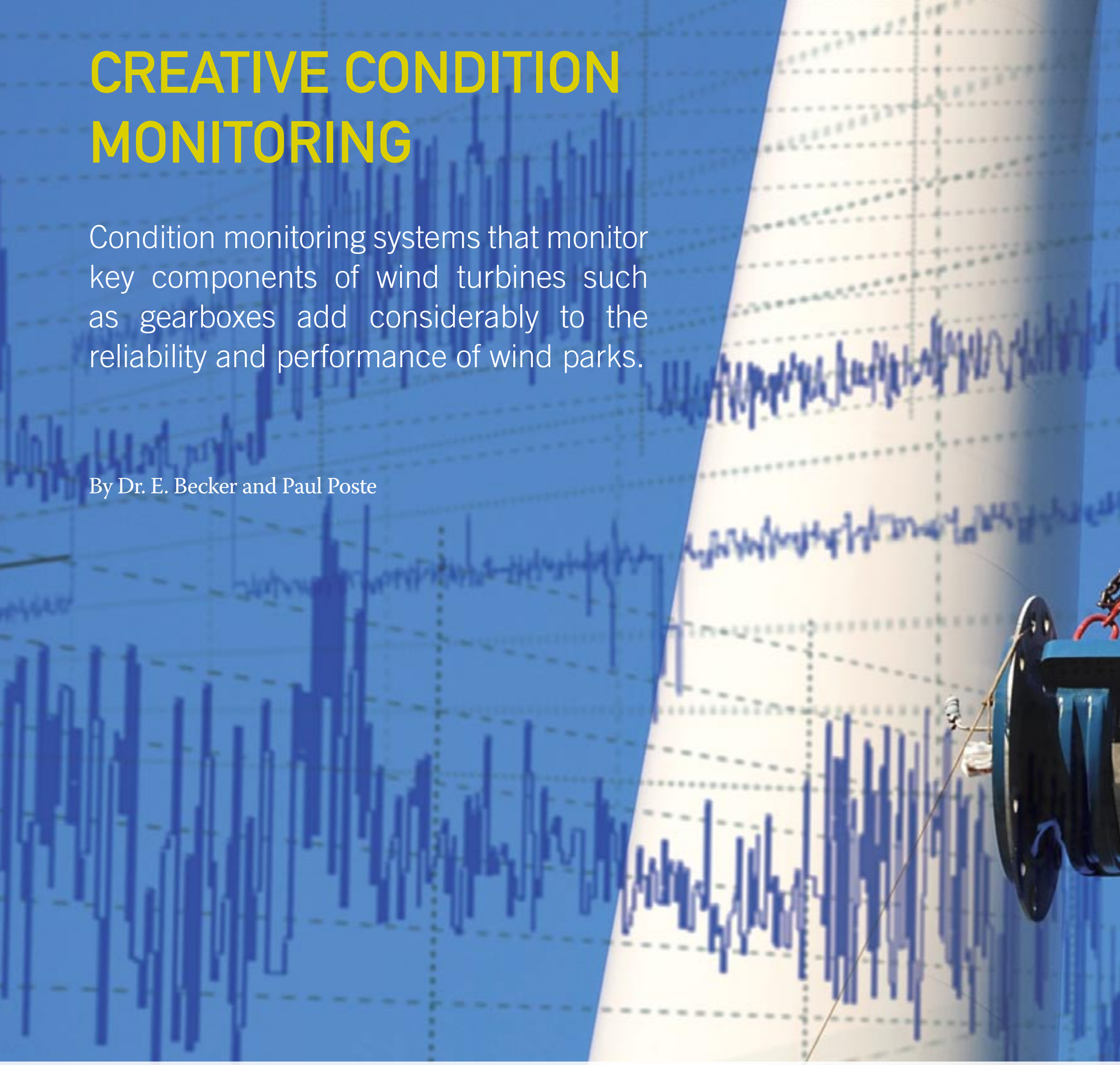
CREATIVE CONDITION MONITORING

Condition monitoring systems that monitor key components of wind turbines such as gearboxes add considerably to the reliability and performance of wind parks.

By Dr. E. Becker and Paul Poste



Dr. E. Becker and Paul Poste are with PRÜFTECHNIK Condition Monitoring, which is based in Ismaning, Germany. To learn more contact U.S. representative LUDECA at (305) 591-8935, info@ludeca.com, or www.ludeca.com.

CONDITION MONITORING IS A MACHINE maintenance tool that is becoming a component of long-term service packages provided by some wind turbine manufacturers. In general, the actual condition of rotating machinery can be measured and evaluated offline using mobile measurement equipment and online using permanently installed devices. Today it is state-of-the-art for onshore and offshore wind turbines to be equipped with vibration-based condition monitoring.

Wind turbine gear manufacturers are being challenged to supply gears with a reduced mass-to-output ratio that are low in noise and vibration and that provide the required operating reliability and lifespan. Figure 1 shows the most widespread Danish drive train design, with a planetary/spur gear. Experience in the wind energy sector shows that some gear types of this design did not meet the new requirements and needed retrofitting after only a few thousand hours of operation. Because of the high incidence of gear damage found, German insurers introduced a so-called review clause in 2002 as a “cost deterrent” to encourage an improvement in operating life. It requires that all roller bearings in a drive train be replaced after either 40,000 operating hours or five years, whichever is earlier, unless an appropriate Condition Monitoring System (CMS) has been installed. This review clause has also been used by insurers to modify insurance contracts and introduce less

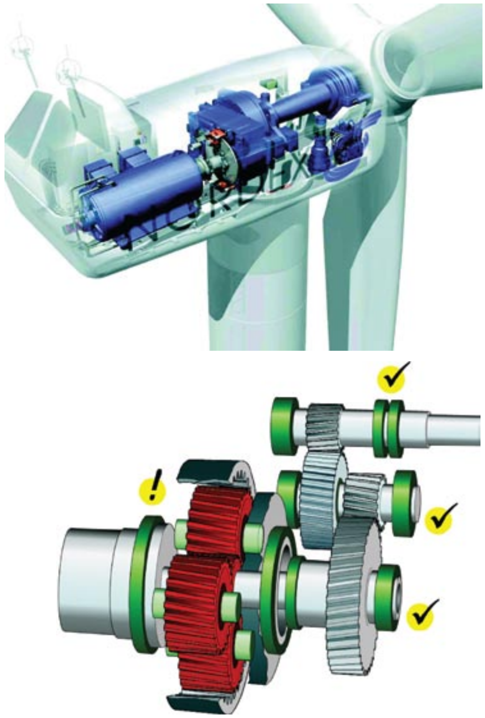


Fig 1: Drive train and planetary/spur gear for wind turbines up to approximately 2 MW.

favorable write-offs for the policyholder. Additionally, Allianz has stipulated CMS operational requirements that include comprehensive testing procedures before a CMS system is approved for use. While Allianz will only accept inspected online CMS in its insurance contracts, the Gothaer Insurance Company drew up guidelines for mobile condition monitoring by independent inspectors. In 2003, GL WindEnergie expanded insurer requirements and made a certified CMS obligatory for GL-certified offshore wind turbines.

In the meantime, in Germany, several thousand mobile vibration measurements have been performed on wind turbines, and some 1,000 online condition monitoring systems have been installed. Experience has shown that condition monitoring on the main gears of the drive train presented a number of problems. In some cases, gearboxes were unnecessarily dismantled due to diagnostic errors, and CMS results were misused for legal disputes between the operator and manufacturer. Notwithstanding these early problems, and independently of insurer demands, operators of small wind turbines are becoming increasingly interested in integrating simple condition monitoring systems into their wind parks. These systems permanently record diagnostic parameters of components and indicate any changes in their operating condition (fig. 2).

A range of condition monitoring solutions is now available on the market that is also certified by leading German insurers and by GL WindEnergie. Many of them are mobile monitoring solutions that can, for example, be linked up with an analysis service or diagnostics center. Low-priced online models are available for use in fixed-speed and variable speed wind turbines that do not require a dedicated computer in the wind turbine, even when used on variable-speed turbines with resampling. Data can be sent from these systems via e-mail to a remote service center.

VIBRATION-BASED CONDITION MONITORING

Various levels of condition monitoring are possible. Level 1 condition monitoring of wind turbines is based on threshold monitoring of broadband vibration parameters. The so-called vibration severity is often used. In accordance with ISO 10816-3, it classifies vibration velocity amplitudes in the frequency range 10 to 1000 Hz as a function of turbine output. The threshold values for wind turbines are as yet undefined but are currently being prepared by a VDI workgroup (a German engineering association). Gear manufacturers and system manufacturers like to stipulate in the contract the vibration severities and velocities in the frequency range of 10 Hz to 100 Hz. However, this only applies to acceptance testing on test benches. Level 2 condition monitoring is performed by monitoring the thresholds of band-selective diagnostic parameters, which are tracked at fixed speeds and variable speeds. Frequency spectra are measured when the CMS is put into operation and when the thresholds are exceeded. The spectra are sent to a diagnostic center by e-mail. Level 3 condition monitoring is based on in-depth diagnoses and takes place after measurements are taken, for example, in a diagnostic center. It works with amplitude spectra, envelope spectra, cepstra, time analyses, and other special procedures. Level 2 and Level 3 condition monitoring use the empirical evidence from the spectral analysis of gears, toothing, rotors, roller bearings, and electrical parts, such as significant vibration patterns and damage characteristics typical for these parts.

It is the task of Level 2 and Level 3 condition monitoring to correlate the components in the spectral analyses with the individual drive train parts and to set suitable frequency bands and warning and alarm thresholds for each measurement location. In total, the Danish drive train design depicted in fig. 1 has about 200 bands that must be set and monitored if the condition monitoring strategy is to be in accordance with the Allianz Center for Technology (AZT) and GL WindEnergie certification. In addition, practitioners know that several harmonics and/or sidebands appear in frequency spectra such as those of tooth mesh frequencies—a phenomenon that further increases the number of frequency bands.

If the operator wishes to measure a tooth breakage in a planet gear, an adequate number of passes and about five minutes of measuring time are needed to measure any disturbances. For information on the bearing condition of the planet gears, suitable filters in the envelope spectrum must be selected and rotational frequency excitations in the envelope spectra monitored. Another important diagnostic tool for planetary bearings with spherical roller bearings is sideband analysis. Bearing play results in multiple sidebands that influence the acoustic and vibration-related running characteristics of the planetary stage.

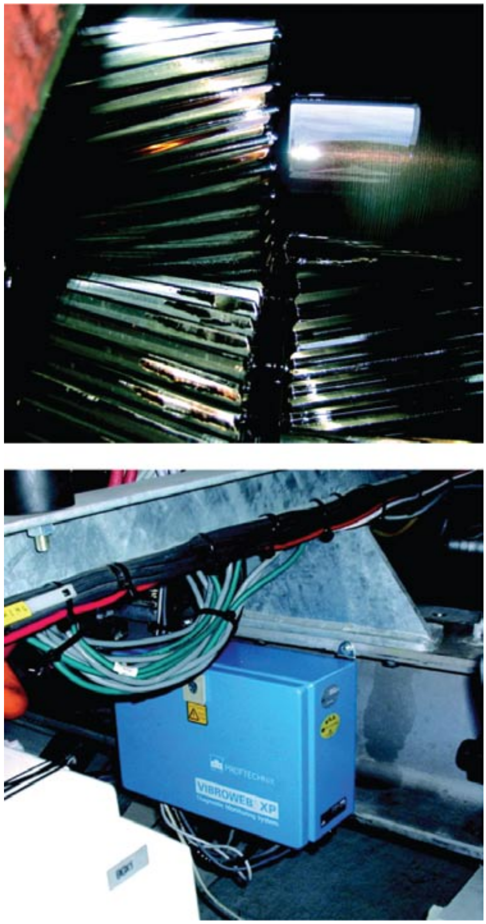


Fig. 2: View of tooth damage in a wind turbine gear and a CMS mounted on the main carrier of a wind turbine.

Analysis of roller bearing and gear conditions is relatively straightforward if the frequency or order spectra remain unchanged over a period of weeks, months, or years, and if diagnostic parameters remain stable. Monitoring can be performed using so-called “traffic light” frequency spectra or by monitoring the corresponding diagnostic parameters. If the warning threshold is exceeded or the yellow area in the traffic light frequency spectra is reached, e-mails containing the frequency analyses are sent to the service specialist. The affected wind turbine is given a higher diagnostic priority, and diagnostic specialists are able to directly monitor the affected turbine and activate further special analyses. An alarm message is issued if the red area is reached. Additional diagnoses and selective maintenance can be planned for and prepared.

Fig. 3: Typical measurement locations for mobile measurement and view of a VIBXPERT unit.

Depending on the type of damage, advanced warning of up to six months can be achieved.

MOBILE MONITORING

Experienced engineers are aware that the load on gears with planetary stages, helical gearing, and tooth corrections has a significant influence on vibration characteristics. When testing gear loads, the rule generally applies that measurements should occur at a minimum of 20 percent of rated torque and at the rated rotational speed. In the wind energy sector, it is state-of-the-art today for leading gear manufacturers to test wind turbine gearing at the rated torque and to measure and record parameters such as the frequency spectra of the vibration velocity during test runs. Such constant load conditions over extended periods only exist in exposed mountainous regions or offshore. In the case of onshore wind turbines, the mean wind force changes more or less hourly and the gear loads are influenced by wind gusts.

To perform mobile measurements, the minimum load should be present, and the effect of wind gusts should be averaged by using sufficiently long measurement periods. Moreover, repeat measurements must be measured in the same load window. Because of the unpredictability of wind speed, etc., external measurement technicians who have to travel long distances to make specific measurements rarely meet with the same wind conditions. It is for this reason that mobile condition monitoring solutions have been developed, making it possible for engineers to confine their vibration-based condition measurements to wind speeds of six to 10 m/s over extended measurement periods. The measurement locations, diagnos-

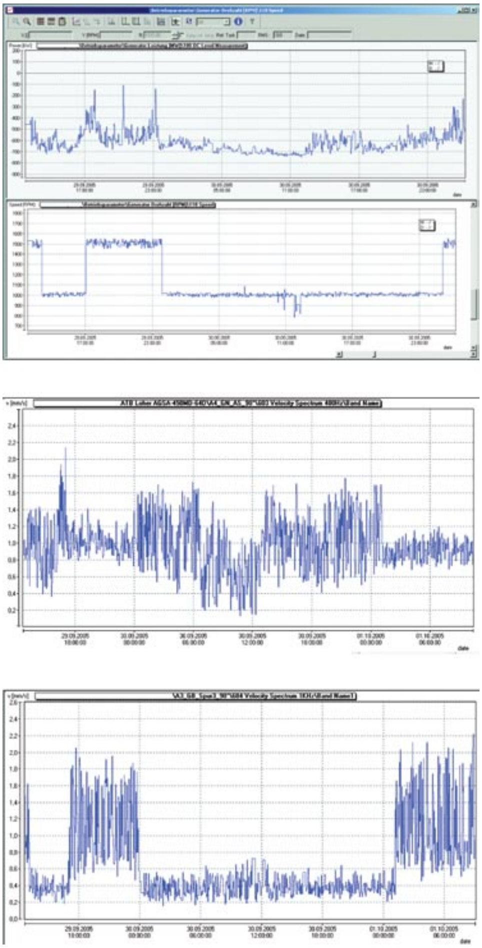


Fig. 4: Measurement of various parameters for a fixed-speed, stall-controlled turbine with a pole-changeable generator measured over a three-day period.

tic procedure and measurement route can be prepared and all results saved for the specific turbine. The measurement results can then be downloaded from the Internet.

ONLINE MONITORING

Fixed-Speed Stall-Controlled Turbines: Medium-sized wind turbines often use multipole generators that rotate at approximately 1,005 rpm at wind speeds up to six m/s and then switch to a higher speed of around 1,505 rpm at greater wind speeds. In this way the wind turbine can be operated close to maximum capacity at both low and high wind speeds. Figure 4 shows an example of various parameters for this type of turbine with a pole-changeable generator measured over a three-day period: the generator power; the generator speed; the vibration severity of the gearbox, which is measured radially; and the vibration severity of the generator. The output signal in kW was taken from the control unit, the amplitudes of the vibrations in mm/s were determined using the frequency spectra measured online, and the speed in rpm was obtained by non-contact measurement. In this type of chart the varying load conditions can be identified and it can be concluded that, in this particular case, the rotational vibrations in the generator decrease at greater output. The reason for the high vibration amplitudes was a pronounced tooth correction that only took effect at the rated load. A requirement for this type of analysis and interpretation is knowledge of the gear design, and of course a suitable condition monitoring system. It is common that two-stage or three-stage spur gears are usually used up to approximately 450 kW, and planetary stages only come into use in the gear input stage in larger turbines.

If the threshold limit in fig. 4 is exceeded, an e-mail notification containing the associated frequency spectra can be automatically sent to a diagnostic center. If the threshold is not exceeded, it is sufficient for the CMS to independently extract the diagnostic parameters from the frequency spectra and store a value once per minute. Since the parameter values in the circular buffer will be overwritten after some time, insurance companies demand that the parameter values be e-mailed on a regular basis, for example once per day, and stored in a service database. If the wind turbine is not running, or if the vibration values barely change, the data is compressed to avoid the transmission of large data volumes. Some CMS can continuously provide information on how the gear vibrations change at each of a pre-selected number of locations as a function of the wind load. Some insurance companies in Germany reward this diagnostic strategy with fewer wind turbine inspections and improved write-off conditions.

Variable-Speed Turbines: Turbines that exceed 1.5 MW tend to employ variable-speed drive trains in which any change in wind speed results in a change in the rotational speed. Rotational speeds can occasionally vary by as much as 60 percent of the maximum speed. This variability influences the measured vibration spectra and gear characteristics of the turbine. Additional factors are blade pitch variations, load changes, dynamic load such as from oblique incident flow, and loads from the converter control unit acting on the generator side. The most common system today in geared variable-speed wind turbines is the doubly fed induction generator, but it is gradually being replaced by fully rated converters. Due to the controlled operation of the wind turbine, both systems can be operated efficiently

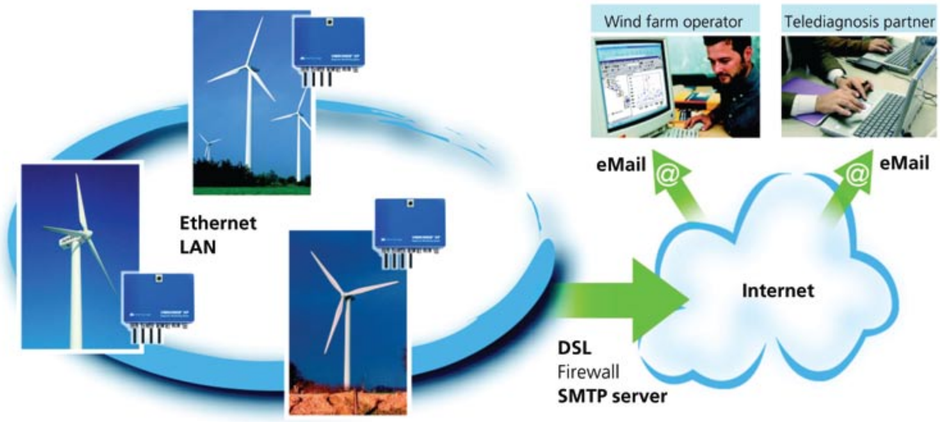


Fig. 5: Data management structure with e-mail data transmission.

at low winds as well, and damped control can reduce mechanical loads in the drive train. In high winds, the rotor output is additionally limited by pitch control or stall/active-stall control.

With respect to condition monitoring this means that not only the output, but also the gear-specific excitation frequencies vary with the wind speed. The frequency spectra measured over extended periods blur to such a degree that it becomes impossible to distinguish the individual frequency components and valuable diagnosis information is lost. In such cases order analyses are essential to obtain well-defined spectral analyses in variable-speed wind turbines. Thus, instead of determining the average frequency spectrum, some CMS solutions determine the order analyses by means of resampling. Wind-related rotational speed fluctuations are accounted for in the vibration signals and the diagnostician is provided with familiar diagrams, although now in the form of an order spectrum. Experience has shown that in addition to the gear design, the system and control parameters also have an effect on the vibration characteristics, which vary with the manufacturer and machine. To be able to distinguish operation-related influences on vibration from condition-related influences, the vibration and diagnostic parameters and the condition diagnosis are measured as a function of the operating parameters: rotational speed, generator output, and wind speed. AZT and GL WindEnergie require that all CMS certified to their standards must always send measurement results to a monitoring center to permit the data to be processed again in their entirety.

MONITORING CENTER TASKS

Field experience indicates that a certified condition monitoring hardware system does not necessarily lead to reliable fault diagnosis. The result depends on the correct installation, parameterization, and implementation of the online CMS, as well as on a rapid and appropriate response to notifications of a change in condition.

The costs and the time spent by personnel for condition monitoring increase rapidly if measurement data is "collected" from several hundred turbines via telephone modem and specialists must travel to the wind farm to change programming, alarm, and threshold values. To overcome these problems, e-mail data transfer systems with central data storage automate as many routine tasks as possible and avoid needless lost time collecting data. The operator and turbine manufacturer can decide whether they would like to purchase the hosting service with condition diagnosis on call or a teleservice package. Figure 5 shows an example of a basic data management concept. The wind turbine data from the wind farm is sent to the monitoring center via Ethernet. The control center and the diagnostic center have access to the databases. On this basis, condition monitoring and service experience can be built up in partnerships and managed centrally.

In the monitoring center, the incoming measurement data are routinely checked, threshold values are adjusted if necessary, condition reports are prepared and incoming alarms and warning messages are responded to. Measures that can be taken to deal with incipient damage are suggested. The employees of the monitoring center must be familiar with the special characteristics of the wind turbine being monitored to distinguish whether an exceeded threshold is due to random or operation-related causes or due to damage-related alarms. Condition-based maintenance becomes reality.