Remote monitoring of wind turbines gives successful results

Four case studies demonstrate how an effective remote condition monitoring strategy avoids costly downtime and consequential damage

Brüel & Kjær Vibro Surveillance Centre has been remotely monitoring several hundred wind turbines over the last 4 years. A number of diagnosed faults have been documented for wind turbines over this period and four of these case studies are described in the article, based on the actual Alarm reports prepared for one of our customers, a wind turbine operator. In each case machine downtime has been minimized and repair costs reduced since early fault detection and diagnosis has avoided a catastrophic failure from occurring, which could lead to extensive consequential damage.
The remote monitoring concept used in these four case studies is described in the Technical Focus article on page 7. The monitoring strategy used on the four different wind turbines includes over 100 scalar vibration and process parameters that are automatically monitored, combined with a detailed signal analysis of the acquired time waveform signals.

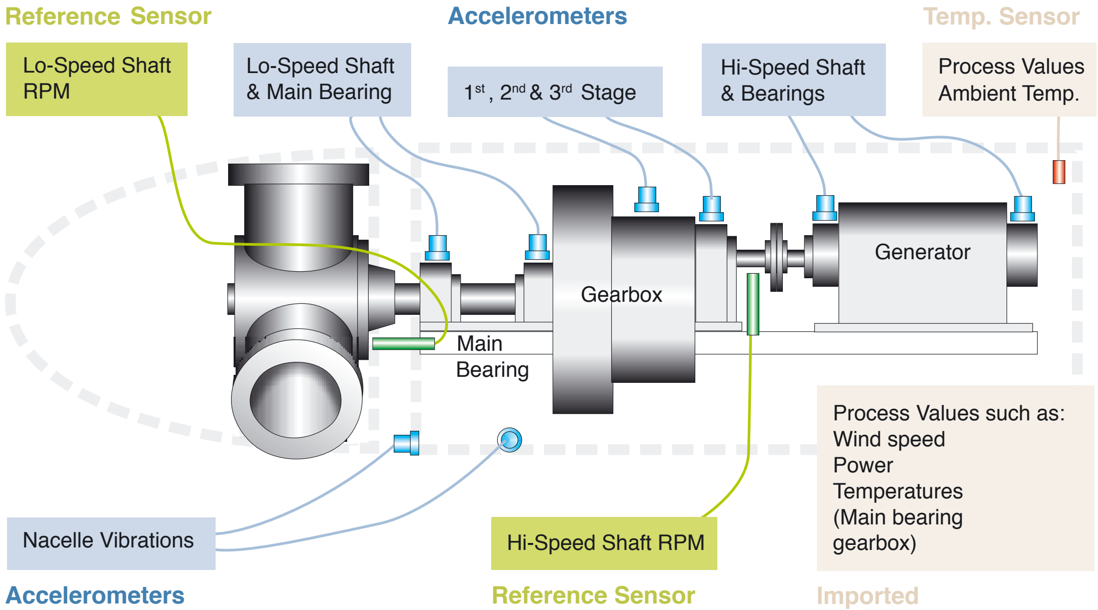


Figure 1 Sensor types and locations on a typical wind turbine generating unit train.

The critical areas to monitor on a wind turbine are shown in Figure 1. Monitoring wind turbines to an adaptive monitoring strategy is absolutely imperative for reliable, early fault detection. Unlike a baseload power station, a wind turbine is subject to a wide range of loading for different wind conditions. In order to distinguish between a vibration and process signal amplitude change due to a change in operating conditions and that due to a developing fault, it is necessary to use an adaptive monitoring strategy such as active power bins (e.g. power classes). See Figure 2 for an example of vibration change due to a generator speed variation. The concept of active power bins is described in more detail in the Technical Focus article on page 9 and 10.

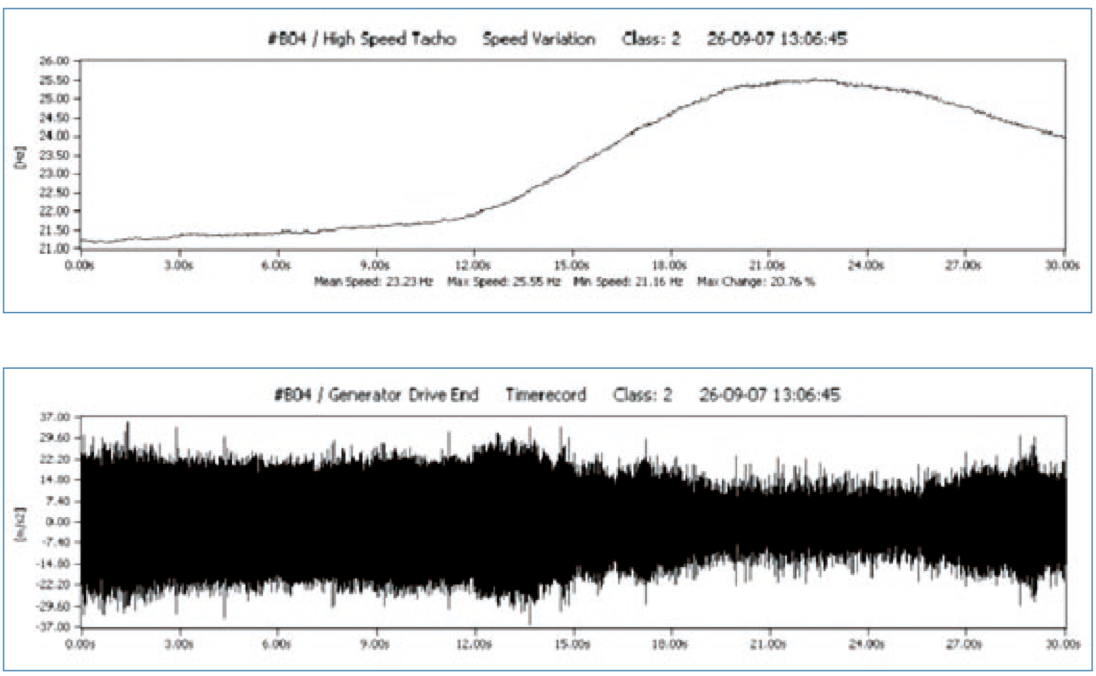
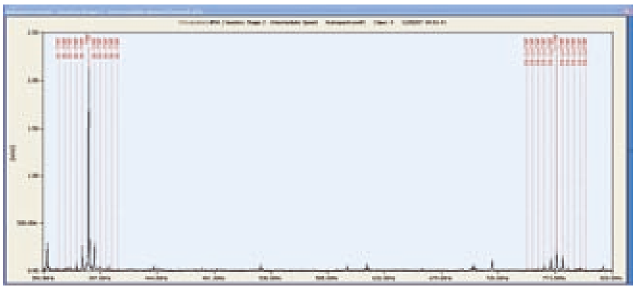


Figure 2. The upper plot shows the speed variation of around 20% over a 30 second period. The time waveform plot below shows the corresponding generator drive end bearing vibration response for comparison. To effectively monitor under these conditions, an adaptive monitoring strategy is needed.

Case study 1 Wind turbine gearbox defect

Observations

Gearbox second stage gear mesh frequency (first order) exceeds the Alert alarm limit.



Interpretation

Detailed analysis shows sidebands around the first and second order gear mesh frequencies of the gearbox second stage, which confirm a gearbox fault.

Advice/action

The gearbox should be visually examined when convenient, paying particular attention to the second stage gear teeth condition. The gearbox mounting bolts and support structure should also be checked.

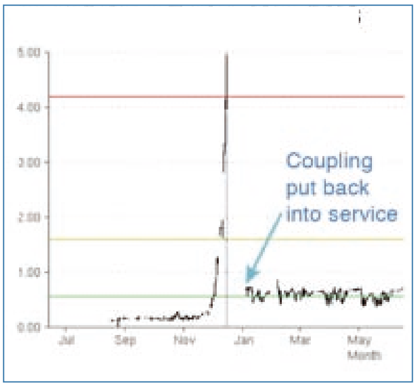
Feedback after service

Photo showing the metal shavings in the oil filter coming from the damaged second stage of the gearbox. A new gearbox was installed. The damaged gearbox required minimal repair since a catastrophic failure was avoided. The trend plot above shows the gear mesh frequency trend before and after servicing the gearbox.

Case study 2 Coupling defect

Observations

Rapid rise in the first order BMS vibration magnitude exceeds Danger alarm limits. The other measurements indicate there was no rotor unbalance or bearing faults



Interpretation

The rapid rise in generator driven end first order magnitude indicates a change in the stiffness of the bearing or the coupling, possibly due to loose holding down bolts or structural components.

Advice/action

Inspect generator rotor, bearing and coupling for possible loose components.

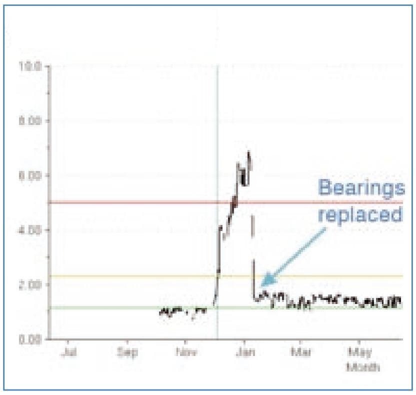
Feedback after service

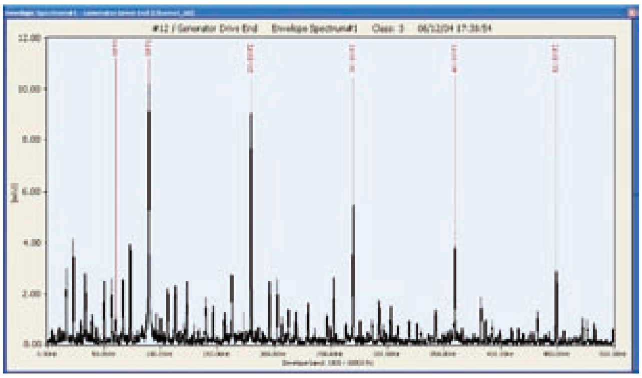
Photos showing the sheared coupling links.
The trend plot above shows the first order magnitude vibration trend both before and after servicing the coupling.

Case study 3 Bearing fault at generator driver end

Observations

Generator driver end BCU (Bearing Condition Unit) measurement exceeds Danger alarm limits.





Interpretation

Further analysis using envelope plot confirms an inner race bearing fault. This is typically characterized by a series of harmonics from the inner race bearing fault frequency (BPFI).

Advice/action

The bearing should be checked as soon as possible and replaced, if necessary.

Feedback after service

Photos showing the damaged inner race.

Case study 4 Gearbox suspension support fault

Observations

Rapid rise in second stage gearbox overall vibration level to above Danger level in power bin 5 (>1200kW). progressive rise but below Alert level in power class 4.

The other measurements indicated there was no problem in the gears themselves.

Interpretation

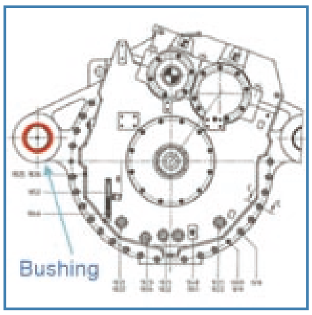
The rapid progressive rise in the second stage gearbox overall vibration level indicates a deterioration in the condition of, or looseness, in the gearbox support pads or structure. Because it occurs only at the highest active power bin, there could be a possible structural resonance resulting from a reduced structural stiffness due to looseness of the support structure.

Advice/action

The gearbox should be inspected immediately for mounting or looseness problems. It should also be visually inspected internally for possible contacting rotating parts.

Feedback after service

Photo showing the cracked rubber bushing on the support bracket (drawing on the right shows the location of the bushing on the gearbox).The trend spot above shows the trend both before and after exchanging the bushing.



Cost-effective monitoring of wind turbines using external Surveillance Centre

technical focus

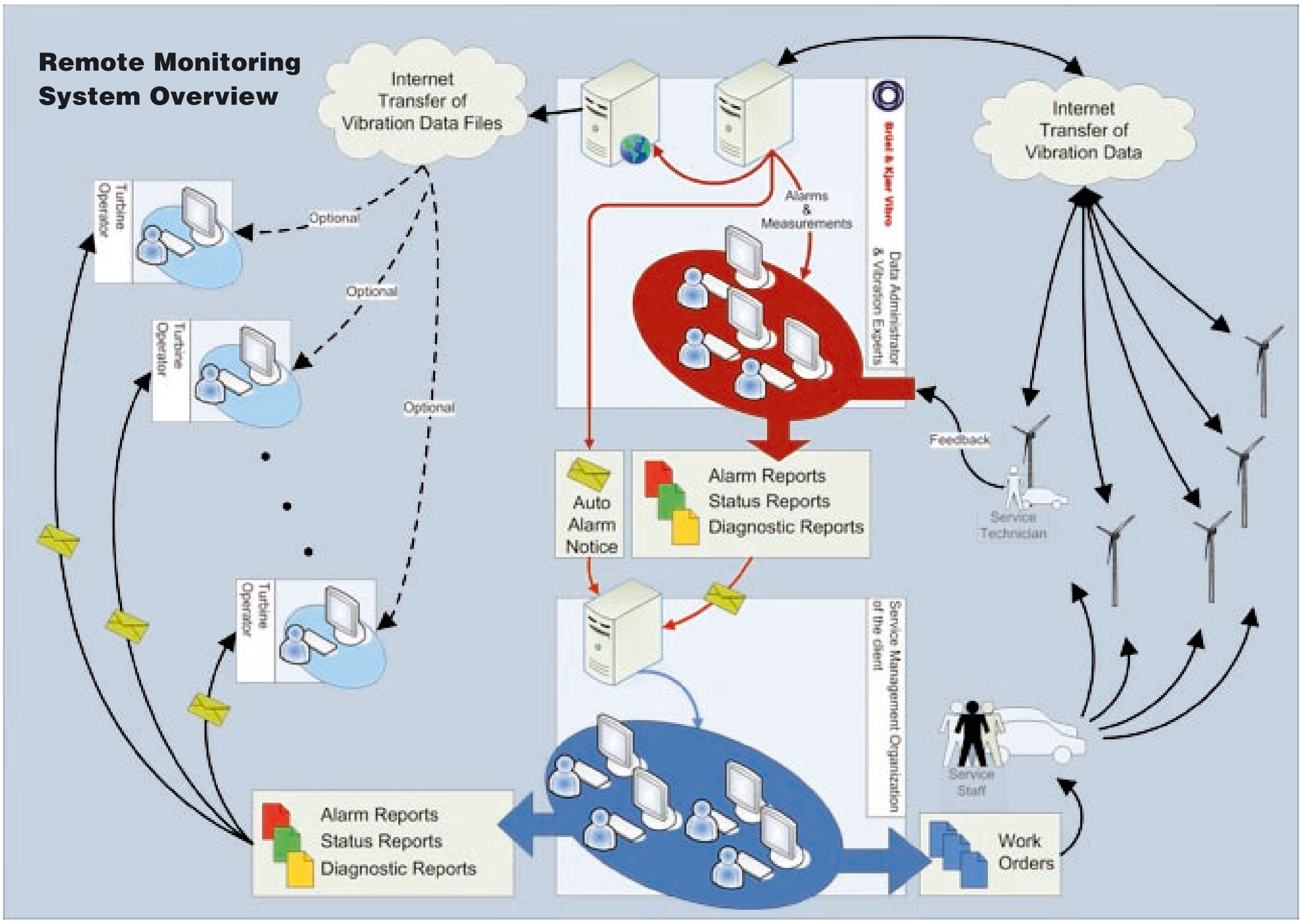
This article presents an example in the wind turbine industry on how an effective remote monitoring system coupled with an external surveillance and diagnosis centre can bridge the gap between achieving greater uptime with less investment. It is the second part to the technical article in the last issue of Uptime entitled "Remote Monitoring and Diagnosis Concept".

Keeping machinery running reliably is more important today than ever before. The demands for fast, reliable delivery, production flexibility and increasing product quality are compounded by an industry-wide reduction of maintenance budgets, personnel and a lack of specialists. This results in a significant loss of on-site knowledge and experience in condition monitoring. Despite this, the operators have to keep increasingly stressed machines running longer and with greater output.
Most agree that a predictive monitoring strategy holds the most promise to increase machine uptime, but this requires both an appropriate condition monitoring system and qualified diagnostic specialists. How can this be done cost-effectively and with limited on-site expertise?

Wind turbine monitoring requirements and challenges

Brüel & Kjær Vibro has worked with end-users over the years to come up with cost-effective solutions to address the issues of limited customer monitoring expertise in a number of industries. This article focuses on one particular solution that was started in the wind turbine industry.

The wind power industry has expanded rapidly during the past few years, where the focus has been on a growing market for larger wind turbine parks and the development of larger wind turbines. The installed wind turbines are subject to high and varying loads and extreme weather conditions, and therefore require special attention in a maintenance program. Normal lifetime assessment of the machinery is not always valid under these circumstances. A vibration condition-monitoring program is a vital tool for planning a maintenance pro-



gram in case of accelerated degradation of machine components due to the harsh conditions. Without such a program, uptime can only be achieved by rapid response times and fast service to correct the problems. Such an approach is difficult to carry through with success, especially for offshore wind parks where turbines only can be reached during proper weather conditions.

Condition monitoring in the wind power industry is relatively new, and there are several challenges that make it difficult to use a "standard" condition monitoring system on a wind turbine:

- Varying operating conditions
- Varying speed
- Low rotational speeds
- Complex gearbox (planetary)
- Non-rigid machine foundations

Before implementing a remote Surveillance Centre for wind turbines, a considerable amount of work had to be done with turbine manufacturers to better understand the machines and their failure modes. At the same time, both the wind turbine manufacturers and Brüel & Kjær Vibro had to work closely with the standards and certifying bodies. Germanischer Lloyd, one of the only certifying bodies for wind turbines, certified the Surveillance Centre concept and the condition monitoring system for the wind turbines. It was also accepted by Allianz, which ultimately results

Figure 1 Remote monitoring and diagnosis at the Surveillance Centre

in lower insurance costs for the operators who use the certified remote monitoring and diagnosis system and service. The specialists in the Surveillance Centre are ISO certified.

Remote monitoring and Surveillance Centre for wind turbines

The primary elements in the remote monitoring and diagnosis Surveillance Centre, as shown in Figure 1 and explained in the following sections, are:

- Local data acquisition units in the wind turbines
- Remote diagnostic server

- Remote Surveillance Centre service
- End-user service group and wind turbine operators

Data acquisition system

For many industrial plants, a single, plant-wide, comprehensive stand-alone condition monitoring system is sufficient for their monitoring requirements. If outside help is needed for analysis and diagnosis, specialists can be contracted to do this by remotely gaining access to the database. But for those industries like the wind turbine industry where there are many machines that are remotely located from each other, a comprehensive stand-alone condition monitoring system would be cost prohibitive. In such a case, it is more cost-effective to install a remote, distributed monitoring system. This consists of a web-enabled data acquisition unit in each turbine, and a single, remotely located central diagnostic server.
The data acquisition units themselves are not accessed by the end-user and therefore can be considered as a remote part of the diagnostic server. The benefits of this solution are lower system cost (less hardware), less space occupied by the system, no customer IT investment or support required for a condition monitoring server or database, no training, and no customer specialist needed.

The primary functions of the data acquisition unit are:

- Automatic monitoring – Vibration, process parameter and time series are automatically monitored at fixed intervals and remotely sent to the diagnostic server
- User-requested time waveforms – Used for detailed frequency and time series analysis
- Automatic event recorder – Time waveform data is automatically stored before and after a user-defined event, thus allowing the diagnostic centre to do advanced vibration post-analysis to identify developing faults

Figure 2
Example of active power bins (e.g. power classes)

The data acquisition unit must be able to withstand harsh environmental conditions such as operating temperatures from -40 to 70 deg. C, high humidity and salt mist as well as shock and vibration exposure.

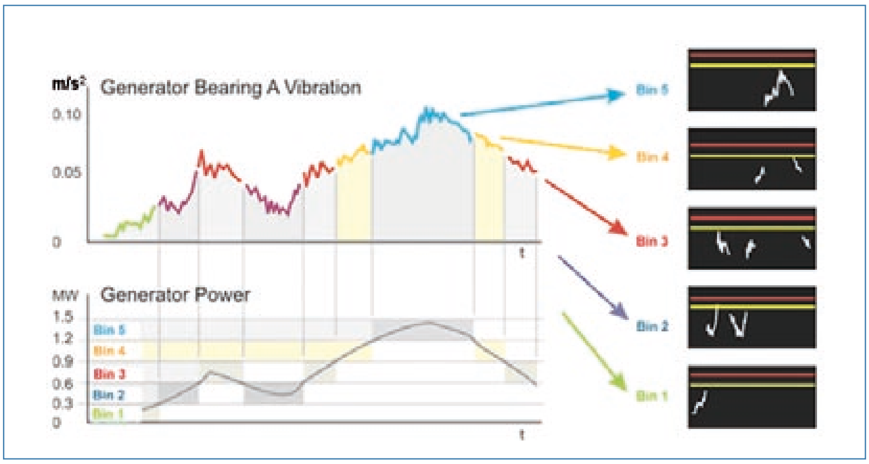
A GPRS modem or a LAN is used that has sufficient bandwidth to transmit scalar data and time series over a web-server to the central diagnostic server. Over 100 parameters classified according to the operating conditions are monitored in each wind turbine.

Central diagnostic server

The specialists in the Surveillance Centre use the diagnostic server for doing analyses and diagnoses of the raw data, so they can advise the wind turbine operators on the condition of the wind turbines, and recommend any action that has to be taken.
The primary function of the diagnostic server is to:

- Automatically take in “raw” data, e.g. scalar values and time series, from several hundred data acquisition units located in the wind turbines
- Automatically condition and process data
- Automatically classify the data according to the operational conditions
- Automatically compare data to alarm limits, prioritize them and issue alarms if exceeded (Alarm Manager)
- Automatically store data in the database for long-term storage and trending
- Take vibration time wave forms by user request
- Take vibration time waveforms at regular intervals

Wind turbines operate in widely varying conditions, and consequently the vibration response of the machine components also varies. A group of active power bins (e.g. power class-



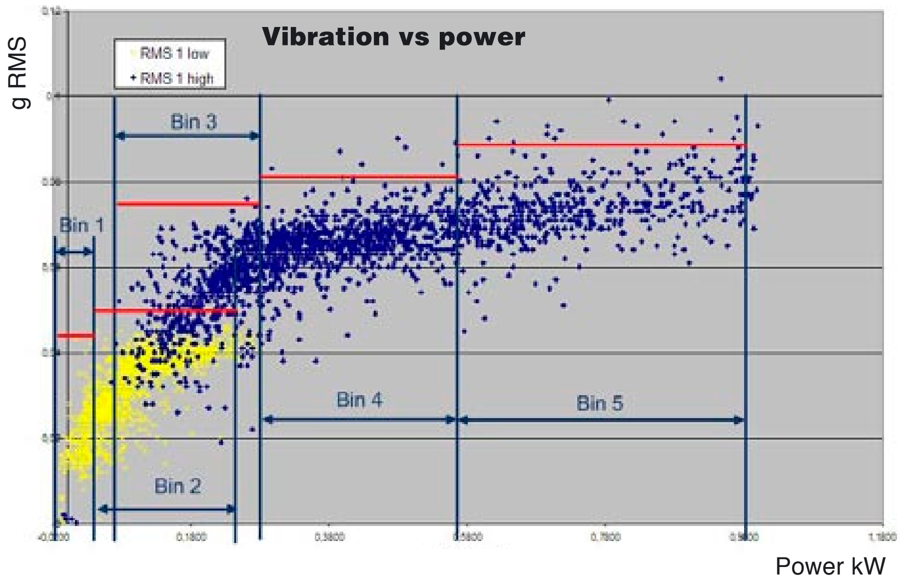


Figure 3 Another example of how the power bins are defined for actual wind turbine data. The yellow and blue data points represent two different operating modes for the generator.

es) and their corresponding alarm limits were defined by Brüel & Kjær Vibro and the machine manufacturer so they can be monitored and stored individually. This allows faults to be automatically detected in any active power bin without generating false alarms. It also makes a "cleaner" trend when plotting the progress of the fault.

The Alarm Manager is an important function in the diagnostic server for wind turbines. More than a hundred characteristic scalar values are monitored for each turbine. Each of these values is stored in an active power bin reflecting the running conditions of the turbine when the value was recorded. Each active power bin has its own alarm limits resulting in 500 to1000 alarm limits for each turbine. The diagnostic server closely monitors each of the recorded values and provides an alarm each time an alarm limit is exceeded. The combined pattern of these alarms indicates a progressing mechanical fault on one or more of the turbine components. The Alarm Manager program looks for high-resolution alarm information in the diagnostic server database, as shown in Figure 2. All incoming and previous alarms are evaluated and transformed into a single alarm notification for each part of the turbine. The alarm information is graduated into five severity levels in order to provide the user with a lead-time estimate on a developing fault (see Table 1). Notifications from the Alarm Manager are sent via e-mails to a number of assigned users.

Surveillance Centre

No matter how good the diagnostic server is – whether it is installed locally with the machines or is part of an external Surveillance Centre – it has little value if there are no specialists who can do the analysis, interpret the results and advise the customer on required service. The "back-office" service of the Surveillance Centre includes the tasks and

Severity	Type	Description	Required Action
1	Danger	Severe progressing failure	Immediate action. Operating the turbine has serious risk of functional loss and possible severe consequential damage.
2	Alert	Considerable progressing failure	Action as soon as possible. Recommended within 2 weeks.
3	Alert	Progressing failure	Action when convenient. Recommended within 2 months.
4	Alert	Small or none progressing failure	Action at next service.
5	Good	No abnormalities detected	No action required.
6	System	Hardware system problem	Correct as soon as possible.

Table 1 Alarm criteria used in the Alarm Manager program

responsibilities of the specialists and the how they interact with the end-user's service group.

In the wind turbine industry, several hundred wind turbines are currently being monitored in Europe from a dedicated Surveillance Centre in Denmark. The specialists work full-time only for wind turbines, and are responsible for detecting and diagnosing the faults, and providing actionable information to the end-user service group. By looking over so many wind turbines, the specialists have seen a wide range of faults in the bearings and the complex planetary gearboxes.

The specialists in the Surveillance Centre work directly with the wind-turbine end-user service group. Close collaboration is vital to ensure the diagnoses are understood, the correct action is done and feedback from the end-user is used to refine the failure mode analysis model to be more accurate. There are three types of tasks (reports) carried out by the specialists:

- Alarm report
- Status report
- Diagnostic report

The Alarm report is done when a developing fault has been detected. The Alarm Manager program, described earlier, assigns a preliminary severity assessment to the alarm condition. In an alarm situation, the Surveillance Centre functions as follows:

- Both the end-user and specialists are automatically informed of the alarm condition by the diagnostic server (described in the previous section)
- Specialists at the Surveillance Centre do detailed analysis and diagnosis of the detected fault, assign a final severity assessment to the alarm and provide service recommendations to the end-user service group in a short and concise alarm report describing what has been observed, an interpretation of the observation and a recommended action to remedy the problem.
- End-user takes action and closes the alarm report
- End-user gives feedback on the report to the specialists so they fine-tune their prognosis model for the next time the same fault occurs again

The Status report is a routine review on the condition of the wind turbines after a pre-determined interval of time, such as six months. In this case the report presents a general assessment on the condition of the wind turbines for the last six months and makes a prognosis for the next six months.

The Diagnostic report is a special customer request to make a thorough investigation of a machine component, such as a troublesome gearbox.

Remote access by the end-user

Most of the wind-turbine operators do not have their own vibration specialists so they use Brüel & Kjær Vibro Surveillance Centre for all their fault detection and diagnosis needs. There are, however, some end-users who have some level of expertise, and they want to verify the diagnoses made by the Surveillance Centre and/or share the responsibilities of diagnosing faults on the wind turbines. This shared responsibility is quite common with many industries that have their own stand-alone condition monitoring systems.

Brüel & Kjær Vibro offers full data transparency. Wind turbine operator's access to data is possible in the Surveillance Centre diagnostic server. A

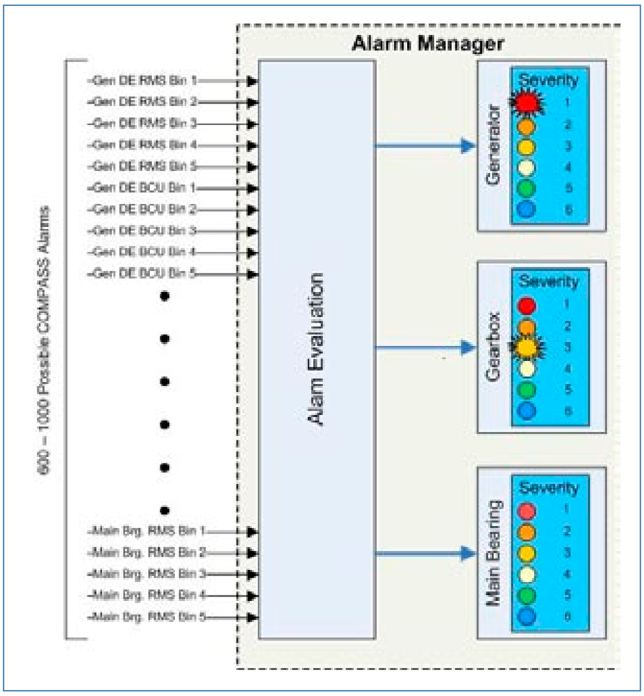


Figure 4
The Alarm Manager program evaluates incoming and previous alarms

special analysis program has been developed by Brüel & Kjær Vibro that allows the end-user to access the “raw” vibration and process data and time series so they can do their own analysis. The advanced data analysis program and the raw vibration data in the form of time wave forms can be downloaded from the so called Data Subscription Homepage. This homepage also provides each user access to a park alarm status as well as a detailed alarm status per turbine.

Data ownership

One of the advantages for the customers is that Brüel & Kjær Vibro hosts the IT system that takes care of the customer’s data. The customer still owns the data. This is comparable home banking via the Internet, where you are the owner of the money shown on your accounts and always have access to an overview. And like in a bank, Brüel & Kjær Vibro ensures that all data is backed up and secured and the system is running 24/7. The remote monitoring group has its own dedicated IT support specialized in handling the application and the communication with the front end of the monitoring systems via GPRS or LAN. Upon termination of the condition monitoring service contract, the customers can get their data delivered in an industry standard database format.

Conclusion

The comprehensive, stand-alone condition monitoring system that is used in some plants is very costly to implement if there are many remotely located machines. In addition to this, a shortage of customer expertise in vibration analysis and diagnosis limits the success they can achieve in optimizing machine uptime.

The remote monitoring and diagnosis concept introduced in the wind turbine industry addresses these problems in a collaborative, cost-effective manner that involves the wind turbine operators, the wind turbine manufacturer and the monitoring system manufacturer. The monitoring hardware on the machines is limited to only web-enabled data acquisition units, and the diagnostic server is moved to an external Surveillance Centre. Here a group of qualified vibration specialists detect and diagnose faults, and give service recommendations to the end-user service group. After the service is done, the Surveillance Centre is informed by the end-user so they can improve their diagnostic and prognosis techniques. The wind turbine operator in return can ask the Surveillance Centre to do diagnostic tests on troublesome machine components.

The Surveillance Centre for the wind turbine industry has been in operation for more than four years, with installations on several hundred wind turbines in Europe. ■

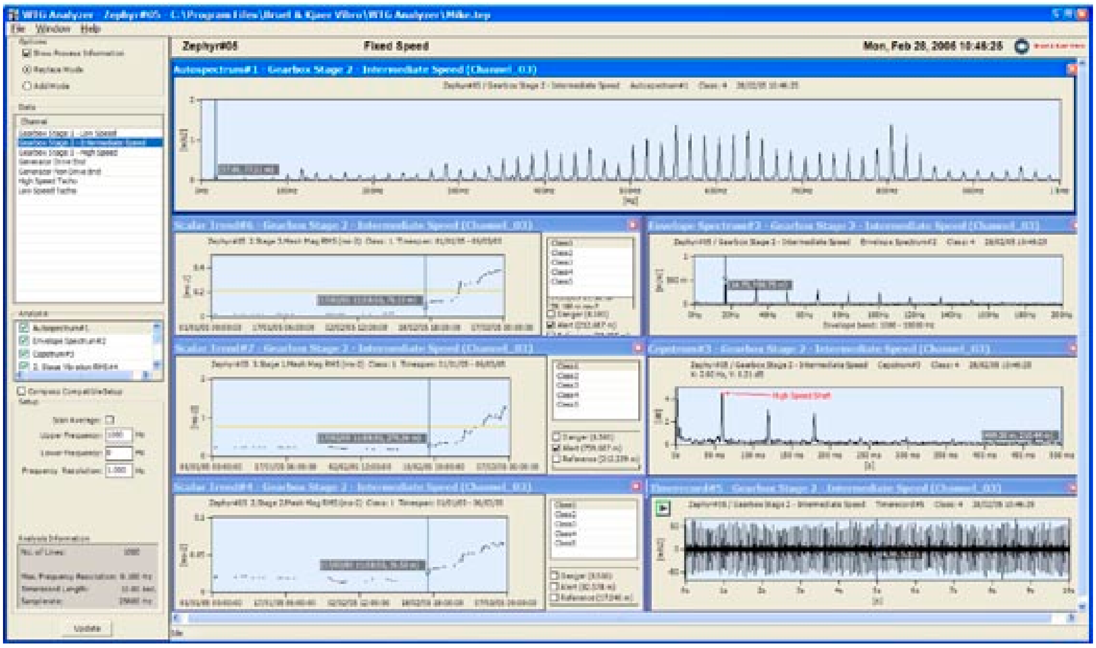


Figure 5 Wind Turbine Generator Analysis program for analyzing data from the Surveillance Centre diagnostic server by the end-user