of all, what is a physics based model? A physics based modeling approach can be used to establish a relationship between the forces acting on a component and the consumption of the component's useful lifetime. Physics based modelling requires intricate knowledge of forces and how the component in question is affected by those forces and what the forces influence is on lifetime. The influence of different forces on the component's lifetime is often well established during the design engineering carried out by wind turbine manufacturers.

In this E-Book the lifetime a wind turbine's main bearing is investigated. The axial and the radial forces bear the most influence on lifetime of the main bearing. These two forces are combined into one dynamic equivalent force. However, in the measurement data set used in this E-Book the axial and radial forces were not available. Luckily, they were available in a simulated data set that was made available by the wind turbine manufacturer for this project. By combining the measurement data and simulated data the dynamic equivalent force could be estimated by correlation using the blade root bending moment that was available in both the measurement data and simulated data.

It was found that the design life of the main bearing was significantly lower when actual measurement data was used compared to simulated data. With measurement data the lifetime of the main bearing was 31 years and with simulated data it was 79 years. It is a big difference but both are still sufficiently larger than the technical lifetime assumptions that are normally used for wind turbine investments. Furthermore, it was found that the consumption of lifetime of the main bearing is higher under certain wind conditions. Lifetime consumption for the main bearing is highest at the "knick" of the power curve at wind speeds around 12-14 m/s i.e. before rated power is reached.

It was also concluded that it is possible to generalize the approach taken in this project for any wind turbine component provided that sufficient information is available. In general, to make use of a physical modelling approach requires measurement of different forces acting on the component in question and an in depth understanding / mathematical formula of the effect of these forces on components under consideration.

The next step in the project investigated if this information is or can be made available to the wind turbine owner from the OEM. Five owners of various portfolio sizes were interviewed. It was concluded that making lifetime calculations as done in this case is not possible to do at scale as owners do not possess the required information

1. Measurements of forces (without investing in specific measurement equipment)
2. Design documentation detailing the forces effect on components

Information above is in most cases considered proprietary to the OEM and hence not readily released to the wind turbine owner.

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Foreword

This paper is a part of a master thesis conducted at Chalmers University of Technology in cooperation with Breeze. The purpose of this project was to investigate how wind turbine components remaining lifetime can be estimated based on online measurement data. Additionally, it was also of interest to investigate whether the estimated component lifetime from the physical model differed from the design lifetime predicted by the manufacturer through simulations. It was also of interest to find out if turbine owners have enough information regarding their turbines in order to perform similar studies.

Project Description

The design life of a wind turbine is often said to be around 20 years. In practice it is frequently observed that components in a turbine fail earlier and must be replaced before the stated lifetime. Therefore, it is very important for the stakeholders of wind turbines to be able to get a good estimation of a component's remaining lifetime so they can put up a suitable maintenance schedule and decide on how to exhaust the component in the most optimal manner. By possessing that knowledge, preventive measures can be taken to reduce the stakeholder's losses. However, it is unclear how much information concerning the turbines the owners have access to, which can limit their possibility of analysing their turbines.

The project can be divided into two parts. The first part examines the operation of the wind turbine itself while the second part focuses on the ”information flow” between different actors concerning the design aspect of the technology.

In the first part, the main focus was to investigate how the remaining lifetime of a wind turbine component can be estimated based on online measurement data. There are many different factors influencing the actual operation of the turbine and one must be careful to not put too much faith in the manufacturer's expected operation of the turbine. Therefore, it was of interest to compare how the initially designed lifetime of a component differed when the turbine had been in operation for some period of time.

Access to design documents and simulations for a specific wind turbine was granted. It included information about the design of the turbine as well as information of its expected performance. In addition, measurement data from different sensors placed on the turbine was provided. The measured data represent the actual performance of the turbine, i.e. when the turbine has been in operation for a period of time. The wind turbine considered in this project is a direct drive multi-MW wind turbine and it was decided to focus on the main bearing, which is positioned on the shaft.

The lifetime equation used in this project is straight forward, and it is relatively simple to perform the calculations. However, the project took a turn when an essential parameter needed in the equation was missing from the measured data. Therefore, the focus was put on finding a correlation between that parameter and another signal that existed in the measurement programme. In that way the missing parameter could be calculated and so the lifetime estimation was performed.

The second part of the project involved conducting five qualitative interviews with wind turbine owners with a varied range of installed capacity. The purpose of those interviews was to find out what kind of information the manufacturer is willing to give to the buyer of their turbines. It was of interest to examine if wind turbine owners have the possibility to do similar calculations as were made in this project. Factors such as if the size and ranking of the company played a part in the flow of information were looked into as well as how, or if, turbine owners used this information for their turbine's operation and maintenance.

Design Requirements of Wind Turbines

Before a decision is made about erecting a turbine at a particular site, simulations are required to estimate the site's feasibility. The simulations predict loads over a range of different wind speeds and for different operating conditions. The results from the simulations must be clearly stated in a design documentation, which every turbine has. The design documentation contains results from the simulations for different load cases, which are determined by combining various operational modes or other design situations with external conditions affecting the turbine. The simulated data sets are probability functions as they inform how many percent of the total lifetime a certain load case is expected to occur over the span of 20 years. Furthermore, it estimates the wind distribution within each load case. Wind turbine's lifetime estimation includes all of the design load cases and their probability of occurring during the time period in question.

Inspected Turbine Component

For this project, the lifetime of the main bearing was examined. The bearing lifetime indicates how long the bearing in question is expected to last. However, there are many factors that need to be taken into account, such as how the loads applied to the bearings fluctuate depending on wind conditions [1]. To compare if the expected performance of the wind turbine corresponds to its actual performance it was investigated whether the lifetime differed. Therefore, two sets of lifetime calculations were performed for the main bearing, one based on the simulated data and one based on the measured data. The simulated data represent the expected performance of the wind turbine while the measured data represents the actual performance.

Due to the restricted time of the project, only one design load case was investigated, which was the normal power production case for fatigue loads. When the wind turbine is in the normal power production mode there are no unexpected faults or downtime of the turbine present. Additionally, the wind speed is between the cut-in wind speed and the cut-out wind speed, which means there are no start-ups or shut-downs included in the load case.

Evaluation of Collected Data

The measured data came from a one-year long measurement programme that consisted of a number of sensors sending several signals every second about the functionality of the turbine as well as factors affecting the turbine. In order to limit the amount of collected data a decision was made to base the lifetime calculations on data files containing a 10-minute average data for the measured signals. The files were sorted based on their 10-minute average wind speed with a bin interval of 1 m/s.

The signals required in the lifetime calculation of the main bearing are the ones measuring the axial-and radial forces acting on the main bearing as well as the shaft's rotor speed. There were no problems finding the aforementioned signals for the simulated data and the lifetime could be obtained relatively simply. However, for the measured data the signals measuring the forces acting on the main bearing were missing and the lifetime could therefore not be calculated directly. A decision was made to examine if a correlation could be found between the simulated axial-and radial forces to other simulated signals. The correlation could then be used for determining the values of the measured axial-and radial forces acting on the main bearing. It was decided to focus on the blade root bending moments in order to find a possible correlation. The decision was made because data from the blade root bending moments are available both in the measurement programme and in the simulated programme. In addition, the loads on the turbine blades are passed on to other components and can therefore determine their loading to a great extent [2].

Figure 1 shows the bending moments acting on the turbine blades along with the forces acting on the main bearing. The red areas indicate where the sensors were positioned.

The radial force, Fr, is not illustrated in Figure 1. It is the resultant force of the vertical-and lateral forces acting on the main bearing as can be seen in Equation 1.

$$F_r = \sqrt{F_{lateral}^2 + F_{vertical}^2} \qquad [N]$$

Equation 1

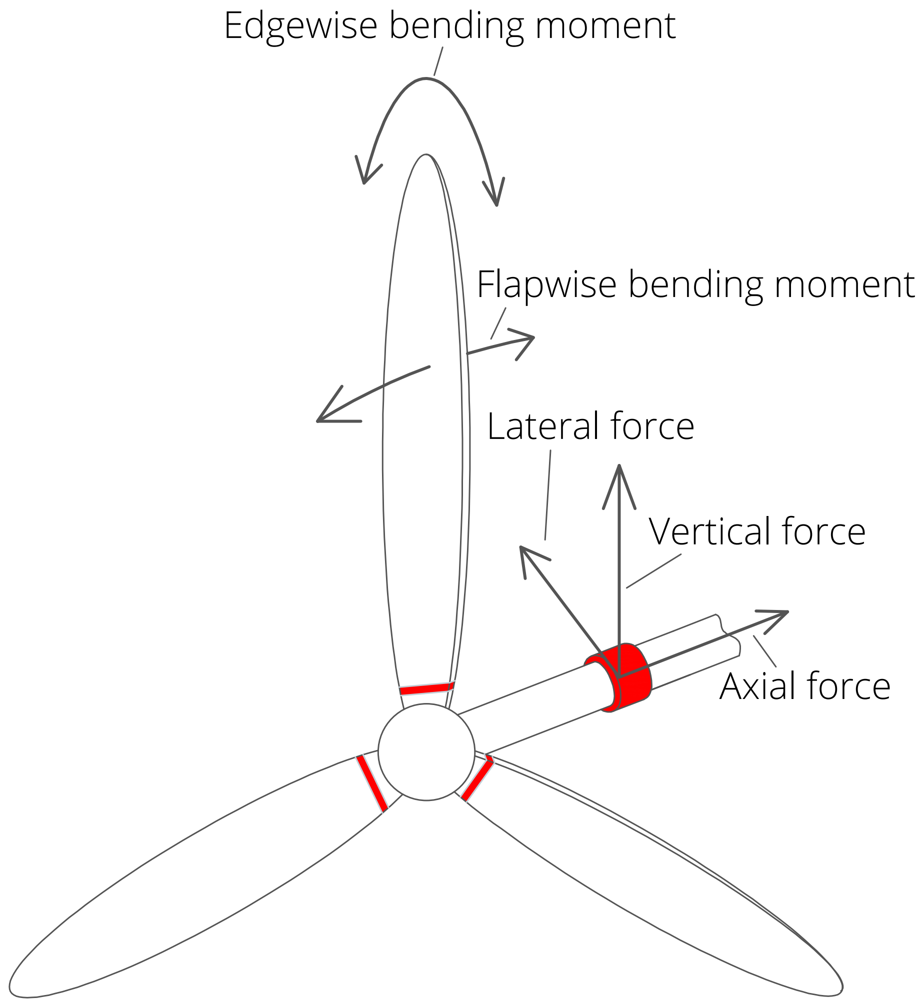


Figure 1: Bending moments acting on the turbine blades and forces acting on the main bearing.

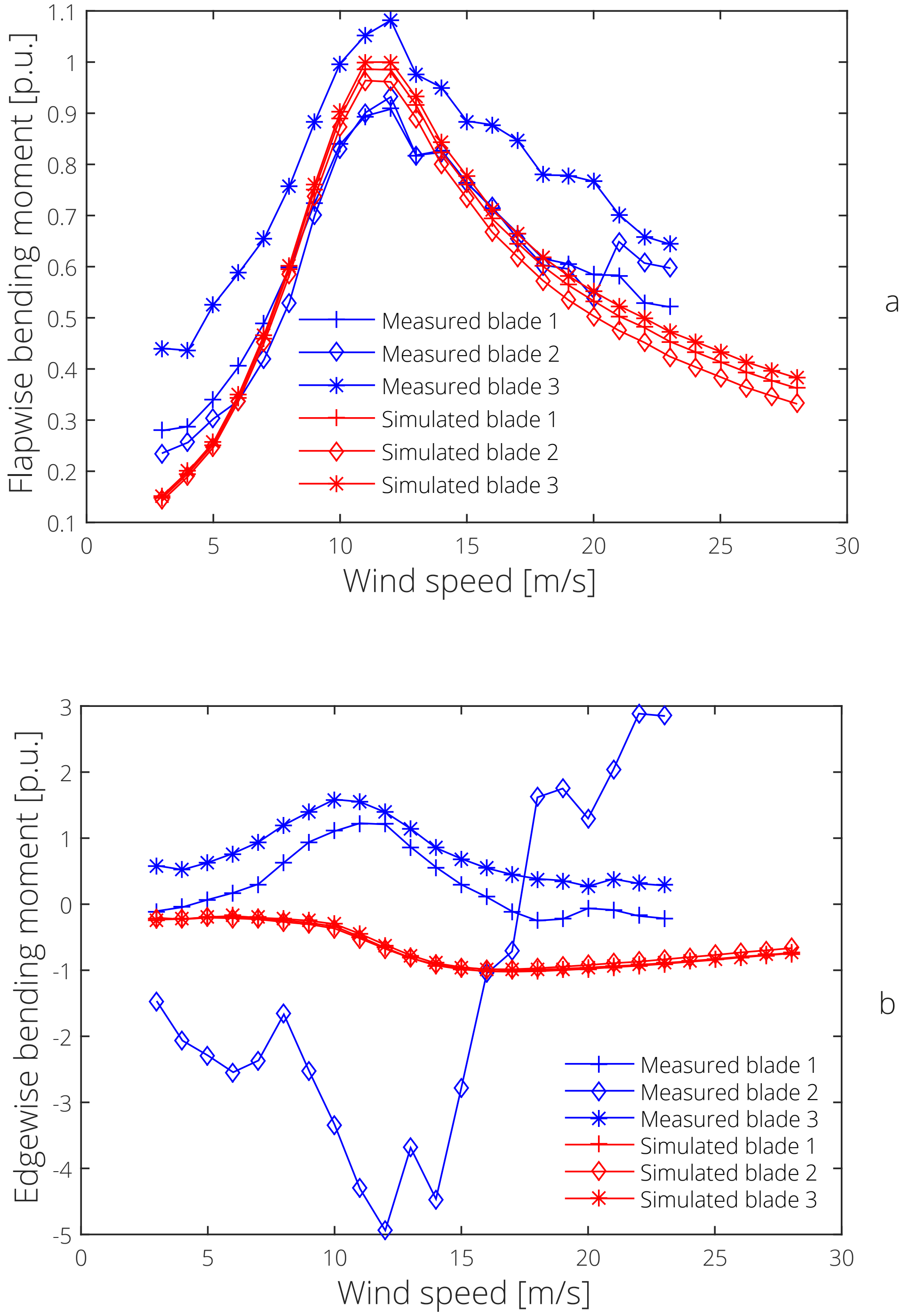
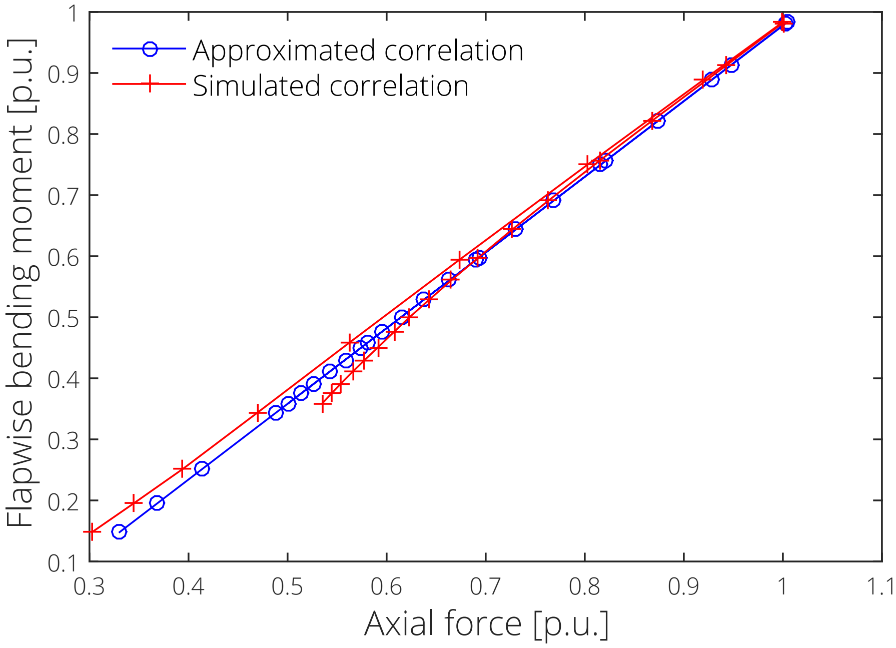


Figure 2: Simulated and measured flapwise bending moment (a), and edgewise bending moment (b).



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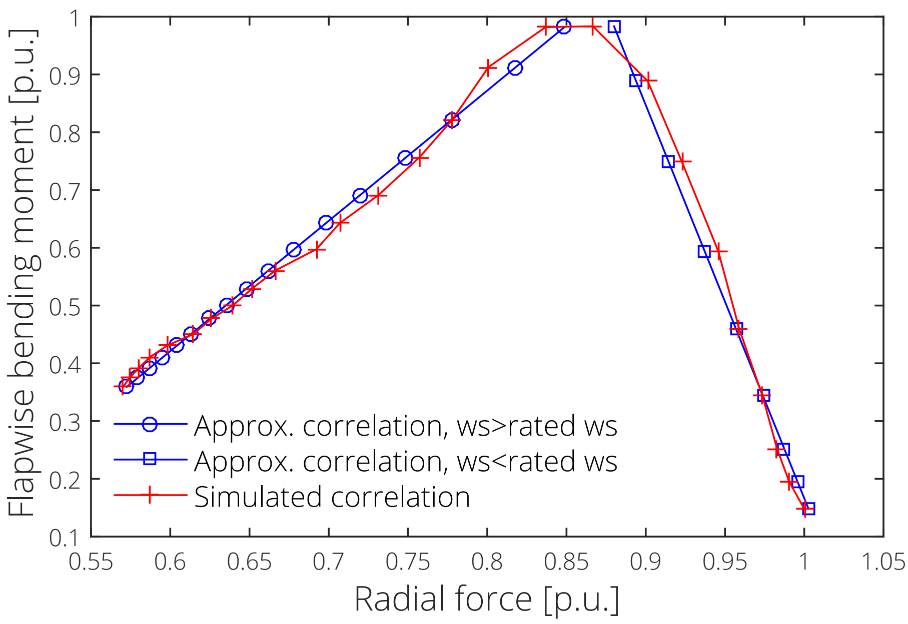


b

Figure 3: Correlation between the average flapwise bending moment of the three blades against the axial force (a), the radial force (b).

Both the flapwise-and edgewise bending moments were extracted from the measured- and simulated data, the results are shown in Figure 2.

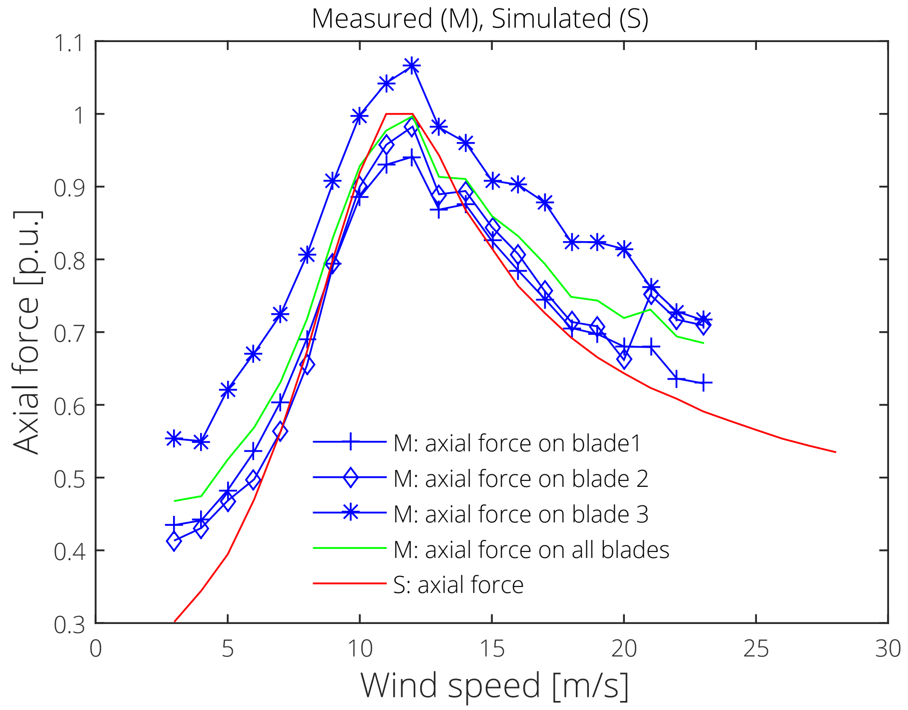
The comparison measured and simulated flapwise bending moment illustrated that the measured values closely follow the trend of the simulated values. However, the measured values for the edgewise bending moments did not match the simulated values. Hence, it was assumed that the measured edgewise bending moments are not accurate. Consequently, on the flapwise bending moment data was used to find a correlation to the axial and the radial forces on the main bearing.

Correlation

It was of interest to see if the lifetime would differ depending on which blade the correlation was based on, therefore four correlations were examined. One was based on the average of all three blades and the others were based on Blade 1-3 individually. The result of the correlations based on the average flapwise bending moment on all three blades and the forces acting on the main bearing are demonstrated in Figure 3.

Similar graphs were constructed based on the three blades individually. The correlations were approximated as linear and the equations for the linear relations were obtained. By using the equations, the axial-and radial forces were calculated based on the measured flapwise bending moment. The result can be seen in Figure 4 together with the forces obtained from the simulation.

Figure 4a shows that the axial force is increasing with wind speed until the pitching of the blades occur. When the blade is pitched the wind is hitting a smaller area of the blade and therefore the axial force is decreasing at higher wind speeds. It is assumed that the wind is lifting up the hub and the blades, therefore the radial force is decreasing with higher wind speeds as shown in Figure 4b.



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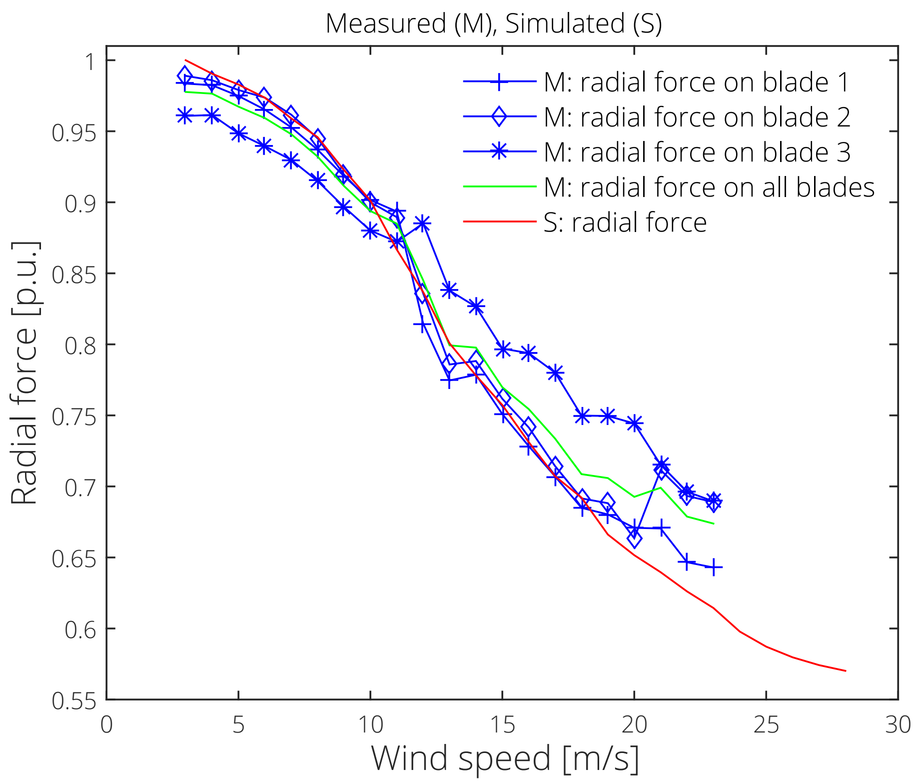

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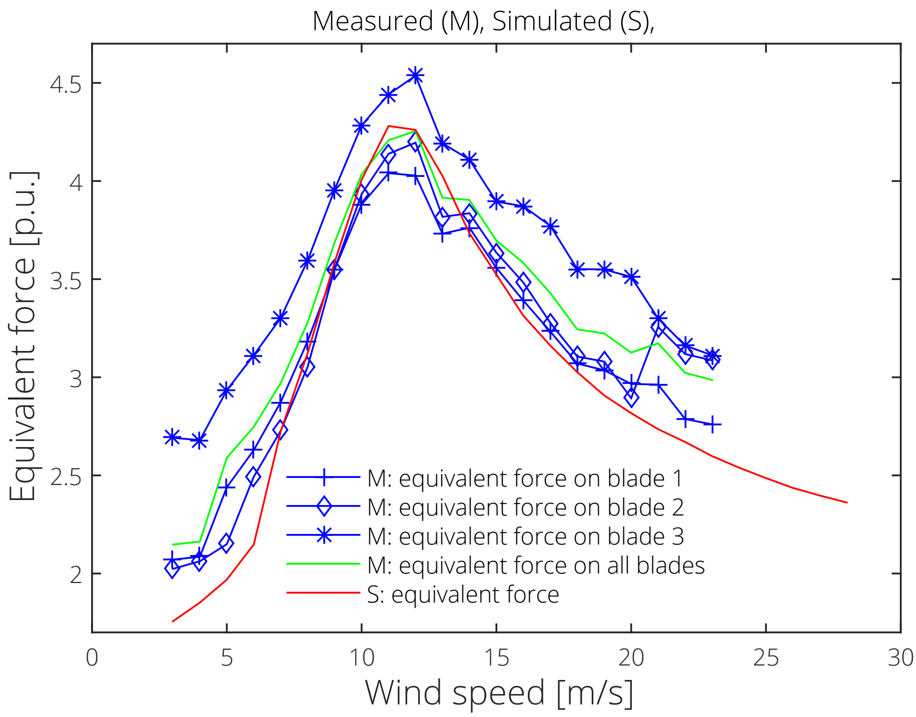
Figure 4: The axial (a) and radial (b) forces acting on the main bearing based on the simulated and the measured data.



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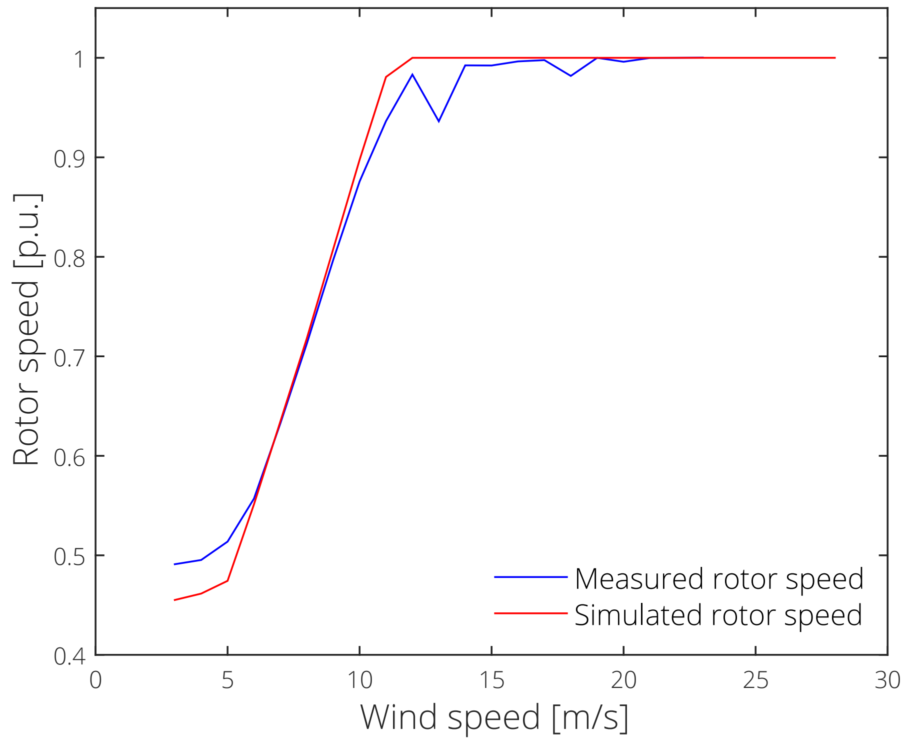


b

Figure 5: The axial (a) and radial (b) forces acting on the main bearing based on the simulated and the measured data.

Lifetime Calculations of the Main Bearing

A specific combination of the main bearing's axial-and radial forces, as shown in Equation 2, is called the dynamic equivalent force, Pd. It is the equivalent force acting on the main bearing and it is a function of time as it is dependent on wind speed and direction of the wind [3].

$$P_d = b_x F_r + b_y F_a \qquad [N]$$

Equation 2: Fr= radial force [N], Fa= axial force [N] , bx, by= calculation factors for the specific spherical roller bearing type.

Figure 5a shows the relation between the dynamic equivalent force and the wind speed while Figure 5b shows the corresponding rotor speed of the shaft to its respective wind speed. These two variables are used for the main bearing's lifetime calculations.

The lifetime of the main bearing measured in years is calculated by using Equation 3 [4], [3].

$$L_n = \frac{a_1 a_2 a_3 \frac{10^6}{60n} \left(\frac{C}{P_d}\right)^p}{hours/yr} \qquad [years]$$

Equation 3: n=rotating speed [min−1], ai= life correction coefficient, C= basic load rating, [N], Pd= dynamic equivalent force, [N], p= 10 for roller bearing 3.

In this project, the a1 factor was set to 0.99 which corresponds to a 99% reliability of the main bearing surviving the estimated lifetime [1]. The a2 factor corresponds to the steel material used in the bearing. The a3 factor is a condition factor and includes lubrication conditions and cleanness among other things. The C and p are found in the SKF handbook and are relating to the specific spherical rolling bearing.

By using the lifetime equation, the lifetime was calculated for each wind speed and the results are shown in Figure 6. The figure is constructed in a way that the lifetime is stated in years for a constant value of the wind speed. For example, if the wind speed

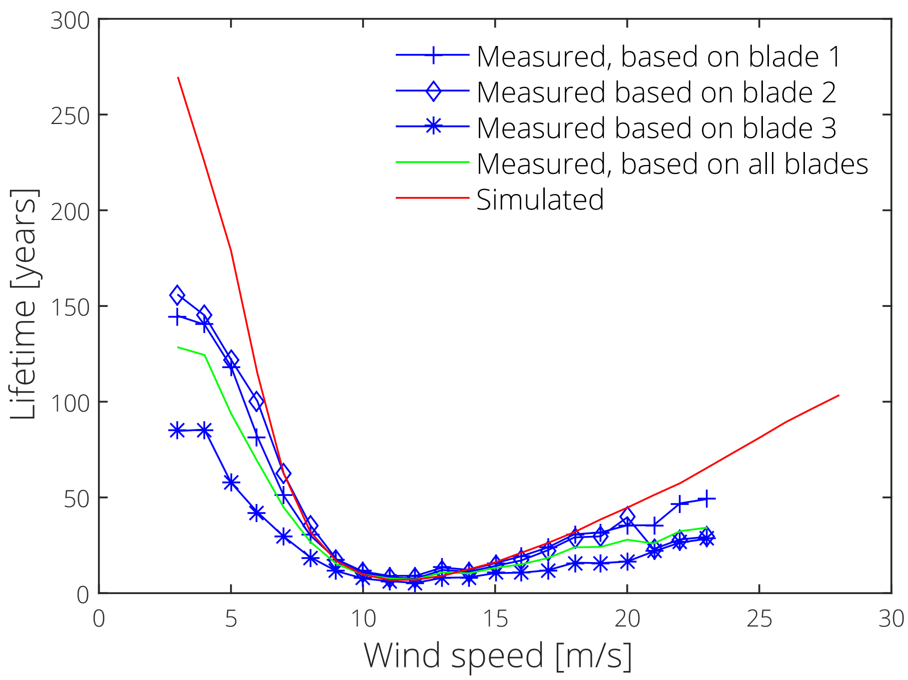


Figure 6: The lifetime of the main bearing based on the measured and the simulated data.

throughout the years would constantly be 5 m/s the lifetime based on measurements from Blade 3 would be around 50 years.

Figure 6 shows that the lifetime of the main bearing is similar for the measured-and simulated data at medium high wind speeds. However, the lifetime differs a lot between the different data sets at low wind speeds. The lifetime is closely connected to the forces acting on the main bearing, as can be seen in Equation 3, the lifetime decreases as the forces increase. An explanation to this relation can partly be seen from Figure 4a where the axial forces acting on the main bearing for the measured case at low wind speeds are much higher than the axial forces for the simulated case at low wind speeds. This difference between the two data sets explains the deviation in lifetime at lower wind speeds as shown in Figure 6. Furthermore, the higher the rotor speed is, the shorter the lifetime becomes. A low rotor speed in combination with a low equivalent dynamic force results in longer lifetime at low wind speeds.

The lifetime of the main bearing illustrated in Figure 6 shows the lifetime assuming a constant wind speed throughout the year. This is, of course, not the reality and to get a reliable number for the lifetime the wind speed's probability distribution in the case of normal power production needs to be included. Therefore, Equation 3 must be modified to include the variation in wind speed throughout the year. The lifetime equation for every wind speed was multiplied with its probability to occur, prob(ws). A summation was then made over the equation to include all the wind speeds between the cut-in wind speed and the cut-out wind speed.

$$L_n = \sum_{ws=cut-in}^{ws=cut-out} \frac{a_1 a_2 a_3 \frac{10^6}{60n(ws)} \left(\frac{C}{P_d(ws)}\right)^p}{hours/yr} * prob(ws) \qquad [years]$$

Equation 4: The modified lifetime equation.

For the simulated case, the total number of hours the turbine is operating with normal power production is about 25% higher than the total number of hours for the measured case. The large difference is a result of the measurements being taken from the first year of wind power production from a new type of wind turbine and therefore a lot of downtime is present throughout the year.

Lifetime calculations were done for two different time periods. The first period contained more than one-year worth of data. The second period contained data from a shorter period where the data for the flapwise bending moment was considered more reliable. The lifetime of the two periods are demonstrated in Table 1 and it corresponds to a 99% reliability of the component reaching that lifetime.

Based on	Lifetime, years (measured data)	Lifetime, years (period measured data)
Blade 1	36.6	36.4
Blade 2	39.8	33.4
Blade 3	20.5	37.3
Average, Blade 1-3	31.0	35.7
Simulated data	79.0	79.0

Table 1: Lifetime of the main bearing based on data from different time periods

Table 1 shows how the lifetime from the simulated data is much higher than the lifetime based on the measured data. This is probably due to the fact that for wind speeds lower than approximately 7 m/s, the lifetime is quite longer for the simulated data than the measured data. Wind speeds below 8 m/s occur for roughly half of the time throughout the year.

The table shows how the lifetimes based on the data obtained from the shorter but more reliably measured period are much more similar compared to the lifetimes based on the full year measurements. Therefore, it is assumed that the lifetime for the shorter period is more accurate.

The lifetime of the bearing must be at least 20 years based on a 90% survival reliability [5]. The calculations performed in this project are based on a 99% reliability, and even though the lifetime of the simulated data is more than twice as high as the measured data, the lifetime based on the measured data still follows the recommendation with a high marginal. However, what needs to be kept in mind is that these calculations are only based on the situation with normal power production and therefore the result is likely to change if all the other design load cases were to be included.

Interviews With Turbine Owners

Interviews with five different turbine owners were conducted. The owners differed a lot in the size of their business, the installed capacity ranged from 35 MW to 6000 MW. It was of interest to find out what kind of information the manufacturer is willing to give access to and if the owners of wind turbines could do similar calculations as were done in this project.

All of the owners have turbines from different manufacturers and they all agreed that it was hard to get an access to documents stating the design of the turbine from them. It differed a bit between manufacturers how willing they were to share information, but it appeared that all of them were quite strict on giving added access to documents if it was not stated in the original agreement. One of the owner expressed his surprise on how the manufacturer treats the owner and the secrecy that is surrounding the manufacturers operation. Based on the experience derived from the gas turbine business, one of the owners observed that the lack of information flow between different actors was unique in the wind turbine industry. All of the owners however understand the reluctance of the manufacturer of disclosing information containing the design of a turbine. The manufacturing business is a competitive one and the manufacturers are afraid of confidential information getting into the wrong hands.

All of the owners agreed that they were interested in receiving documents stating the design of the turbine as well as receiving information on how the dynamic simulations were performed. They all said that it would be very good to have an access to it though some were unsure if they would actually use that information. One of the bigger owner stated that when choosing between different manufacturers they tend to choose to conduct business with the one disclosing more information about the design of the turbine. Those documents could reduce the investment risk. They have previously decided not to proceed with buying a turbine as they felt that there were too many potential risks associated with the turbine. However, that same owner said that if they would have gotten more information about the turbine and its performance they perhaps would have made another decision. Another owner however stated that even though a manufacturer would be willing to share some of the documents, the owner is mostly focused on what kind of turbine he is buying and how that turbine is performing. That owner will choose the most profitable turbine and accept that they do not get all the documentation that they would have liked.

Some of the owners have actively been trying to get access to the documentation for a long time but to no avail. Only one owner, a medium big owner, got access to documents which included the complete load calculations and the all the simulations. However, they only got these documents from one of the manufacturers as the others denied their request. The owners all agreed that it would perhaps be possible to receive more information about the design of the turbine in the negotiating phase when the manufacturers are competing with each other or before the final payment if it is stated in the contract that they should disclose the information. However, if they had not received the information after those two occasions then it is almost impossible to acquire them afterwards.

No owner had access to lifetime calculations on turbine components that were based on simulated data. They were doubtful that they would get access to how the manufacturer performed the simulations. All of the owners agreed that there was no guarantee that a turbine would operate for 20 years, they just have to put their faith in the manufacturer. The manufacturer makes simulations and calculations and states that the turbine should work for 20 years. The owners want to have a second opinion on these calculations and therefore an unbiased third party goes over the accuracy of the lifetime calculations. Some owners said that the only way to guarantee the lifetime is to have a full inclusive service agreement with the manufacturer for 20 years. By doing so, the owners trust that the manufacturer believes in their own design otherwise the manufacturer would not take the risk of having to have to repair it so often. However, this lifetime agreement is very expensive.

Normally the manufacturer will give an access to around 20-50 signal measurements out of maybe 2000. The signals can vary in resolution and the manufacturer can insist on charging the owner more money for a higher resolution signals while some will not even give them that opportunity. The measured data is used proactive to minimize the downtime of the turbine as well as it helps them understand why a certain component is failing at a higher rate than was expected. Added access to signals can be reached by, for example, installing a CMS (condition monitoring system). However, a turbine is normally under warranty for the first two to five years. If the owner wants to use an additional measurement system, like the CMS, the warranty will not apply as then the manufacturer will say that the implementation of the system is influencing their own system and they cannot be held responsible. Therefore, the owner is more or less forced to wait for the warranty to end before they install the new system to gain additional signals.

Many owners try to have a preventive maintenance but it is hard to predict when it is needed. They try to look into the CMS but they are maybe not using it as much as they could. Some owners have their own technicians constantly checking the condition of the turbines to see in advance if a fault occurs. One owner states that when they see a failure occur in the CMS they will try to understand the root cause and at what pace the failure will affect other components in the turbine. If they see a serial defect on some component they can start to do some preventive maintenance or try to delay the failure and start to replace the components in different turbines proactively before they fail. When they can see in advance that a component is failing they can decide on how to exhaust the component in the most optimal manner. They could choose to replace it during summer when the wind is less, the electricity price is low or when the company has enough capacity. The owner say they have a rather good indicator as to how long each failure will take until a total breakdown of the component occurs. The owners all have turbines from different manufacturers and not enough turbines of the same type. Therefore, comparative analysis and planning a preventive maintenance can be very hard.

One owner said that sometimes it is not necessary for them to get a longer lifetime of a component as they want to repower a site. That is, they will take down a smaller turbine and replace it with a bigger one. It can be beneficial for them to take down smaller turbines and sell them to Italy or Ireland as the smaller turbines will lead to higher subsidiaries in those countries. By selling the small turbines, the owner will gain some revenue and also they can reuse their permit for building bigger turbines at the same site and gain more power. In this case the lifetime of the turbine is not that important, the important thing is to find the most optimal time to decommission the turbines.

Only one owner mentioned that they have started to do similar studies as in this project for some bearings in older turbines as well as for some other components. They want to see if they can see a difference in how heavily the turbines have been loaded over the years and to find out if there is a difference to their expected lifetime compared to their actual one. However, the owner has to ask the manufacturer to calculate the lifetime as they do not have the tools or sufficient information to do that themselves. Those calculations can help approximate for how long the owner can use the components in question. Only some manufacturers offer these services. The larger manufacturers, in fact, do collaborate with customers with whom they have bigger business interests and assist them with services such as investigation of the bearing lifetimes. However, the smaller manufacturers and the ones that do not have a big business with the owner think that these investigations are too expensive or they think that these are confidential information which they are afraid that their competitors can take advantage of.

Discussion & Conclusion

The main findings from this project are that there are great differences in the lifetime estimations depending on if it is based on the turbine's simulated-or measured data. Furthermore, it was concluded that the simulations of a wind turbine could be used to find correlations between different signals. However, it seems like the turbine owners do not have enough access to information in order to perform lifetime calculations in a similar way as was done in this project.

The results from the calculations in this project do not give a full picture of the lifetime of the main bearing since only the normal power production case was taken into account. The project rather shows a method of how to analyse the lifetime of a bearing and it examines differences between the expected and the actual performance of a wind turbine.

In this project the 10-minute average data was used to estimate the lifetime of the component. It would of course give a more accurate estimate a higher frequency data was used.

Even though a lot of access to private documents was granted for this project, it was at times hard to use the data. In many cases, the source of the data was not sufficiently explained, such as from which part of the turbine the signals were coming and what some sensors were actually measuring. These issues had quite an impact on the work process as it made the project more complicated than initially expected. In addition, there are some shortcomings in the data files, as around 15-days worth of data is missing as well as some signals are not present at every time interval. Therefore, one must be careful when assessing the results as inaccurate data can influence the outcomes. Furthermore, it is very important to verify the measured data as the sensors do sometimes give inaccurate measurements during some periods, as was the case in this project. Therefore, basing calculations or predictions utilizing measured data without confirming its reliability can have a big impact on the result.

As a result from the interviews, it seems like the owners of the turbines are unable to perform lifetime calculations based on the expected performance. This is due to the fact that they are not getting enough information about their turbines from the manufacturer. Since they do not get access to the simulation, they are unable to find correlations to other signals as done in this project. They could however, get an estimate of the lifetime of the main bearing based on measured data. This comes with the constraint that they have to install sensors measuring the forces on the main bearing. Furthermore, it was concluded in the interviews that all of the turbine owners were interested in obtaining more information regarding the expected performance of their wind turbines. However, only a few of them thought that they would actually use this information.

Relevance to Breeze

If the owners of wind turbines were to install sensors measuring the forces acting on the bearings these measurements could be sent to Breeze. Breeze could then continuously monitor the lifetime of the bearings. In that way, one could realise how the wear of the component is at each moment and calculations on the expected remaining lifetime could be performed. In addition, comparisons to other turbines and other periods of time could be made.

In this project a direct drive wind turbine was investigated. It would however be useful to perform similar calculations on the bearings in a gearbox since the gearboxes are very prone to fail and causes long downtimes.

It would also be useful to make similar lifetime calculations for other turbine components. Breeze could monitor and visualize the remaining lifetime of the considered components and so a plan for replacements of parts could be made. By doing so, one will better understand how different factors affect the lifetime and perhaps develop new and better ways of operating and maintaining the turbine. An example of this is illustrated in Figure 6 where the highest wear of the main bearing seems to occur at wind speeds close to the rated wind speed. It would therefore be interesting to find where the highest wear of other turbine components occurs. If the highest wear for those components takes place in the same wind range, one could discuss the profitability of stopping the wind turbine during those wind speeds. That decision could be practical if a lot of lifetime would be spared and if the electricity prices are low during the times when those particular wind speeds are occurring. This could be implemented as a warning system where Breeze sends out signals when the electricity prices are low and the wear of a turbine parts exceeds a certain threshold. However, of course one has to consider the effect the frequent shut-downs has on the turbine, if that would in turn wear some other components out more. Further studies in lifetime calculations of different components and increased analysis of signal outputs could make it easier to improve a turbine's maintenance schedule and even shift more to a preventive maintenance schedule compared to an only time based one.

The decision to change from an existing regime to another one is largely based on how much the transition will cost. There will, for example, be an added cost by installing more sensors on the turbines for increased measurements possibilities but the investment must be put into perspective of possible gains. By having a better measurement system and a team of analysts the gain in production time that can be reached by replacing parts before they break down can be worthwhile.

Breeze - A Modern System for Data Collection and Wind Farm Optimization

With more turbines comes more data and a universal need to capture and understand this data. Collecting, managing and analyzing data are challenges for owners and operators with expanding, diverse portfolios. For many years, software solutions for the wind energy industry were lacking or immature.

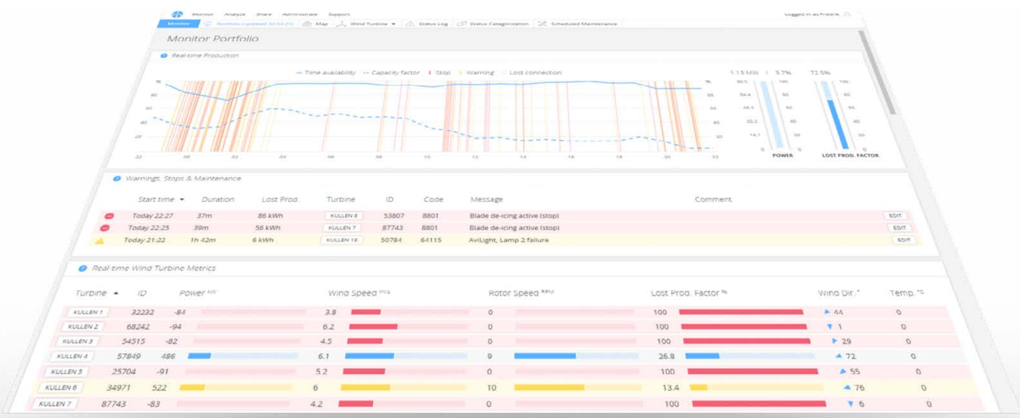
Created specifically for the wind energy industry, Breeze is a modern scalable wind farm management system used by active owners and operators to increase energy production.

A key task in increasing power performance is to identify under performing wind turbines and to discuss what actions can be taken to increase power performance of individual wind turbines or the wind farm as a whole.

Breeze has the capabilities to measure and verify the effects of actions and expenditures intended to improve performance. By quantification of the ROI, the owner will know if actions make financial sense to implement on other wind turbines.

This is an exciting field that will become more and more important and widespread as turbines are managed under production based availability contracts and as turbines come out of warranty. Breeze intends to maintain a leadership role in this field.

To learn more about Breeze, visit www.breezesystem.com.



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