inFOCUS

Boosting operating efficiency

Predictive maintenance based on vibration monitoring can raise the efficiency of wind turbines by preventing catastrophic failure and unscheduled downtime.

By Martin Armson

The cost of maintenance in the wind-turbine industry is escalating: A report from GlobalData estimates that the cost of turbine maintenance will rise to about $17 billion in 2020 — nearly twice that of 2014. It's because the number of turbines is increasing — including many old ones that require more frequent maintenance. For an offshore wind farm, about one-quarter of total cost is accounted for by operation and maintenance.

Introducing sophisticated condition monitoring technology can help keep these costs under control. Employing vibration monitoring to keep tabs on a turbine's rotating parts helps maintenance teams to spot potential problems and carry out necessary repairs at the earliest opportunity in order to avoid breakdowns. In this technique, the vibration "signature" of bearings and other moving parts is monitored using vibration sensors (otherwise known as "accelerometers"). Any variation from the norm can indicate early signs of failure, allowing small problems to be corrected before they spiral out of control.

Wind power is a booming area of engineering. In 2017, global capacity for wind turbines hit 539,581, according to the Global Wind Energy Council. Not surprisingly, this figure is expected to grow significantly over the next decade — some outlets suggest global capacity may be four times higher by 2030.

AC accelerometers are typically used with data collectors for the vibration monitoring of more critical or complex machines, such as gearboxes and turbines, so they are the sensor of choice for wind turbines. (Courtesy: Hansford Sensors)

Let's not forget, however, that wind power is also highly demanding. To achieve profit, operators must run as efficiently as possible by raising output and controlling costs. Preventing unscheduled downtime — such as through catastrophic part failure — is key to this. However, wind turbines must perform under punishing conditions: There have been instances in recent years of high winds causing turbines to explode through gear failure. As well as footing the repair bill, operators may also be faced with fines and compensation costs.

While the sensors used in high-spec applications like wind turbines are top of the range, their price has come down far enough to justify the use of multiple sensors, which

enhances data gathering. Using multiple sensors also helps to boost techniques such as acceleration enveloping (more on this later), which "extracts" the vibration signal of a failing bearing by filtering out the "noise" of other components.

DOWNTIME COSTS

Unscheduled downtime does not just affect the wind-turbine industry: According to a recent joint survey from plantservices.com and ARC advisory group, the problem costs global process industries about $20 billion every year. The goal for nearly 90 percent of all companies using predictive maintenance was to increase uptime, said the survey. In addition, more than half wanted to use predictive maintenance techniques and processes to cut maintenance and overall operational costs.

Among its conclusions, the survey recommended that predictive maintenance should ideally be integrated with plant-wide control systems, and that the operation and outcomes of such systems should be linked to financial incentives for plant operators. It makes a strong case for fitting such systems, especially in an industry such as wind energy where maintenance is difficult and costly, and operators are under pressure to maximize efficiency and productivity.

While this type of maintenance regime has its obvious advantages, there are historical factors to overcome: Many engineers have genuinely considered it cheaper to continue running with worn equipment rather than invest in "costly" replacements. However, when the costs of unscheduled downtime are considered, this "efficiency" theory is proved to be nothing more than myth.

Machines that have begun to exhibit defects are at greater risk of failure than those without defects, so they are more likely to generate unwelcome downtime costs. In contrast, a condition-monitoring system helps engineers plan maintenance and replace defective components before problems occur.

SENSOR INSTALLATION

When mounted in key positions on mechanical equipment, vibration sensors offer continuous monitoring and analysis. While this requires investment, it is minimal when compared with the potential cost of downtime on a wind turbine.

There are two main types of industrial accelerometers: AC accelerometers and 4-20mA accelerometers. AC accelerometers are typically used with data collectors for the vibration monitoring of more critical or complex machines, such as gearboxes and turbines, so are the sensor of choice for wind turbines. In general, 4-20mA sensors are used with PLCs to measure lower value assets such as pumps and motors.

The latest vibration monitoring sensors operate over a wide temperature range, measuring both high and low frequencies with low hysteresis characteristics and high levels of accuracy. Because of the punishing conditions they must withstand, they offer robust and reliable service thanks to stainless steel sensor housings to prevent the ingress of moisture, dust, oils, and other contaminants.

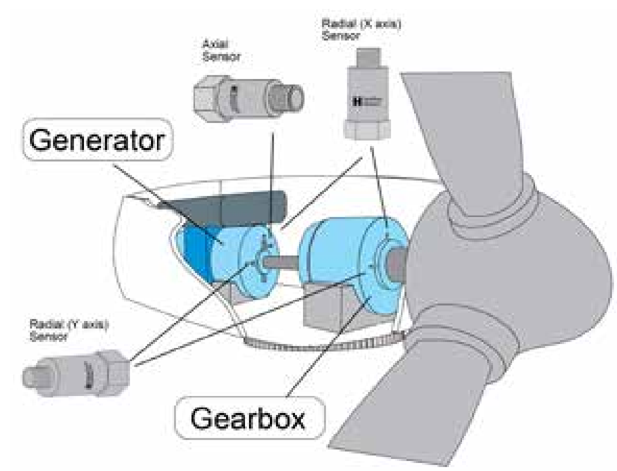
Accelerometers can be mounted on casings to measure the vibrations of the casing and/or the radial and axial vibration of rotating shafts. A typical approach is to examine the individual frequencies in a signal that correspond to certain mechanical components or types of malfunction – such as shaft imbalance or misalignment, so analysis of this data can identify the location and nature of a given problem. A typical example would be a rolling-element bearing that exhibits increasing vibration signals at specific frequencies as wear increases.

VIBRATION SPECIFICATION

To specify a vibration accelerometer correctly, engineers must consider the vibration level and frequency range to be measured, weight or fitting restrictions, and environmental conditions. It's best to work closely with a supplier that has appropriate industry experience and knowledge.

For wind-turbine applications, low-frequency accelerometers are the ideal choice for detecting anomalies. In general, the models used on wind turbines are 100mV/g, or the higher sensitivity 250 or even 500mV/g. These might

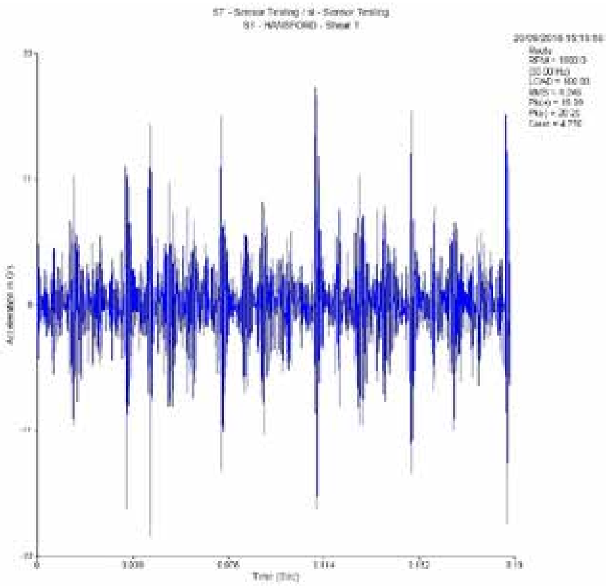
When mounted in key positions on mechanical equipment, vibration sensors offer continuous monitoring and analysis. While this requires investment, it is minimal when compared with the potential cost of downtime on a wind turbine. (Courtesy: Hansford Sensors)



The typical locations of sensors in wind turbines. (Courtesy: Hansford Sensors)

be used to monitor the low-speed aspects of the generator such as output shafts.

In most of the wind-turbine projects Hansford Sensors has been involved in, a local junction box was used to house the accelerometer cabling at the top of the turbine. This is usually fed back down to the ground using multi-core screened twisted pair cable to connect it to an online monitoring system, allowing operators to monitor turbine conditions in real time using a handheld device with internet access. Such a system will identify faults and enable maintenance engineers to take corrective action prior to failure.



This typical vibration monitoring signature shows acceleration over time from an AC output accelerometer. (Courtesy: Hansford Sensors)

ACCELERATED RESULTS

While the latest accelerometers are highly sophisticated, in some instances it can be a challenge to find a signal — such as that of a malfunctioning bearing — among all the other vibrations generated by a turbine.

An effective way to do it is to use acceleration enveloping: a signal processing technique that filters out low-level, repetitive vibrations to leave a "clean" signal that indicates the sound of a bearing alone. It is used in many applications to separate the signal of a malfunctioning bearing from the noise from the rest of a machine. It enables engineers to overcome the limitations of conventional velocity spectrum measurements and detect component failures at the earliest possible stage. The rate of wear then can be monitored and maintenance work planned accordingly.

A defect in a rolling element will cause repeated impacts that generate resonant frequencies in the surrounding machine surfaces, causing a "ringing" signal. Although the amplitude of the signal decays between impacts and becomes part of the overall vibration signal of the machine, it will affect the natural resonance response of the machine at the impact frequencies.

The signal from an accelerometer can be enhanced with acceleration enveloping. It progressively filters out unwanted parts of the vibration spectrum until the signal of the bearing defect can be isolated from the noise around it and clearly be identified.

LOW AND HIGH

The unfiltered waveform from a failing bearing is a mixture of low and high frequencies with no obvious pattern. Acceleration enveloping uses a two-step process to overcome this. The first step is to apply a band pass filter, which isolates only those frequencies in which the signal of interest is hiding. The filtered output pinpoints repeating, high frequency signals, caused by impacts of the rolling elements hitting the defect of the rotating bearing. These signals are represented graphically by a series of energy "spikes."

In the second step, the filtered output is passed through an envelope. Here, the waveform is rectified — that is, the negative part is inverted to positive. This is then demodulated by tracing a line over the general shape of the rectified signal. This "envelope" is now used as a true vibration signal, helping it stand out from the noise.

The envelope helps to contain regularly spaced signals, such as a single defect on a raceway. Other causes of noise, such as shaft rub, are random, so they will not produce evenly spaced peaks. Once the signal has been filtered, the information is taken from the accelerometer using a data collector. A specialist can then review and interpret the data and decide whether maintenance is required immediately or can be done as part of routine schedules.

CONCLUSION

Wind-turbine operators are under constant pressure to run operations as efficiently as possible by raising output and controlling costs.

A predictive maintenance regime based on vibration monitoring can reduce catastrophic breakdowns, boost turbine availability, and increase the economic viability of wind energy. Coupling this with acceleration enveloping can further enhance efficiency.

This kind of maintenance regime is especially effective for offshore wind turbines, which are more expensive to repair due to their remoteness. Together, these techniques can help to cut the cost of maintenance and begin chipping away at the wind-power sector's potential $17 billion maintenance bill by 2020.

Martin Armson heads up the U.S. operations for Hansford Sensors based in one of the fastest-growing states, South Carolina. Armson has a Mechanical Engineering degree. He first became involved in the vibration monitoring industry in the 1980s. Since then, Armson has worked with several leading companies before joining Hansford Sensors in 2017.

When machines wear out, they perform worse, are less productive, and finally, begin to fail as a result of mechanical damage. (Courtesy: Photostock)

Protecting critical equipment

How tribology can help extend machinery service life.

By Edgar Martínez

Tribology is the science of interacting surfaces in relative motion. Basically, it studies friction, wear, and lubrication — three phenomena linked to surface degradation and, thus, to machine reliability and performance. When machines wear out, they perform worse, are less productive, and finally, begin to fail as a result of mechanical damage.

A major reference covering all major aspects of tribology is the book published by Emeritus Professor Ernest Rabinowicz, Ph.D. in Physical Chemistry, who worked for several decades at the Massachusetts Institute of Technology doing research in this field. He studied the things that cause machines used in a variety of industries to lose usefulness. According to Rabinowicz, surface degradation was the cause of more than 50 percent of loss of usefulness, as shown in the graph in Figure 1.

Therefore, controlling the conditions that affect tribological behavior is of the utmost importance to protect critical equipment. Drawing on knowledge from the fields of materials technology, physics, and chemistry, tribology is a truly multidisciplinary area. Its applications aim at reducing machine downtime while increasing productivity. Tribology can help extend the service life of critical machinery, as it provides the tools required to optimize friction and wear values.

Researchers around the world have shown the huge potential savings that can be achieved with improved tribological knowledge in a variety of industries. According to Theo Mang, Kirsten Bobzin, and Thorsten Bartels, authors of Industrial Tribology: Tribosystems, Friction, Wear and Surface Engineering, Lubrication (2011), gross domestic savings resulting from proper use of tribological knowledge could amount to 1.5 percent of the GDP. In the European Union, up to $303 billion could be saved with better tribological practice.

HOW CAN TRIBOLOGY HELP PREVENT MACHINE FAILURE?

Each tribological system (that is, machine and lubricant taken as a whole) has its own features. Therefore, there is no single answer to this question.

To minimize machine failure, the first step is to choose the right lubricant. Depending on the industry, there are original equipment manufacturer (OEM) classifications and specific recommendations that should be followed at all times. When this information is not available, experts in lubricants can give advice on technical specifications such as viscosity,

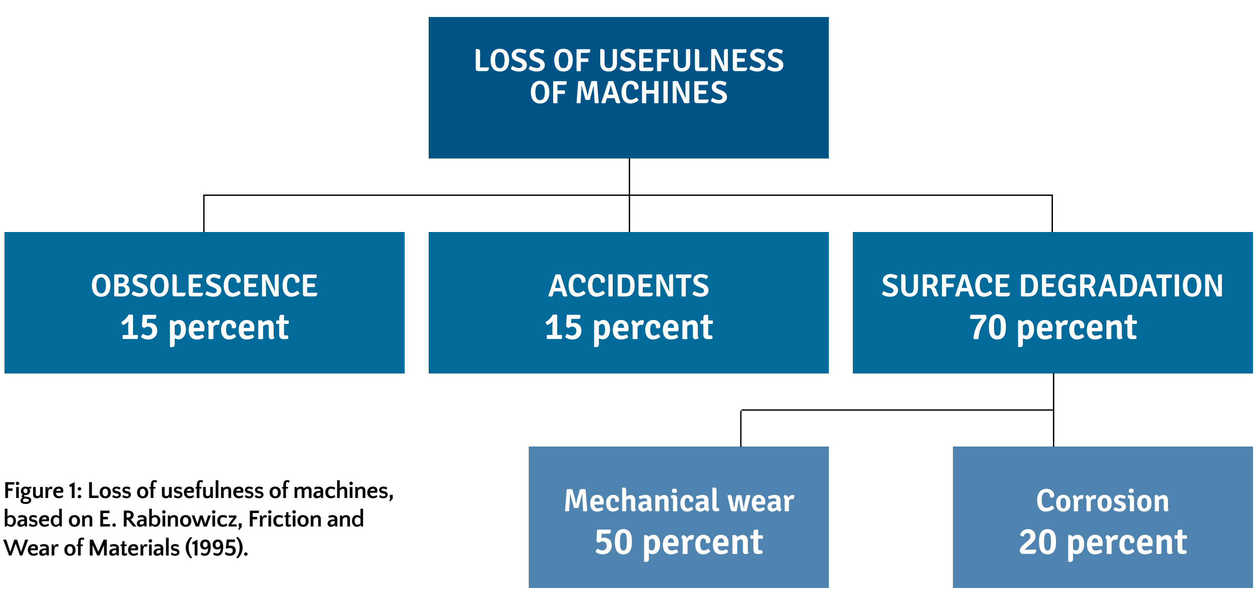


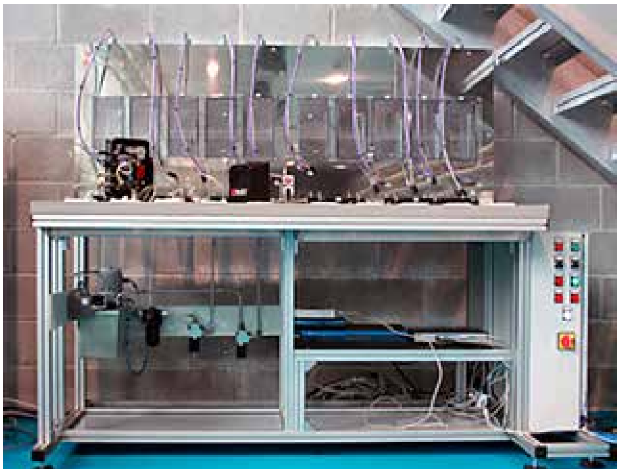
Figure 1: Loss of usefulness of machines, based on E. Rabinowicz, Friction and Wear of Materials (1995).

An optical sensor that monitors the state of lubricant oil. (Courtesy: Atten2)

base oils, additives, and so on.

Another key to keeping machinery at optimal performance involves monitoring fluid condition and checking start-up operation. Users must be fully aware of OEM fluid cleanliness recommendations before starting a machine. Since new oils can come with high contamination levels, filtering them before starting up the machine can be an effective measure.

When partial oil changes are performed, it is important to prevent undesirable oil blends that can facilitate reactions that change the properties of the lubricating fluid or the condition of machine surfaces. A lubricating oil with inadequate viscosity values, for example, will not function as expected throughout its lifespan. The fluid film that separates the metal surfaces of tools and machines will be too thin, allowing for contact between them, and thus leading to wear and, eventually, failure. In addition, potentially incompatible chemicals in the different lubricants may come into contact, in which case a complete system flush is required to drain the full volume of used oil before refilling the system with new oil.



A work table at Atten2. (Courtesy: Atten2)

Three basic parameters should be assessed in order to ensure good tribological behavior: lubricant degradation, tribological system contamination, and machine wear.

> Tribology can help extend the service life of critical machinery, as it provides the tools required to optimize friction and wear values.

Inadequate tribology-based analysis of critical equipment can lead to catastrophic machine failure (adapted from Machinery Lubrication).

Monitoring all the aforementioned elements of oil-lubricated equipment is one of the best tribological practices. The criticality and type of the machines being assessed will determine whether regular offline analysis can be carried out or innovative online monitoring technologies should be applied.

Online sensors can also be used for measuring critical characteristics of lubricating oils and to provide indicators of the condition of the machines the oils are used in.

HOW CAN LUBRICATING OIL SERVICE LIFE BE MAXIMIZED IN CRITICAL EQUIPMENT?

Lubricating oil service life is affected by a number of factors. You can extend it, or at least prevent rapid degradation, by using it properly. The following best practices are recommended:

Choosing the right lubricant: ISO grades and viscosity are the most important parameters, since they are the primary indicators for the ability of fluids to keep contact areas separated. It is necessary to choose the right additive package as well, since additives cover or enhance a range of properties of the base stock, such as inhibiting the production of air bubbles or foam, preventing the metal from causing oil oxidation, or keeping metal surfaces from touching even at high pressure inside gears.

Maintaining the machine and the lubricating system in optimal working conditions: The machine-lubricant system needs to work within a specific range of parameters; otherwise, the stress on the system increases, leading to higher temperatures and rapid degradation of the lubricating oil. Particle production and air entering the lubricating fluid might increase, too, affecting the degradation process. Using the proper filters and anti-foam agents can help reduce the impact of external factors such as metal particles or water, thus maximizing the useful life of the lubricating oil.

Monitoring the lubricating oil can help detect critical degradation values, so the user can take measures to extend the fluid's lifetime and enhance the reliability of the critical machinery and the processes involved.

WHAT MEASURES ARE TO BE TAKEN AFTER MONITORING AND ANALYZING THE TRIBOLOGICAL CONDITION OF CRITICAL MACHINERY?

Optimizing tribological conditions prevents premature machinery wear and reduces friction, thus increasing energy efficiency and ensuring a longer service life for your machinery.

Controlling the tribological conditions in critical equipment provides useful information on probable causes for failure. Assessing the tribosystem allows for the identification of factors (surfaces, working conditions, lubricating fluids) that can be controlled by taking corrective and preventive maintenance measures. For instance, identifying the types of wear can help determine whether machine failure is the result of lubricant condition or surface damage. With this information in hand, maintenance engineers and technicians can make better-informed decisions for greater machine efficiency and optimized costs.

Likewise, corrosion as the cause of wear is associated with inadequate oil condition, while wear resulting from mechanical abrasion will lead to control of the tribological condition of the contacting surfaces.

Edgar Martínez De Aguas has been the CEO at Atten2 since 2016. He has an extensive career with more than 15 years of experience in O&M management projects in different sectors (paper, steel, petrochemical, food), failure and root cause analysis. Martínez is a mechanical engineer by the Universidad Simón Bolivar in Venezuela, and he also completed an MBA by the Instituto de Empresa in Madrid. He also holds a project management and direction certificate, Vibration Analysis Level I and Certified Maintenance and Reliability Professional (CMRP).

Hardware and software are critical for the secure and economical operation of wind turbines. (Courtesy: NREL)

Tackling turbine security

Turbine hardware and software aren't made in a bubble, which sparks the need to tackle security vulnerabilities.

By Robert Weber for Bachmann electronic

One wind turbine can create 18 full-time jobs in the U.S., and so even detractors are having a hard time ignoring wind power's momentum. The challenge for the coming years, however, is plant security. The industry is looking at a challenge from grid operators and regulators: How can the wind industry support efforts leading to more security?

For the past year, independent security researcher Maxim Rupp has been in great demand, particularly in the wind-power sector. It was about a year ago when this Germany-based security specialist published a document on the security vulnerabilities of wind turbines in the United States.

Rupp discovered many risks including: He could change the administrator password using a so-called cross site request forgery, so that he could then make changes to the turbine blade or the network settings. He also found a security breach on the web connections of the plants. The results of Rupp's work were disturbing for operators and the entire industry. Forbes magazine published a major report on the discoveries.

WHERE PROBLEMS START

The problem begins when an application is developed. Suppliers still start from the premise that devices will be implemented in a secure network, Rupp told Forbes. The German security expert said this was an assumption that arose in the '90s. For Rupp, there is no difference between a web page or a wind turbine. Both systems are susceptible to attack and must be protected.

According to Forbes, Rupp said wind turbines were operating in Europe without protection. Case in point: Not only in Europe, but also in the U.S., many turbines are still using Windows 95 computers. A simple search using the shodan.io search machine revealed security risks such as modifying the turbine operation and accessing the grid. However, PLC suppliers have responded to this with a solution that involves updated controls and software. Rupp has also noticed this. Companies are beginning to understand the situation and are making more effort to protect their products, Rupp reports.

However, the issue seems initially limited to the U.S. In Germany, there are only a few publications over the last several years that have addressed attacks or security breaches on wind turbines.

In the U.S., Brian Hill from Bachmann electronic talks frequently to his customers about security. The importance of wind-farm security has increased and is at the top of the agenda for many customers. U.S. authorities set high standards with regard to security, since failures in infrastructure must be prevented. The government is working on more stringent regulations and requirements for the operators.

REGULATIONS IN PLAY

There are many new regulations coming from the NERC. The Energy Policy Act of 2005 (Energy Policy Act) gave the Federal Energy Regulatory Commission (FERC) authority to oversee the reliability of the bulk power system, commonly referred to as the bulk electric system or the power grid. This includes authority to approve mandatory cybersecurity reliability standards.

The North American Electric Reliability Corporation (NERC), which FERC has certified as the nation's Electric Reliability Organization, developed Critical Infrastructure Protection (CIP) cyber security reliability standards. On January 18, 2008, the Commission issued Order No. 706, the final rule approving the CIP reliability standards, while concurrently directing NERC to develop significant modifications addressing specific concerns.

Additionally, the electric industry is incorporating information technology (IT) systems into its operations — commonly referred to as smart grid — as part of nationwide efforts to improve reliability and efficiency. There is concern that if these efforts are not implemented securely, the electric grid could become more vulnerable to attacks and loss of service. To address this concern, the Energy Independence and Security Act of 2007 (EISA) gave FERC and the National Institute of Standards and Technology (NIST) responsibilities related to coordinating the development and adoption of smart grid guidelines and standards.

SECURE INFRASTRUCTURES

Bachmann is ready to create secure infrastructures for its customers, according to Hill. Bachmann electronic provides its customers worldwide with new hardware and regularly supplies new software updates to address ongoing security concerns. Customers only have to install the software patches on their own or have their service provider do it for them.

Hardware and software are critical for the secure and economical operation of wind turbines. For this reason, Bachmann electronic is involved in the retrofitting of existing systems. Hill and his colleagues are working together with a variety of owner/operators. Their goal is to retrofit wind turbines with state-of-the-art Bachmann electronic technology in order to modify the various wind-turbine fleets, bring them into compliance with current regulations, and have the flexibility to meet the unforeseen regulations of the future.

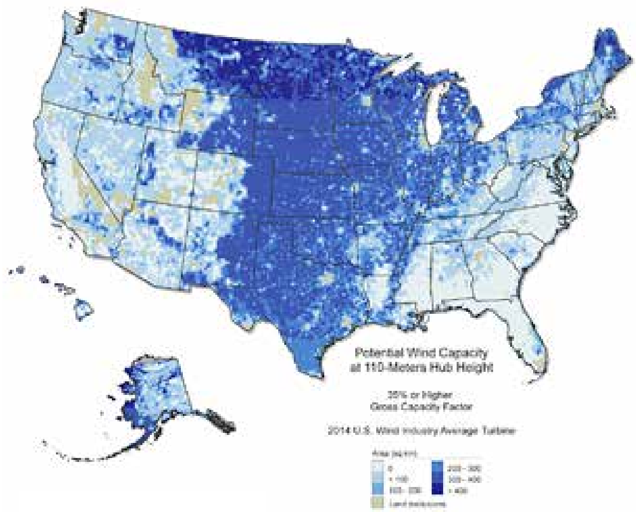
RETROFIT GOALS

Bachmann electronic is working with one of the U.S. national labs on one such retrofit where researchers will be able to carry out tests on wind turbines, change parameters, and adapt them to actual conditions. They can use the results for more efficient systems laboratory tests that will ultimately help improve turbine operation. The plan is to help them through the application of a new controller system, replacing the original wind-turbine controls' hardware and software, according to Hill, who is expecting new orders in the U.S. resulting from the collaboration with the lab and the test results.

In North America, Bachmann is concentrating on existing systems, Hill said. In the world's largest wind-power market, condition monitoring systems from Bachmann electronic are also in demand and are likely to be coupled with a controls retrofit solution.

A lot of new wind-energy capacity is moving forward this year and next through the benefit of continued momentum of clean-energy initiatives. Federal, state, and local governments, along with large corporations such as Google and Amazon, will continue to invest in renewable energy, Hill said.

These investments in wind power in the U.S. are creating new jobs. The U.S. Department of Energy estimates there will be about 250,000 Americans working in the wind-power sector by 2020, and even up to 600,000 by 2050. The sector continues to be optimistic about the future in spite of some opposition and in spite of the U.S. withdrawal from the Paris Climate Accord.



This map shows wind potential in the U.S. (Courtesy: Department of Energy)

The U.S. Department of Energy estimates there will be about 250,000 Americans working in the wind-power sector by 2020.

Hill said he still has some concerns.

"We have a lot of space in North America for land-based wind projects, but one of the biggest challenges is moving the energy from wind turbines to the population/load centers," Hill said. "Our U.S. colleagues also understand the issues around the power grid. It's been my experience that it is easier to build power stations than power lines."

The grid is overloaded in some regions; however, new lines are planned, and this will help wind power in the United States.

In the meantime, Rupp continues to highlight the security features of the controller suppliers and is eagerly publishing security breaches in wind turbines in the U.S., Europe, and elsewhere in the world. There was one disturbing fact that arose from his discovery of security risks in June 2015: When it comes to hacking the computers of a wind farm, it's not that difficult.

Robert Weber is a technology journalist and founder. Until May 2015, he was responsible for the German-language trade journal Elektrotechnik. Instead of concentrating on his journalistic career, Weber now focuses on his start-up Industrial Newsgames, which develops communication solutions for the challenges of IIoT.