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Don't Blame the Oil

Transient events — not gearbox oil — are the leading cause of wind-turbine gearbox failure.

By Paul Baker

In the wind industry, complex organo-metallic gear-oil chemistry and its resulting higher water content have sometimes been blamed for gearbox damage or failure. But water in oil is not the cause of gearbox failure. Rather, the characteristics of wind-turbine operations and the resulting transient loads are the root cause of nearly all failures.

Transient loads are the underlying cause of gearbox failure. Common characteristics of organo-metallic oil formulation — those typically using molybdenum-based EP additives — have met with some criticism, but it does not lead to these costly failures. Despite some currently held industry theory, it is inaccurate to attribute gearbox failure to organo-metallic gearbox oil that is able to hold a higher amount of water.

ENVIRONMENTAL TURBINE CHALLENGES

- Lubrication points are subject to dirt, dust, water, high turbulence, and extreme temperatures and can be hundreds of feet in the air.
- Access to offshore installations can be hindered by logistical factors including high seas.

OPERATIONAL AND COMMERCIAL TURBINE CHALLENGES

- Turbines need to run intermittently and at varying speeds, and are subject to a wide range of temperatures from minus-40 degrees C to greater than 50 degrees C.
- High levels of vibration put pressure on moving parts.
- Greater output demand increases the loading on bearings, drives, and gearboxes.

Source: Castrol Wind Turbine Brochure

Castrol

THE CHALLENGES OF WIND EQUIPMENT

Wind-equipment conditions are different than those in any other industrial gearing application.

A wind turbine's substantial load of overhanging weight — combined with varied climate and geographical conditions and consistently unpredictable weather extremes — presents a series of challenges seen only in the wind industry.

In fact, sheer weight has an exponential impact on equipment. For example: A turbine's blades and hub weigh 30 tons — which is supported by one bearing and gearbox with a three-foot generator on the other end — and it's all held 300 feet in the air by a solid-steel shaft two feet in diameter.

The resulting effects of unpredictable conditions can be extraordinary.

TRANSIENT EVENTS

When a wind turbine experiences a transient event — a short-lived burst of energy caused by a sudden change of state — it can be a violent occurrence.

Gears and bearings are designed around specifications for normal operating conditions.

In other industries, normal operating conditions are easy to predict. But with a wind turbine, it is impossible to measure transient loads.

A wind turbine is not, by nature, designed to handle these events.

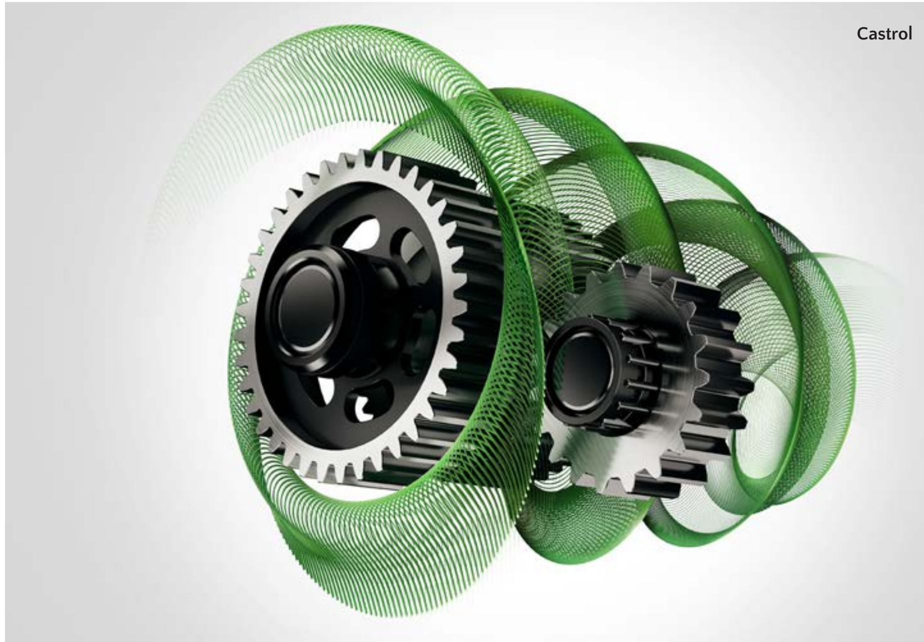
What's more, many of these transient events happen hundreds of times a day — for example, with a gust of wind or change of wind direction. As a result, while wind turbines are designed for normal operating conditions, there is no way to anticipate what transient loads might be seen.

I employ the American Gear Manufacturers Association's safety factor to determine normal operating conditions. But while this evaluation applies to typical industrial gearing, this is not the case in wind. The standard safety factor for wind turbines is 30 percent (which falls in between AGMA light and medium duty). Anyone in the industry will say a wind turbine is a heavy-duty application.

Building equipment based on normal operating conditions will

Precision gearing uses clean, high-performance gear lubricant.

ALSO IN THIS SECTION



An X-ray diagram of a wind turbine shows the key mechanical components of a wind turbine and the lubricant necessary.

satisfy 95 percent of concerns. But the remaining 5 percent is what separates the art from the science.

There are ways to monitor the progression of failure in a live machine in order to prevent that failure. Examples of "condition monitoring" tactics include measuring temperature, cleanliness of oil, vibrations the bearings and gear meshes create as they rotate, power output, and power consumption.

But in my experience in monitoring gearbox failure in general and wind-turbine gearbox failure in particular, all of these variable factors should be considered "symptoms." In fact, transient loads are the cause of the actual failure.

STOPPING PROTOCOLS

In my current role, I measure the effects of stopping protocols, and I have found stopping protocols result in more than triple a wind turbine's normal torque, but in the opposite direction. And in some turbines, stopping protocols (which include emergency stops/E-stops) can happen 200 to 300 times a year.

POWER GRID FAILURE

When grid failure occurs, resistance is gone almost instantly. The system can now unwind in the opposite direction of what it is used to, causing torque reversals and "wreaking havoc."

You can have the best gears, bearings, and oil on the planet. You can have diligent ongoing live equipment monitoring. You can work on either side of the design equation, experimenting with handling more load or less load. You can try building with different steel and alter other fabrication elements. But at the end of the day, none of these variables has anywhere near the impact on gearbox failure than the loads themselves.

DOES GEAR OIL CAUSE GEARBOX FAILURE?

As anyone in the wind industry knows, when a gearbox fails, it can be a costly occurrence. It also can lead to the inevitable desire to get to the root of the problem and look to assign blame.

Most turbines that fail are still using their original gear oil fill — so it's not uncommon for managers to group the original oil in with the original equipment when discussing gearbox failure.

But in the wind industry, there are few, if any, lube-related failures.

These OEM first-fill gear oils fall victim to this incorrect theory primarily because of their association with the original equipment. There are certain gear-oil formulations that, even though they offer long-lasting protection for costly machinery, have certain attributes or results that have been called into question on occasion.

But these qualities or visual characteristics do not affect gearbox failure.

WATER IN OIL

A common discussion in the wind industry relates to high-water content in gearbox oil. Overall, the impact of water content in synthetic gearbox oil is dependent upon whether the water content is near the saturation limit and if the water is fully dissolved in the oil.

Certain organo-metallic oil chemistry results in an affinity to water that enables the oil to handle up to five times as much water as some ashless and sulfur/phosphorous-based gear oils. If the oil is formulated to hold a high level of water, then water in that oil is simply not an issue.

Most oils (e.g., ashless) can't capture more than 300 parts per million (PPM) without failing. So, if that oil tests at 150 PPM, it could be a cause for concern, as that water can escape solution, interfere with gears and bearings, and cause corrosion.

WATER AND THE ADDITIVE PACKAGE

Organo-metallic gear oils are engineered to protect and maximize the performance of wind-turbine gwearboxes. Some characteristics of organo-metallic oil with the ability to hold higher levels of water display visible signs. But these conditions do not affect gearbox failure.

Some of these signs include:

Sludge: Due to the complex additive package in these oils, water can react with some of the additives and "fall out of solution." The resulting out-of-solution additives are referred to as sludge. Sludge can collect in the low-flow area of a gearbox and cause staining. But while this may make looking at gearbox damage more difficult, the sludge itself does not cause damage or failure.

Foaming and Micro-pitting: The other condition that can arise from gear oil with a high water content is foaming, caused as the oil churns up and captures air. Foam can sometimes cause a small amount of near-surface micro-pitting — but we are not seeing that it causes any failures, unless foam has replaced oil. In wind equipment, the micro-pitting is more likely attributed to transient loads.

INVESTIGATING TRANSIENT EVENTS

Over the past 12 years, I have inspected a lot of turbines. Nearly all failures are caused by transient loads (which are also peak loads, versus loads under normal operating conditions) — and they happen much more frequently than people suspect.

Specific failures include those attributed to gears and bearings.

Gear Failure: The two leading causes of gear failure are soft metal inclusions and grind temper damage in gear teeth. Interestingly, both of these phenomena exist in 95 percent of the world's gears, but the equipment in other industries typically continues to run no signs of these conditions, and they don't cause damage or failures. But in the wind industry, one peak load can expose these defects.

Bearing Failure: The two most common causes of bearing failures are axial cracks (also called white-etch cracks, so called when the bearing surface and sub-surface fatigue failures are characterized by white edges along the cracks) in roller bearings and spalling in tapered roller bearings. Both of these failure modes are caused by "hard spots" in the steel structure of the bearing. But they manifest differently.

These hard spots deep within the steel structure are known as adiabatic shear bands. In the case of wind-equipment roller bearings, the origins of shear bands can be attributed to peak transient loads. And they are the root cause of the axial cracks and spalling that are, in essence, crack-initiation points.

Hydrogen Embrittlement: Hydrogen embrittlement occurs when metals such as steel become brittle and fracture due to the introduction and subsequent diffusion of hydrogen into the metal. When white-etch cracking was first discovered in wind-turbine bearings, the bearing manufacturer attributed the problem to hydrogen embrittlement and blamed the gear oil. The theory was that if too much water was entrained in gear oil, the steel attracted hydrogen out of the water when heat and pressure were introduced, resulting in hydrogen embrittlement.

I dispute this theory. White-etch cracking/hydrogen embrittlement can't happen unless there is already a crack or inclusion brought on by transient loads. In fact, I hypothesize hydrogen embrittlement may not even factor into the problem at all if adiabatic shear bands already exist.

Given the factors that are unique to the relatively young wind industry and my extensive examinations of wind turbines and their gearboxes

TRANSIENT EVENTS THAT CAN 'WREAK HAVOC'

Transient events, which are also peak loads, have everything to do with wind-turbine failure. Even if they happen often, they are not considered normal operating conditions.

Examples of transient events include:

- Wind shear, when wind comes at a blade at an odd or obtuse angle
- Wind gusts
- Changes in wind direction
- Startups, shutdowns, and emergency stops
- Failure of power grid

EXTREME CONDITIONS: HOW A TURBINE OPERATES

- Three massive blades capture enxergy from wind. The power it captures and the thrust of it is tremendous. The bladesr 300-foot diameter equals high inertia created at the end of the blade.
- Wind thrust is converted into rotational energy (high torque/low speed). Turning this main rotor shaft at 15 RPM on average.
- Rotational energy is transferred into the gearbox at 15 RPM, which changes high torque/low speed energy into high speed/low torque energy for the generator. Gear ratio is typically 100:1.
- The gear ratio increases the rotational speed from 15 RPM to 1,500 RPM to drive the generator and make electric power.

> It's the transient events that have everything to do with wind-turbine failure.

for more than a decade, I concluded that, despite some industry theories, the presence of water in gear oil that is formulated to hold a high level of water is not an issue. In fact, water in these oils cannot be linked to gearbox failure.

Unless the oil being used is not correct for the application — for example, mineral oil being used in an extremely cold climate — the best solution is to stay with a wind turbine's original oil fill product to avoid potential problems.

IN SUMMARY

Through my lengthy tenure and hands-on experience in the wind industry, I confirm water content in gear oil is not the cause of gearbox failure.

Rather, gear-and-bearing failure can be attributed to the transient events that occur hundreds of times per year — the effects of which can never be predicted in equipment that has been designed for normal operating conditions.

You can have the best gears, bearings, and oil on the planet. You can have diligent ongoing live equipment monitoring. But it's the transient events that have everything to do with wind-turbine failure.

FOR MORE INFORMATION

Castrol has more than 30 years of experience supporting the wind-energy industry, supplying lubricants to thousands of wind turbines and providing global product support services. In addition, BP, Castrol's parent company, is one of the largest wind-park owners in the United States, with a gross generating capacity of approximately 2,600 MW, which equates to electricity to power more than 775,000 average American homes.

Castrol's global reach provides access to a worldwide network of sales, engineering, research, and manufacturing capabilities to support wind-farm operations and maintenance needs. A network of specialist service companies also supports oil-change procedures in line with the requirements of wind-turbine OEMs. For more information, go to www.castrol.com/windenergy.

Adwen and Winergy Develop the World's Biggest Gearbox

Adwen/Winergy

Adwen and Winergy have developed the biggest gearbox in the world for Adwen's AD 8-180 offshore wind turbine. With an input torque of close to 10,000 kilonewton-meters (kNm) and a weight of 86 metric tons, it is the largest wind turbine gearbox ever built.

Winergy's gearbox was designed exclusively for the AD 8-180 wind turbine. It is part of a medium-speed drive-train concept that will considerably help reduce the levelized cost of energy (LCoE) on Adwen's new offshore giant. At 180 meters, the AD 8-180 boasts the world's largest-diameter rotor. In combination with a nominal electrical power of 8 MW, the gearbox attains an input torque of close to 10,000 kNm — a value never before equaled.

This 70-percent increase in torque capacity was achieved with only a 20-percent weight increase compared to other gearboxes used in offshore wind turbines larger than 6 MW. The two-stage-planetary gearbox is directly connected to a medium-speed generator via a flange connection. Thanks to the choice of a medium-speed gearbox concept and leveraging on proven technologies well-known by both companies, Adwen and Winergy can successfully maximize the efficiency of the drive train, while cutting the cost of the components. In tests, the gearbox attains an efficiency of well over 98 percent. Further, by reducing the built-in components, its reliability increases.

Winergy has manufactured four gearboxes for Adwen with the goal of having them fully validated in three phases. The first one will be at Winergy on a modified test bench being used for the back-to-back testing of two identical gearboxes with up to

The AD 8-180 at the assembly plant.

125 percent over loading. Adwen's validation process, the most stringent ever taken on a gearbox and drivetrain this size, requires these tests to guarantee maximum reliability of this critical component.

The second phase will be at Fraunhofer IWES Test Center's Dynamic Nacelle Testing Laboratory where the gearbox will undergo exhaustive tests in combination of full drivetrain and nacelle. The final phase is field tests with the installation of the AD 8-180 prototype in Bremerhaven, Germany.

"We continue pushing the limits of the industry with our AD 8-180, this time with the largest gearbox ever built," said Adwen CEO Luis Alvarez. "This key component has performed extremely well during the exhaustive validation process which makes us confident the first prototype of the turbine will meet and even exceed our expectations in terms of performance and reliability when it is installed. In addition, as the rest of the main components, it has been designed with scalability in mind enabling the future evolution of the platform."

"Particularly in the offshore sector, reliability is the essential thing," said Winergy CEO Aarnout Kant. "With this medium-speed gearbox concept, we are demonstrating our technological expertise and innovative strength.

The AD 8-180 is the world's largest gearbox.

The integrated drive system is not only very compact and efficient, it is also extremely reliable. It makes us proud to be Adwen's partner on this showcase project."

The dimensions of the gearbox designed for the AD 8-180 wind turbine were showcased at WindEnergy in Hamburg, Germany, in September.

Source: Adwen

For more information, go to www.adwenoffshore.com

A Bolt of Knowledge

Weather-forecasting advances shed new light on lightning damage to wind turbines.

By Shylesh Muralidharan

A carbon-fiber blade from a wind turbine is transformed into shards of debris as it is struck by 30,000-degree lightning.

This disastrous — and costly — scenario is not an uncommon sight for wind-farm operators. But not all lightning damage is so obvious.

After a storm, those tasked with managing and maintaining wind turbines have a challenge: Does each turbine necessitate manual, costly, and time-consuming inspection for lightning damage? Or do wind-farm operators take the risk of operating a damaged turbine, potentially leading to greater issues?

Lightning, the leading cause of turbine-blade damage and unplanned turbine outages, is the greatest operational hazard affecting the fastest-growing source of energy in the world. And, these damages are not easily repaired. Energy companies spend millions in short- and long-term repair, replacement, and upgrades.

Wind farms, though an effective and clean source of energy, possess properties that make them vulnerable to lightning. Beyond the fact they are giant spires often in the middle of a flat field, turbines are constructed from insulating materials.

This predicament poses a particular challenge for wind-farm operators. A turbine struck by lightning can sustain critical damage, but the damage may be imperceptible to the naked eye. Even the use of strike-tracking technology to observe a lightning-producing storm is minimally helpful to those developing the following day's maintenance plan.

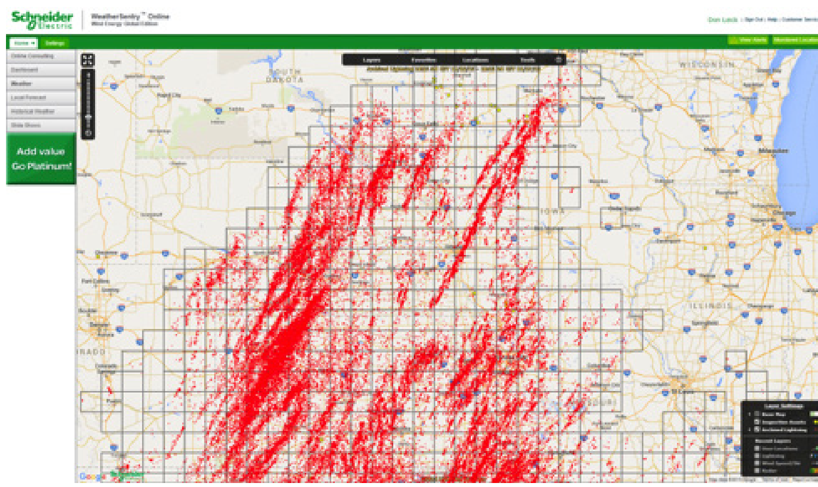


Figure 1: Lightning track data is aggregated, then it is illustrated through GIS-mapped asset overlays.

However, modern advances in weather technology have brought about more precise weather detections for wind-farm operators. After-action reports analyze the likelihood that turbines within a designated radius were struck by lightning, allowing wind-farm operators to better assess potential damage following a storm and conduct more efficient inspection and repair plans.

WHEN LIGHTNING STRIKES

Unrepaired damage to turbine machinery can intensify exponentially. Extensive stress is placed on the blades when operated. When a turbine is impaired without notice — often puncture-related — what may begin as a minuscule crack or fracture that can be easily fixed with minimum cost can expand into a massive and costly fix.

However, economic cost of repair is not the only consequence. Turbines kept from spinning due to lengthy periods looking for potential damage can reduce energy output. Loss of power generation can be avoided with more accurate damage assessments that translate into faster maintenance and repairs.

More efficient and effective assessments are constructed through GIS-mapped asset overlays with highly accurate lightning tracking data. The combination of lightning strike data and specific asset location enables accurate evaluations of potential damage.

WORKING FOR WIND FARMS

A catalog of every wind turbine and its specific location within a wind farm is listed. After a storm, this list of turbine coordinates is compared to the recorded latitude-longitude of the lightning strikes.

Operators are notified of the exact location lightning struck in proximity to a turbine, polarity (positive or negative) of the strike, and the intensity of the lightning when it crosses a certain locational threshold.

A new report is produced every 24 hours giving operators the

Figure 2: A catalog of every wind-turbine asset within a wind farm operation is indexed with its data.

Area - Asset	Distance(m)	Polarity	Amplitude	Date-Time	Latitude	Longitude
Conception-T03	315	-	16	2:36:05.5 AM CST 11/17/15	40.24603	-94.6797
Crosswinds-T03	182	-	80	12:28:32.2 AM CST 11/17/15	43.05408	-94.90556
Crosswinds-T04	290	-	28	12:29:40.1 AM CST 11/17/15	43.06365	-94.90011
Crosswinds-T05	26	-	116	12:29:40.1 AM CST 11/17/15	43.06604	-94.89814
Crosswinds-T05	332	-	28	12:29:40.1 AM CST 11/17/15	43.06365	-94.90011
Crosswinds-T09	21	-	38	12:34:11.5 AM CST 11/17/15	43.08468	-94.88329
Hardin-T01	38	-	14	1:59:12.0 AM CST 11/17/15	42.08263	-94.36556
Hardin-T02	339	-	36	2:07:24.0 AM CST 11/17/15	42.08465	-94.35599
Hardin-T03	25	-	36	2:07:24.0 AM CST 11/17/15	42.08465	-94.35599
Sleeping Bear-T21	299	-	20	11:36:13.8 PM CST 11/16/15	36.63667	-99.46755
Sleeping Bear-T21	306	-	10	11:36:13.8 PM CST 11/16/15	36.63685	-99.46746
Sleeping Bear-T22	7	-	10	11:36:13.8 PM CST 11/16/15	36.63685	-99.46746
Sleeping Bear-T22	29	-	20	11:36:13.8 PM CST 11/16/15	36.63667	-99.46755
Sleeping Bear-T35	95	-	4	11:25:37.3 PM CST 11/16/15	36.65079	-99.50849
Sleeping Bear-T36	343	-	4	11:25:37.3 PM CST 11/16/15	36.65079	-99.50849

ability to assess and prioritize a turbine-inspection-and-maintenance schedule for the day.

VALUE OF LIGHTNING DATA

While real-time lightning is tracked and reported, the data from the report is archived and available long after the lightning activity is over. That means wind farmers can study every lightning strike on their property from the day they sign up for the service. This feature helps wind farms track lightning activity near a turbine or to see specific locations in the wind farm which might be susceptible to lightning strikes. This archived information also is useful to identify patterns of lightning activity that might be useful when looking for locations to install new turbines to extend a wind farm.

LOOKING AHEAD

Wind-farm operators are not the sole beneficiaries of this asset-specific lightning threat assessment. The entire utility industry can take advantage of weather system services to create safer, faster, and more efficient response efforts to threat assessments of assets.

And, with the recent launch of Hub Height Winds forecasting capabilities, the energy industry will be able to identify potential risks of high wind speeds and wind gusts, as well as the impact they may have on assets.

The energy industry can now use predictive intelligence to plan ahead and improve reliability and decrease costs down the road. With increasing weather volatility and pressure on asset-management budgets, this capability is critical for understanding weather's impact on assets and how best to manage them.

Protecting the Blades

Leading-edge erosion can dig into a turbine's performance, but solutions exist to keep minor worries from becoming major problems.

By Santhosh Chandrabalan

Wind-protection tapes and coating can extend the life of wind-turbine blades.

Every year, wind-turbine blades face numerous environmental and weather challenges — including rain, hail, blowing sand, and salt spray — that can cause significant leading-edge erosion. Although small in size, these elements can lead to pitting, gouging, and delamination of the blade, severely affecting the entire wind turbine.

In addition to drastically compromising the integrity of the blade, leading-edge erosion also affects a turbine's overall aerodynamic efficiency. Remarkably, structural changes caused by even minor erosion can have a significant effect on annual energy production (AEP) and return on investment (ROI). In fact, recent studies have demonstrated that pitting and gouging can reduce AEP by approximately 4 to 10 percent, while delamination can reduce AEP by up to 20 percent.

Regardless of geographical location, blade height or length, leading-edge erosion is an issue that affects all wind turbines. So, it's imperative to proactively implement innovative solutions to address and mitigate the problem. Best practices for wind-turbine repair and maintenance include:

WIND PROTECTION TAPE

One of the most popular and trusted solutions for leading-edge erosion repair is wind-protection tape. Constructed with durable, abrasion-resistant polyurethane elastomers, this product originally was developed for the heavy-duty use of aircraft radomes and helicopter blades. After installation on a blade's leading edge, wind-protection tape shields the blade from erosion, puncturing, tearing, weathering, and water damage.

While coatings may be affected by external conditions, including humidity and temperature, tapes provide uniform thickness and finish, making it one of the most consistent and reliable products for a project.

It's important for OEMs to research a variety of wind-protection tapes to determine what material composition and application instructions will work best for each repair scenario. Special considerations also should be made to determine UV stability in warmer climates. Fortunately, due to recent innovations, many of the tapes on the market have been designed for simple application in the factory or in the field via rope or platform access, regardless of weather or terrain.

WIND BLADE PROTECTIVE COATINGS

Two-component polyurethane coatings are designed to help protect the leading edge of a wind-turbine blade from sand, rain, and other minimal impacts. Protective coatings are applied with either a brush or casting, and they provide excellent erosion protection in a single or multiple layer.

When deciding what application process to use, OEMs should consider that both tapes and coatings can extend the life of a blade by providing maximum turbine efficiency and reducing interruptions caused by service from maintenance and repair. Additionally, when selecting a wind-blade protection coating, attention should focus on a product that can easily be applied in both the factory and the field to ensure an efficient curing process.

Finally, it is also important to consider additional repair options, such as fillers, abrasives, and accessories, if the wind-turbine blade has signs

Leading-edge erosion can reduce AEP by up to 20 percent.


3M Wind Energy

of previous damage. These tactics are typically used in concurrence with protective coatings to ensure a successful repair process.

WIND EPOXY AND POLYURETHANE FILLERS

If the wind blade has sustained damage past the point of protection and needs repair, epoxy or polyurethane (PU) fillers can be used to remedy surface damage.

When selecting epoxy or PU fillers, three crucial components should be considered: performance, time, and application methods. There are several options available that incorporate innovative cartridge and applicator systems, which ensure accurate mixing and reduce the possibility of error and waste.

As wind blades are designed to flex substantially during use, fillers need to be flexible, yet tough, to prevent any surface cracking. As fillers become the base of the leading edge, it's essential to select the correct filler, coating, or wind protection tape to avoid additional blade damage.

SURFACE BONDING APPLICATIONS

In addition to extending the life of a wind-turbine blade with preventative measures, there are several tools available to proactively optimize aerodynamic efficiency and AEP. These bonding and composite tools are used to secure aerodynamic attachments — including vortex generators — or bond composite wind blades. Depending on the project, several application solutions are available, including:

Acrylic Foam Tapes: Acrylic foam tapes provide an exceptional substitute to liquid adhesives and mechanical fasteners, due to their durability, ease of application, and ability to withstand residual forces including high UV rays and severe weather conditions. This product is typically used for applications when reliable bonding or sealing is required, and accommodates rigorous flexing and fatigue.

Wind Blade Bonding Adhesives: A two-part, structural epoxy adhesive for bonding composite wind-turbine blades, this high-performance, tough adhesive combines shear and peel strength along with excellent durability. Bonding adhesives also provide a faster cure speed, saving up to six hours of mold time per blade.

Structural Adhesives: Used for bonding composite wind-turbine blades and other general-purpose applications, this rigid adhesive combines high shear strength with excellent toughness and durability.

Dry Layup Adhesive: Dry layup adhesive is a sprayable, synthetic elastomer-based adhesive for bonding and holding glass fabrics and other reinforcements and materials (i.e. flow media) in place during the infusion process.


3M Wind Energy

Surface bonding applications can be used to secure attachments to optimize efficiency.

CONCLUSION

In an effort to maximize ROI, OEMs must consistently research and identify the best solutions to reduce leading-edge erosion.

By implementing a proactive approach, individuals can address both prevention and repair through the correct use of fillers, protective coatings, tapes, and aerodynamic upgrades.

More importantly, a comprehensive approach to wind-turbine maintenance can lead to a sizeable increase in future earnings and AEP.

For more information about 3M Wind Energy, go to 3M.com/wind.

Advance Warning Advantage

Condition monitoring can maximize maintenance resources.

By Greg Ziegler

Before the next maintenance inspection for a wind turbine, much can happen. At every turn, critical components can be moving toward failure. Wind turbines are complex systems integrating thousands of components and will be buffeted by many of the same operational and maintenance issues associated with any machinery. And fixes to the systems can be costly in time, money, and wind-farm productivity.

When unplanned turbine downtime becomes unavoidable because an essential component has failed without warning, potentially sky-high costs can follow. Expensive cranes may have to be transported and mobilized on land or offshore to access the trouble spots; replacement parts will need to be sourced and delivered, and technicians may have to be redeployed from other essential tasks to handle the immediate problem.

With the reliability and productivity of wind turbines hanging in the balance, technologies to monitor and track deteriorating component conditions in real time have gained considerable interest and applications. When the market was still in its relative infancy, condition-monitoring systems specifically engineered for turbines were few and far between. Today, as the industry has begun to mature in various regions, most new turbines will be equipped with some level of monitoring system to keep turbine health current.

When a wind turbine fails, on-site technicians likely will be the first responders. Advance warning can make a substantial difference in keeping turbines productive and operating reliably.

SKF

But for unmonitored installations, performance can go awry with little or no advance notice. With the typical 20-year service life for the average wind turbine, it is not a question of “if” but “when” maintenance attention will be required. Proactive monitoring of critical wind-turbine components can eliminate many of the unknowns, while unlocking optimized capacity and long-term profitability on the wind farm.

TURNING TO COMPONENTS

Most large, modern wind turbines are horizontal-axis types. Their primary components include blades or rotors (which convert the energy in the wind to rotational-shaft energy), drive train (usually including a gearbox and generator), tower (support structure for the rotor and drive train), and other equipment, including controls, electrical cables, ground support, and interconnection equipment.

When a wind turbine fails, on-site technicians likely will be the first responders. However, the resolution to remedy the failure will vary by installation. Operators may rely upon OEMs, independent repair and maintenance contractors, their own in-house technicians, or a combination. Local distributors will be enlisted to supply components for out-of-warranty repair.

Advance warning can make a substantial difference in keeping turbines productive and operating reliably, while promoting timely maintenance practices in the process. Successfully transferred from applications in other industries, condition-monitoring systems (CMS) enable early detection and diagnosis of potential component failures and serve as a platform for implementing condition-based maintenance (CBM) practices. CMS also can detect wind-turbine problems from causes other than component failure, such as rotor imbalance due to icing and electrical faults.

DETECTING PROBLEMS

Condition monitoring is a strategy whereby physical parameters (including vibration, temperature, lubrication particles, and others) are measured regularly to determine equipment condition. This process makes it possible to detect machine and component problems before they can lead to unexpected downtime and unplanned costs from maintenance and lost production.

An online condition-monitoring system offers a powerful tool for managing day-to-day maintenance routines and can include the capability to review data remotely.

An online condition-monitoring system offers a powerful tool for managing day-to-day maintenance routines inside a wind turbine and consolidating risky, costly maintenance activities. By equipping operators to monitor and track deteriorating component conditions around-the-clock in real-time, expedient maintenance decisions can be based on actual machine conditions instead of arbitrary maintenance schedules. Mounted sensors and related software do the work and pinpoint the problems. Along the way, costs can be saved and unscheduled downtime can be minimized.

The principles of condition monitoring are not new, but the proactive approach has gained significant ground in the industry due to the increasingly sophisticated computational interpretation and analysis capabilities for measured data. CMS data can be applied to adjust scheduled maintenance intervals and strike an ideal balance between the cost of maintenance and the cost of unscheduled fault repairs.

In addition, monitoring systems can enhance and optimize maintenance forecasting by continuously recalculating fault frequencies and delivering accurate values based on reliable trends. This can facilitate the assigning of alarms at various speeds and loads, including low main shaft speeds, and form the basis for trend-based root-cause failure analysis.

Most monitoring systems can accommodate a large population of turbines and multiple data points. Using vibration sensors mounted on a turbine's main shaft bearings, gearbox, and generator, systems (in tandem with software) will continuously monitor and track a wide range of operating conditions for analysis.

Wireless capabilities expand system potential by offering a way to review data remotely from any location with a computer or hand-held device with internet access. This can shorten lead-time from alarm to solution.

EVALUATING CONDITIONS

Operating conditions that can be targeted for early detection, diagnosis, and remedial action include:

- Unbalanced turbine blades
- Misalignment
- Shaft deflections
- Mechanical looseness
- Foundation weakness
- Bearing condition
- Gear damage
- Generator rotor/stator problems
- Resonance problems
- Tower vibrations
- Blade vibrations
- Electrical problems
- Improper or inadequate lubrication

An example of one of the more comprehensive condition-monitoring systems in use at many installations around the world illustrates the advantages.

This particular system is grounded in an "intelligent" monitoring unit, which is mounted inside the turbine's nacelle. The unit features 16 different channels where multiple measurement points can be connected. A typical wind-turbine configuration would incorporate the main bearing (one channel), gearbox (four channels), generator (two channels), and tachometer (one channel). In addition, other monitoring points can be added, including tower/structure vibration, blade vibration, oil temperature, oil pressure, oil quality, and generator temperature.

This system applies built-in hardware auto-diagnostics, which continuously check all sensors, cabling, and electronics for any faults, signal interruption, shorts, or power failures. Any malfunction triggers an alarm.

Such a system even allows operators to use the information to control or postpone repairs, as one SKF customer discovered.

In this customer's case, a monitoring unit was eventually installed on a wind turbine that had been experiencing consistent damage to the low-speed part of its gearbox. After installation, the monitoring system performed as intended and beyond. The system not only registered the damage, but also determined the damage was stable enough to postpone the gearbox replacement and keep the damaged turbine in operation.

After monitoring the damaged part for almost 12 months, the system eventually detected a rapid increase in the damage pattern, and only then was the turbine taken offline for gearbox replacement. By postponing the gearbox replacement for a year, the wind farm was able to generate interest on the capital needed for the overhaul and efficiently plan for parts delivery, shipping, personnel, and cranes for the job.

The alternative would have been a rushed operation accompanied by unnecessary costs, several weeks of downtime, and lost productivity.

EVOLVING TECHNOLOGY

By tracking component health and evaluating data from monitoring, maintenance activities can be coordinated across the wind farm, service calls can be better planned and bundled, and operators can take advantage of planned shutdowns to service several turbines at the same time, since machinery conditions will be known from the monitoring.

A viable condition monitoring system ultimately can assist wind-farm operators in performing appropriate inspections, maintenance activities, and fixes at the right time when and where needed, regardless of the calendar. As a result, wind-farm operators can extend maintenance intervals, consolidate maintenance initiatives, cut operating costs and costs per kWh, reduce the risk of unplanned shutdowns, prevent lost energy production due to breakdowns, and predict remaining service life by turbine. All contribute economies and efficiencies for a wind-farm operation.

The monitoring process for a wind turbine can effectively reduce lifecycle costs and extend service life. Implementing necessary repairs when problems begin to surface, for example, proves easier and much less expensive than running a turbine to catastrophic failure.

Looking ahead, significant research and development is under way involving condition monitoring techniques, fault analysis, and optimized maintenance procedures. The evolving technology intends to help keep operating and maintenance costs to modest levels and contribute overall toward the cost-effectiveness of wind-turbine technology.

The evolution is further continuing with a focus on ergonomics and improved diagnostics and prognostics. And technician requirements may change for the better with advances in technology, leading to improvements in the scheduling and deployment of manpower.

Above all, support is readily available. One of the best practices in navigating the challenges of wind-farm operations and maintenance is to partner with an established services provider experienced in the many interrelated aspects of wind-turbine technology. This will inform operators with the most current engineering resources to help keep the blades turning productively.

For more information, go to www.skfusa.com