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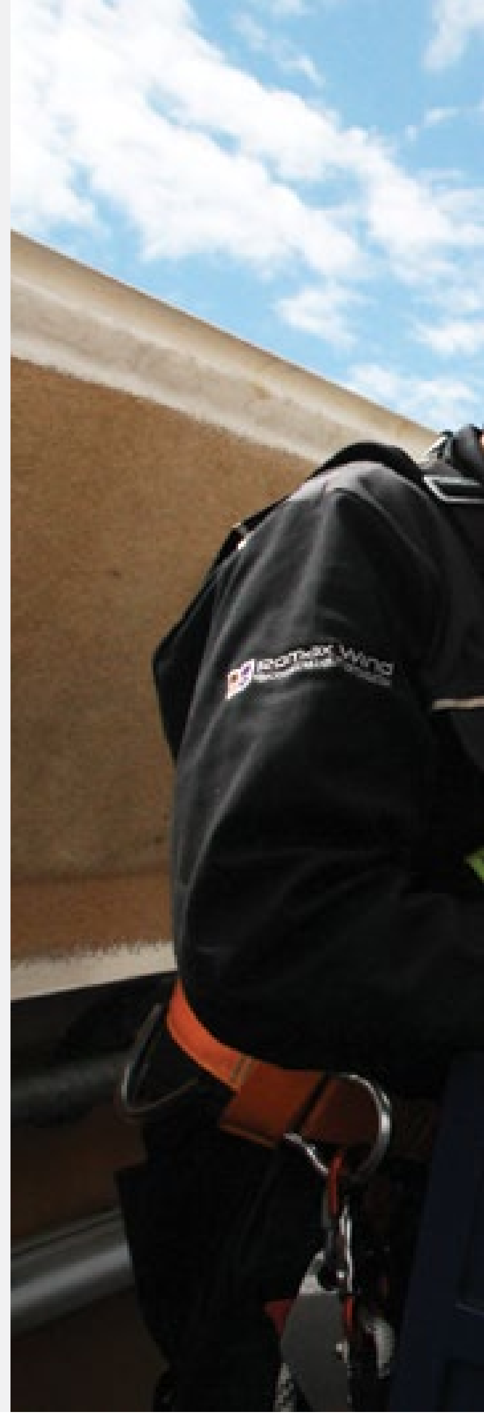
SUPPORTING PROBLEM RESOLUTION IN O&M WITH TEMPORARY INSTRUMENTATION

By Jesse Graeter and Zhiwei Zhang



The purpose of a measurement system is to provide the quantitative data necessary to make educated decisions. In the wind energy sector, temporary measurement methods are often utilized with wind turbines due to the large scale of components, remote location, and dozens of turbines making up a single wind power plant. The measurements, analysis, and interpretations support the owners and operators to better understand the behavior and reliability of the machines so that critical decisions can be made to optimize O&M cost. Temporary measurements can be as simple as using a scale to measure distance, while temporary instrumentation systems may record measurements at 25,000 samples per second from multiple sensors. Some common examples of temporary measurements (load measurement on the main shaft, vibration measurement on the gearbox, etc.) on a typical wind turbine drivetrain are shown in Figure 1.

Wind turbine owners and operators are beginning to use temporary instrumentation systems to measure wind turbine loads in assessing OEM-offered performance and to make modifications that will increase a wind farm's annual energy production (AEP). Such instrumentation systems include blade modifications (i.e., vortex generators and tip extensions), micro-siting, and turbine controller software upgrades. While increased AEP is tempting to the owner, it comes with the uncertainty of negatively affecting the loads on the drivetrain. Increased loads could potentially reduce key component lives or cause premature failures. Some operators are choosing to validate the OEM's modifications by measuring the main shaft torque and bending, which can be supported by use of data loggers and strain gauges, which can often be installed uptower in one day (as shown in Figure 2). The measurement period is continuous for multiple weeks, ideally before and after the performance modification. Sometimes the measurement is conducted on multiple turbines on the same site for neighbor turbine comparison. The data is remotely accessed over cellular network and analyzed for torque, tilt, and yaw moments in time series, frequency spectrums, and load distribution diagrams (LDD). The typical and unusual loading events will be identified and processed. Combined with SCADA data analysis, the operating parameters can be examined during periods of unusual loading, such as peak and transient loads. The detailed measurement and processing programs can be based on the recommendations from IEC 61400-13, which is a standard created by the International Electrotechnical Commission (IEC) that describes the measurement of fundamental structural loads on wind turbines for the purpose of the load simulation model validation. In some applications, measurements have to be repeated multiple times to reduce the statistical uncertainty due to the stochastic character of the site conditions. An example of measured torque and bending moment can be found in Figure 3.

Temporary measurements are also often used during failure root cause analysis (RCA) to determine primarily failure cause and corrective action to increase the O&M efficiency through targeted work planning. The results can also improve the value of the failure data and support the com-


Romax

munication with the turbine OEMs. Failures of wind turbine components can be costly, especially if impacting a batch or an entire fleet. A cause and effect exercise, as shown in Figure 4, can be used to identify all possible causes and a strategy for addressing each of them. Temporary measurement systems can be used to investigate the more complex contributors to the failure. Relatively simple static measurements with dial indicators, digital calipers, and laser measurement can determine the drivetrain alignment, mainframe mounting position, and bearing preload. Specialized data acquisition systems can be used to collect dynamic measurements while a turbine is operating. For example, Romax's portable vibration systems (PVS) can be used to assess rotor imbalance or shaft misalignments. Proximity sensors can monitor component displacements,

ALSO IN THIS SECTION

such as the gearbox motion relative to the mainframe. As previously mentioned, measuring the main shaft torque and bending can also benefit an RCA investigation by comparing the load that the failed gearbox is undertaking with that in a neighbor healthy turbine.

In some instances, a simple physical dimension is desired, yet the limited access or large size of wind turbine components can make collecting these measurements a difficult task. The planetary stage is usually a challenging assembly for measurement and fault detection, and it is more expensive for maintenance and replacement. It is also more complicated than the other stages, as more gears and bearings and undertake higher, more complicated loads from the rotor side. For example, a planet gear tooth fracture, such as in Figure 5, was detected by Romax's PVS and later confirmed by borescope inspection. In the frequency spectrums in Figure 6, pronounced magnitudes can be found from the suspect gearbox (in black) at the repeating harmonics at planet gear rotation frequency compared with the healthy gearbox spectrum (in green). Romax monitoring engineers recommended that all planet gears and the sun gear be inspected at a complete 360-degree circumference, and the failure was found on one of the planet gears.

The ability to simply measure the length, width, and depth of the feature could be enough to responsibly manage the continued operation of the gearbox. A practical method is to take a surface impression replica, meaning a fast curing silicon applied to the gear or bearing surface. The sample can then be easily measured by a variety of equipment in the convenience of a laboratory, as shown in Figure 7. Repeat measurements can establish a rate of progression, hence the remaining life of the component. The ability to quantify the defect eliminates subjective speculation, enabling the turbine

Figure 1: Common wind turbine drivetrain temporary measurements

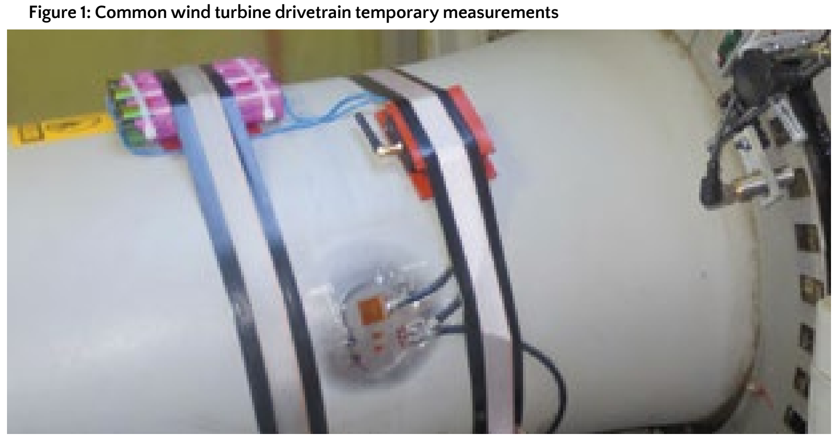


Figure 2: Wind turbine main shaft instrumented with strain gauges

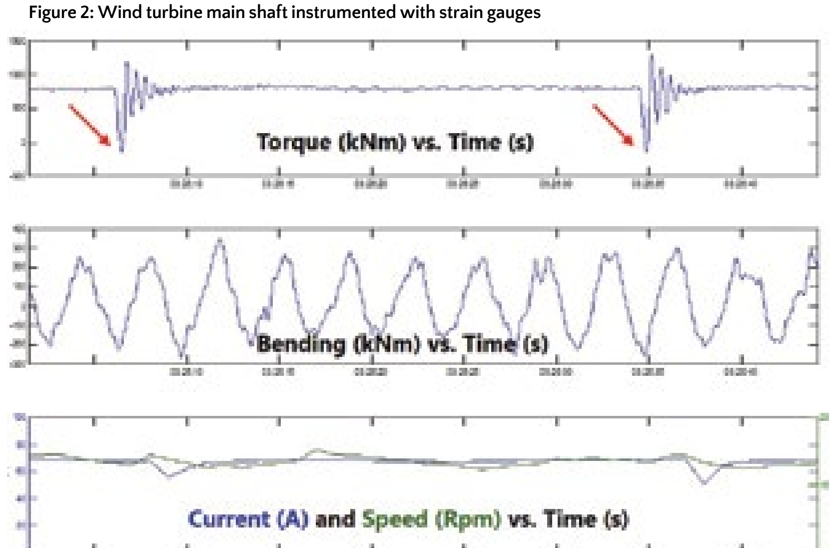


Figure 3: Measured torque reversal event with damped oscillations

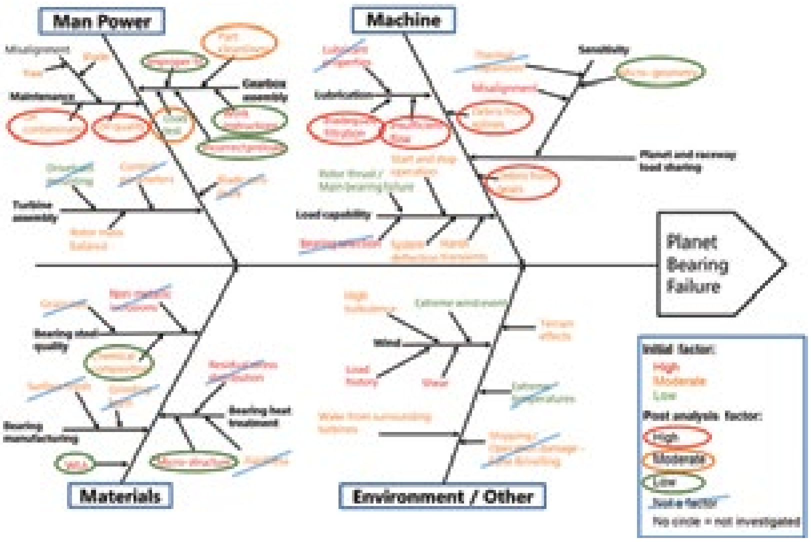


Figure 4: RCA fishbone diagram helps focus on which measurement can determine the cause of failure

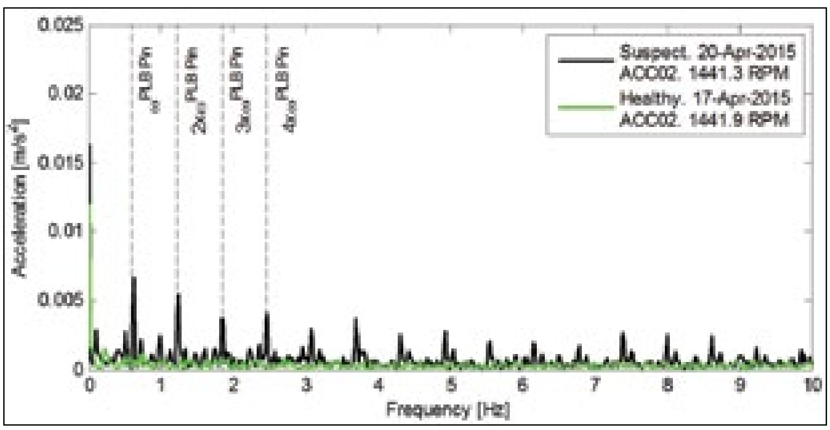


Figure 6: Repeating harmonics at planet gear rotation frequency (suspect versus healthy)

operator to make educated decisions in asset management.

The use of temporary measurement systems is a valuable tool for wind turbine owners and operators. O&M costs can be reduced by mitigating, or even preventing, damage. There is also the opportunity for significant time savings, as well as no upfront capital that's often associated with installing permanent equipment. In some instances, a wind farm's AEP can be increased where the role of the instrumentation is to confirm that the drivetrain loads are still acceptable. Temporary measurement systems can validate design changes or determine the cause of fleet-wide failures. It is ultimately about generating quantitative data for solving today's wind turbine problems.

Figure 5: Example of a fractured tooth crack close to full liberation of the damaged area

Figure 7: Measurement of defect size on a silicon surface replica

Key Factors in Successful Wind Farm Operations

By Jack Wallace

The organization of how things get done between the OEM, subcontractor, and owner can be quite different from wind farm to wind farm, but no matter what type of organization is in place or how old the site is, the main goal of wind farm operations is to have all of the turbines running anytime there is wind. Here, you'll find several points that may help your team improve your wind farm's operation.

MINIMIZING DOWNTIME DURING WIND

An attempt to schedule all repairs and services during low to no wind or when the power has low value would be ideal. During transition periods of no wind, grid drops and direction changes can cause nuisance faults and unnecessary losses in production.

WIND POWER PLANTS VERSUS INDUSTRIAL PLANTS

The main difference between a wind power plant and other types of industrial plants is the fact that we cannot predict or control our power source — the wind.

Another difference is that it is not feasible for the O&M side of the industry to visit each piece of machinery every week, especially if there are a large number of wind turbines in your plant spread out over miles of terrain. For other industries, the ability to visit all of your machinery as frequently as you like is the standard. Note that substandard work concerning the quality of care of your wind farm will quickly show in your turbines' power production.

COMPARING MACHINE OUTPUTS ON A BI-MONTHLY OR MONTHLY BASIS

This is an easy way to see if all your machines are functioning as they should. The turbines will typically follow a trend, such as turbine A performing better than turbine B.

Monitoring systems such as SCADA have become an expected part of the wind turbine. But even so, proper and safe operations happen out in the field, not from a remote computer terminal. Remote resets can cause hazardous conditions and a loss of life or machine. Rules must be followed to prevent an unnecessary tragedy when using remote communication systems. At a minimum, the technician in the field should be in control of the task at hand.

EMPLOYEES

The recommended number of maintenance employees depends on the size of the facility along with the type of machines in use.

In the 1980s, it was typical for wind farms with machines rated between 65 and 150 kW to run two-manned crews for each group of 80 to 130 machines. With the larger machines and taller towers, this is no longer possible. Today, some sites are not manned, but when work is commenced, it is usually with a minimum of two technicians for safety.

Management must weigh the cost of having additional personnel versus having a turbine turned off for extended periods of time due to manpower shortages.

The dangers of having too few trained personnel may also hamper your operations. It is safer to be slightly heavy on trained personnel than light when it concerns your operations. It is also recommended that more than one member of your team share critical knowledge needed to run them, or you may find yourself in a difficult situation should the one key employee leave.

RECORD-KEEPING

Keeping a record of services is a required part of operations. It helps document work you do and allows you to find trends with the equipment. Of course, properly completed paperwork is always appreciated after the fact. Don't overburden your technicians with numerous forms to fill out. Keep it simple. Their time is best spent with the machines.

INVENTORY AND TOOLS

I recommend keeping the minimum amount of inventory on site, but this really depends on the supply pipeline. Someone near Los Angeles has quicker access to most parts and tools than someone in the far reaches of North Dakota.

Additionally, most companies provide their techs with the tools, however, this is not a requirement. It's a good idea to take care of these tools, especially if your company is willing to provide them for you.

DRIVING COMPANY TRUCKS

You must consider where and how to park on a wind farm. Good habits are formed by parking your vehicle facing into the wind and far enough away from areas of turbine work to prevent damage or injury. The wind can rip back an unsuspected door or a tool can hit a parked truck.

HIGH WIND/FOUL WEATHER DAYS

As long as it's safe, these are great days to perform technical training, fabrication, and rebuilding of parts, site cleanup, turbine noise and vibration checks, thermal checks (during high winds only), and any other work that has fallen behind that does not require that the turbines be shut off.

WELDING

Welding in the field requires care and consideration of the vegetation and wind. Fireguards are always recommended and should be required. If it is windy, reschedule the work. If you cannot reschedule, place multiple fireguards and water trucks, water down the area where sparks will be, and stay alert.

In high winds, it is highly recommended that you reschedule welding and heavy grinding work to a day with less wind.

CLIMBING

All climbing requires you to wear and use safety equipment that ties you to the turbine at all times. Some of today's machines are large enough to work in without climbing gear in certain sections of the machines. In these situations, there is no danger of falling, and climbing gear is optional. Most all other areas in these machines require that you stay tied in at all times.

Climbing below another climber places you in danger of falling objects. It is best to wait for the first climber to reach the top or close a section door before starting your climb. And if they drop something, you can bring it up.

Dangers exist when working on top of a machine with climbing gear. It's

Example of a disconnect switch

crucial to keep all lanyards and loose clothing away from all shafts and motors and to treat all of these items as live or moving objects at all times, even when they're not.

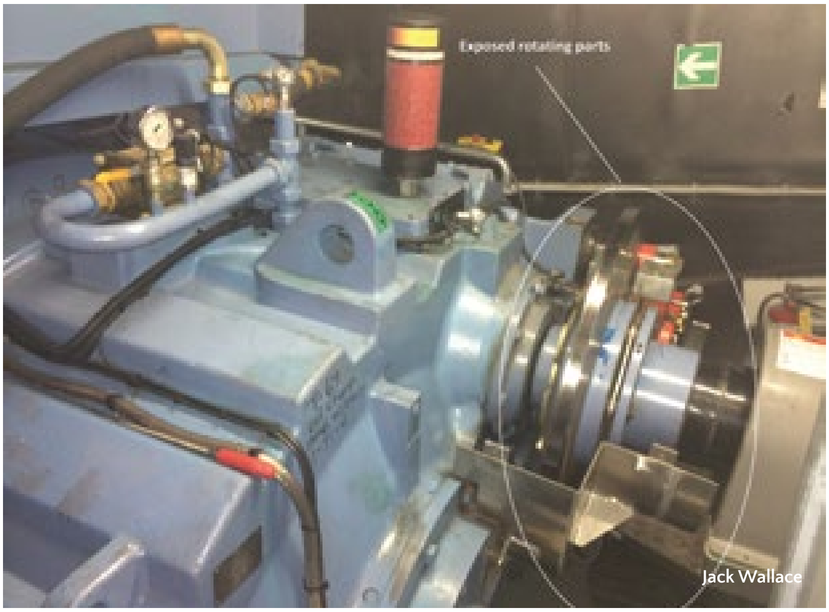
Climbing should not be done if you are working alone.

ELECTRICAL WORK

Electrical work requires training, especially since electrical work on metal structures adds additional safety concerns. Remember to follow standard electrical safety rules such as working with one hand while inside a cabinet with live power. Do not allow another worker to come in contact with you should you not be at the same potential. Whenever it is possible, work with the power off. Proper lock-out and tag-out procedures are essential. Unless the worker is trained to do so, no electrical troubleshooting should be allowed and no panels should be opened. Resetting faults and turning off a problematic machine should be the extent of electrical work for the untrained worker.

Other unsuspecting hazards are in the controller. Although the machine may not be online, there may still be potential on the power conductors. There has been an increase in power electronics used in wind. These devices require extra precautions as there can be stored power or voltage potential with minimal current still on the circuit. This means that even if the turbine is turned off, but is still with power, it may be unsafe to touch. So, "off" doesn't mean off or that it's safe to touch until the disconnect for that circuit is shut off. With some turbine manufacturers, "off" does not necessarily mean anything is turned off until the pad mount transformer is off.

The same may be true if uninterruptible power supplies (UPS) are in use. It is critical to only work on electrical equipment after it has been confirmed with a test meter that the power is off.



The dangers of moving objects illustrated by a gearbox with an exposed brake disc and high-speed shaft

MOVING OBJECTS

Dangerous areas on turbines that consist of rotating objects include (but are not limited to) the blades, rotor, low-speed shafts, high-speed shafts, yaw systems, cooling fans, yaw motor cooling fans, hydraulic pumps, nacelle cover activators, hydraulic rams, and other pinch points.

HOISTING SYSTEMS

Most dangers with hoisting tools are to the person on the ground. It's best to send up multiple loads of tools instead of one extremely heavy load. Don't overload your tool bags, and don't stand directly below a tool being hoisted. It's recommended that you watch the load as it is attached and moved to ensure you know if something falls and where.

COMMUNICATIONS BETWEEN THE TOP AND BOTTOM OF THE TURBINE

Radios are the recommended form of communication from top to bottom. Cell phones are also handy. The days of yelling up and down the tower are over, for the most part, due to the increased heights of the new wind turbines. It is impossible to hear anyone from atop a 60-meter or 200-plus-foot tower with any wind blowing.

Standing in the drop zone of a wind turbine that is being worked on may be hazardous. The person on top of the wind turbine is in the most danger concerning work, so he should be in charge of the repair or service procedure. This includes calling off the repair for safety concerns. The ground man is expected to support his efforts by gathering the requested tools and supplies and possibly controlling the wind turbine functions as requested.

There are many aspects and skills required to run a wind farm safely and productively. You could easily do crane work, electrical work, and stand out on the front of a hub all in one day's work. That's what makes working on a wind farm so exciting and fulfilling. I recommend open communication between all of the operations and maintenance team. They will be much more productive and safer when knowledge is shared.

LAUFER WIND'S RADAR-ACTIVATED OBSTRUCTION LIGHTING SYSTEM MEETS FAA PERFORMANCE

Following the Federal Aviation Administration's (FAA) testing and introduction of new performance guidelines, Laufer Wind is now making its patented Aircraft Detection System (ADS) available in the United States. The ADS is a radar-activated obstruction lighting system designed to turn blinking lights atop wind turbines and tall towers on or off based on the presence or absence of aircraft in the vicinity. This technology allows "lights out" for up to 98 percent of the night, which significantly reduces the towers' visual impacts on surrounding communities.

Last month, the FAA published an updated Advisory Circular 70/7460-1L that set forth standards for marking and lighting obstructions that affect the National Airspace System. The FAA added a new Chapter 14, introducing performance guidelines for radar-activated lighting technologies known as Aircraft Detection Lighting Systems (ADLS).

In a June 2014 demonstration at the National Renewable Energy Laboratory in Boulder, Colorado, FAA researchers conducted flight tests against a Laufer Wind ADS installation configured to control lights on multiple wind turbines and a meteorological tower. An FAA technical note published in October 2015 confirmed that Laufer Wind's ADS meets FAA requirements for aircraft detection lighting systems.

Several wind farms in the U.S. have been permitted with requirements by local governments to include ADLS technology. Laufer Wind said it expects to provide systems for wind farm and communication towers both operational and those still in development.

According to the FAA technical note, "due to the number of existing telecommunications towers and wind turbines, combined with expected future construction, the number of obstructions that have these required lighting fixtures has greatly increased. As a result, it has created a light pollution nuisance to residents living near these obstructions. Using an ADLS could have a positive impact on this problem, while still providing a sufficient level of safety for pilots operating at night in the vicinity of these obstructions."

The report also notes that "the ability to turn off lights when they are not needed could have a positive impact on reducing the number of avian fatalities."

"Radar-activated lighting is an effective tool for wind farm developers and tower owners to assist with permitting and to reduce the impact in local communities and on wildlife," said Eric Laufer, president of Laufer Wind. "We are especially excited to be the only vendor to have received a technical note from the FAA confirming our system's ability to meet the new ADLS requirements."

Laufer Wind's dome-covered radar on a Met tower at the National Renewable Energy Laboratory (NREL)

Laufer, an aeronautical engineer and pilot, began working on the technology several years ago when a wind farm project faced community opposition over lighting impacts.

"This has been an eight-year project of development and testing, and it serves as a model of how the public and private sectors can work cooperatively to the benefit of communities across the country," Laufer said.

— Source: Laufer Wind

For more information, go to www.lauferwind.com.

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WIND ENERGY IMPACTED BY NEW FEDERAL AVIATION ADMINISTRATION REGULATIONS

By Jason Fohr

As wind energy evolved in the United States and turbines appeared in trafficked airspace, the Federal Aviation Administration (FAA) worked to adapt existing regulations governing aviation obstruction lighting and marking to a new dynamic in vertical structures — rotating blades. A new FAA Advisory Circular (70/7460-1L) published in December 2015 illustrates an intensified effort to increase visibility of wind turbines for pilots of low-flying aircraft. This amplified focus also includes guidance for additional marking for turbine owners seeking to limit liability exposure beyond that afforded by full compliance to federal regulations.

MET TOWERS

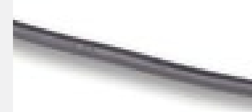
The genesis of a typical wind farm begins with the investigation stage, usually with the placement of tower-supporting meteorological instruments to determine if the area is suitable for the development of a wind farm. These meteorological (MET) towers are often easily and swiftly erected with foundations that are much simpler than those required for a full-scale communication or broadcast tower with some that are even mounted on temporary mobile supports.

This inherent ability for rapid deployment, coupled with the lack of marking, created an unforeseen danger to low-flying aircraft. In the course of one or two days, a MET tower ranging from 60 to 199 feet above ground level (AGL) can be erected, posing a particular hazard to low-flying aircraft such as crop dusters who could encounter a tower directly in their path where none had previously existed.

Although standard FAA marking requirements normally do not address towers under 200 feet AGL in the absence of an airfield, airport, or other anomaly within 5 nautical miles of the determined site, to ensure pilot safety and prevent future incidents, several organizations, including the National Agricultural Aviation Association (NAAA), urged legislation on a state level to require marking (and often lighting) of MET towers.

In 2011, the National Transportation and Safety Board issued a safety alert for pilots who may fly at these heights, and the FAA also released guidelines for suggested marking. The FAA AC 70/7460-1L includes a distinct set of guidelines for marking MET towers in Section 2.7. These regulations include aviation orange and white paint bands on the tower structure and high-visibility sleeves and/or spherical markers on guy support wires.

The described MET tower marking is regarded as "voluntary" versus "required" by the FAA. However, many states have enacted statutes requiring the marking of MET towers. Currently in place as of January 2016: California, Colorado, Idaho, Kansas, Missouri, Montana, Nebraska, North Dakota, Oklahoma, South Dakota, Texas, Washington, and Wyoming. Sixteen other states currently have similarly proposed legislation on the docket. While they are rare, retroactive requirements for pre-existing structures are not unheard of, which could affect many older towers. Owners are strongly urged to research marking requirements on a state-by-state basis. In the absence of federal or state requirements, voluntarily marking pre-existing MET towers in accordance with these recently published FAA guidelines may reduce the tower owner's exposure to liability and avoid local pressure to install lighting on the structure.



REVISED GUIDELINES FOR WIND TURBINES AND WIND FARMS

With the advancement of wind farms and turbine technology, the FAA began to address the need for proper marking of these structures as early as 1985 when it released AC 70/7460-1G and in 2007 when it devoted a separate chapter to wind turbine marking in AC 70/7460-1K Chg 2.

International Tower Lighting, LLC
IFH-1710-000 wind turbine obstruction lighting system, Type L-864(L), red LED (open)

The newly released AC 70/7460-1L takes the marking and lighting of wind energy structures to a new level including more descriptive verbiage in Chapter 13 and four pages of illustrations in Appendix A. Aircraft Detection Lighting Systems (ADLS, or "radar" systems), which are sometimes associated with wind farms, have also been separated in Chapter 14. The FAA consulted several knowledgeable sources in the field of wind energy in an effort to address current and future needs, including taller structures and more elaborate farm designs.

KEY REVISIONS

- Inspection and Monitoring: A visual inspection of obstruction light lenses is required at maximum intervals of 24 months. Though it is not a new requirement, daily monitoring logs for the lighting should be maintained

[1] *Note: All structures and wind farms with a previously assigned determination are still governed by their original respective advisory circular named in said determination unless or until a change is made by the owner (change of heights, major shift of coordinates, additional turbines added to the farm) or other directive(s) are received from the FAA. This is commonly described as "grandfathering."*

International Tower Lighting, LLC

IFH-1710-000 wind turbine obstruction lighting system, Type L-864(L), red LED (closed)

as well. Replacement criteria for beacons or lenses are also included.

- Measurement: One key clarification in the AC 70/7460-1L is the measurement of the overall height of a wind turbine as depicted in Figure A-23 of Appendix A: "Turbine height is determined from the top of the rotor while at top dead center." The illustration clearly indicates the measurement is from ground to the tip of the blade in its most skyward presentation. This differs from many previous interpretations that indicated this measurement should be to the top of the hub or nacelle.
- Lighting: Though not every structure in the wind farm is required to have obstruction lighting, section 13.8 addresses the "Lighting of Wind Turbines During the Construction Phase" and states "to ensure proper conspicuity of turbines at night during construction, all turbines should be lighted with temporary lighting once they reach a height of 200 feet (61 m) or greater until the permanent lighting configuration is turned on." This section further describes detailed temporary lighting requirements as well.
- Farm Configurations: Wind farm configurations are separated into linear, cluster, and grid with associated marking requirements. Acceptable colors for wind turbines are now described in the European-based RAL color standard to accommodate the off-white colors of equipment commonly imported to the U.S. Voluntary marking for snow-prone areas has been established in an effort by the FAA to maintain uniformity and reduce potential confusion to pilots.
- L-810 Marker Synchronization: When combined with L-864 medium-intensity lighting on structures over 699 feet AGL under the new guidelines, L-810 obstruction lighting ("side marker lights") must flash in synchronized fashion with the other lighting on the structure. This also means the L-810 will be considered a "flashing obstruction light" as covered in Section 2.4.2 of the advisory circular, meaning any failure will require NOTAM (Notice To Airmen), which, according to the FAA, is a notice or advisory distributed by means of telecommunication containing information concerning the establishment, conditions, or change in any aeronautical facility, service, procedure, or hazard. The timely knowledge of which is essential to personnel and systems concerned with flight operations.
- Aircraft Detection Lighting Systems (ADLS): While ADLS may not be financially feasible in the case of a smaller wind farm, they may be a necessary investment

at larger farms. These systems are designed to detect any approaching aircraft within a proximity that could possibly result in an impact with the turbine.

The lighting system is normally not activated with the exception of a short test period each day. Once the approaching aircraft is detected, the system will normally send an audible alarm over all aviation-approved radio channels advising the pilot of the obstruction, and then immediately activate the lighting system. While this type of system may initially seem to be highly attractive due to the public appeal and energy savings from being chiefly inactive, it is relatively expensive to install and set up. Flybys must be performed using fixed-wing and rotor-blade aircraft to the activation function. Sensitivity to movement by other objects must be adjusted. The system was fine-tuned to filter and eliminate these distractions. Additional fly-bys were performed in a final test prior to declaring the accurate and safe performance of the system.

Although costs to install, fine-tune, and test the ADLS are significant, the long-term benefits may prove in some areas to be worth the investment. Such systems are designed to address concerns for community and environmental safety, particularly in the interest of protecting population centers, natural attractions, coastlines, lakes, or large bodies of water and migratory birds and other wildlife that are drawn to red obstruction lighting.

ACCESSING THE INFORMATION

In conclusion, becoming familiar with the new FAA AC 70/7460-1L is a priority for everyone in the wind energy industry. Designed to address current safety challenges and to keep pace with anticipated future advancements, the circular is available free of charge to view or download through the FAA website. Go to www.faa.gov. Once at the home page, click on the Regulations & Policies tab. In the search bar, type in the current advisory circular pertaining to this article — "70/7460-IL." Click on "Obstruction Marking and Lighting." From there, download the AC 70/7460-IL PDF.

International Tower Lighting, LLC

The MKR-LTE1-0IR single obstruction light integrates visible red LEDs and infrared LEDs into a single L-810(L). Infrared energy (IR) can enhance compatibility with aviator's night vision imaging systems (ANVIS) and night vision goggles (NVG). Precision-molded Fresnel optics produce a low ground scatter tower lighting solution. The die cast aluminum base provides 3/4-inch conduit hubs for side or bottom mounting. Multiple 9kA MOVs and a 20kA gas plasma discharge tube provide robust surge suppression.