Educational opportunities abound at WINDPOWER 2015

The U.S. wind energy industry meets in Orlando to discuss current challenges and its vision for the future

From press reports

The U.S. utility-scale wind energy industry gathers once again this month for the American Wind Energy Association's annual WINDPOWER Conference & Exhibition. The 2015 event runs from May 18 – 21, at the Orange County Convention Center in Orlando, Florida.

The event could not have come at a better time for an industry that, following record annual installations in 2012, suffered heavily the following year, due largely to policy uncertainty surrounding the production tax credit.

Currently, although the industry remains plagued by both a lack of a clear, long-term policy support and the expiry of the tax credit, it is enjoying somewhat of a rebound.

The industry installed 4,854 MW in 2014 — up from 1,087 MW a year earlier, yet still dwarfed by the record annual installation of 13,131 in 2012.

In April, AWEA announced with the release of its "U.S. Wind Industry Annual Market Report, Year Ending 2014," that 12,700 MW of wind energy projects were currently under construction at the beginning of 2015.

Also setting the stage for WINDPOWER 2015 is a report released in March by the U.S. Department of Energy, which states the U.S. wind energy industry is capable of steady growth in the years and decades to come. The report, titled "Wind Vision: A New Era for Wind Power in the United States," the DOE claims that wind energy can provide 10 percent of the nation's electricity supply by 2020; 20 percent by 2030; and 35 percent by 2050 if certain criteria outlined in the report are met.

These elements have combined to generate more than a fair amount of buzz within the wind industry, and will likely take shape in the discussions and conference sessions scheduled for WINDPOWER 2015.

The education program for WINDPOWER 2015 — consisting of conference sessions, poster presentations, technical training, side meetings, and AWEA committee meetings — is structured based upon six primary market segments, including: Manufacturing & Supply Chain, Project Development & Planning, Operations & Maintenance / Safety, Utilities & Grid Operations, Finance & Investment, and Policy & Law / Legal. AWEA's descriptions of these market segment tracks follow.

Manufacturing & Supply Chain — Cost-effective tools for sustaining success

Wind-related manufacturers have cost-effective access to the tools and information they need for sustained success in an ever-changing environment. Crafting your agenda around this sector will help you address the future of wind energy as it relates to manufacturing and the supply chain, the emerging trends in wind turbine technology, the changing markets and the opportunities they create, and more.

Project Development & Planning — Harvesting the wind

Leading professionals from all areas of the wind project development cycle are bringing their expertise in 2015. Sessions enable the exchange of ideas and insights, and cover every key topic—from siting & permitting to

construction, transportation, logistics, resource assessment, and forecasting. Access the sessions, companies, and key leaders in this industry sector for the information you need to ensure that your wind project delivers top performance and reliability.

Operations & Maintenance, Safety — Preparing for long-term profitability and reliability
Successful wind power operation depends on management strategies that streamline costs, maximize production, ensure workplace safety and extend the life and reliability of your equipment. Below are the resources available to addresses the operational lifecycle issues that challenge owners and operators, now and down the line. Plus, meet with peers and evaluate best practices for managing wind projects.

ALSO IN THIS SECTION:

Utilities & Grid Operations — Delivering the Wind

Your focus is getting wind energy to utility customers and WINDPOWER has what you need. Obtain the information and make the right connections to maximize the successful incorporation of wind energy into the grid. Collaborative sessions and panel discussions address potential impacts, challenges and successes, and offer a deeper understanding of integration cost, price stabilization and fluctuating output management.

Finance & Investment — Lay the Foundation for Financially Successful Project

Whether you want to invest in a new project or discover innovative funding strategies that are impacting the wind energy landscape, the educational program has the knowledge leaders you need to find opportunity in U.S. and international markets.

Policy & Law/Legal — Navigating the Wind Energy Landscape

Dive into how federal, state, and local policy will shape demand. Plus hear from communications experts and law/legal professionals to help you navigate through current and developing market conditions.

In addition to the conference sessions, certain presentations will take place on the Exhibition Hall floor as part of the Thought Leader Theater, sponsored by Mortensen Construction.

At the Thought Leader Theater, industry experts from leading wind energy companies will discuss their expertise, how their company is finding success, and what their company can do for attendees.

These presentations will take place throughout the conference and will be located at Booth #2538 — near the AWEA Booth. The presentations are 30 minutes in duration, and run from 11:00 a.m. through 3:30 p.m. on Tuesday, May 19 and Wednesday, May 20, and from 10:00 a.m. through 12:30 p.m. on Thursday, May 21. A full schedule of the Thought Leader Theater presentations, including times, topics, and sponsors can be found online at the WINDPOWER 2015 website (www.windpowerexpo.org).

For more information about AWEA's WINDPOWER 2015 Conference & Exhibition, including the full schedule of events, an exhibitor floor plan, and related materials, visit www.windpowerexpo.org. The conference session schedule, including session times and topics, as well as exhibiton hall hours of operation can also be found on page 26 of this issue.

2015 Conference Schedule

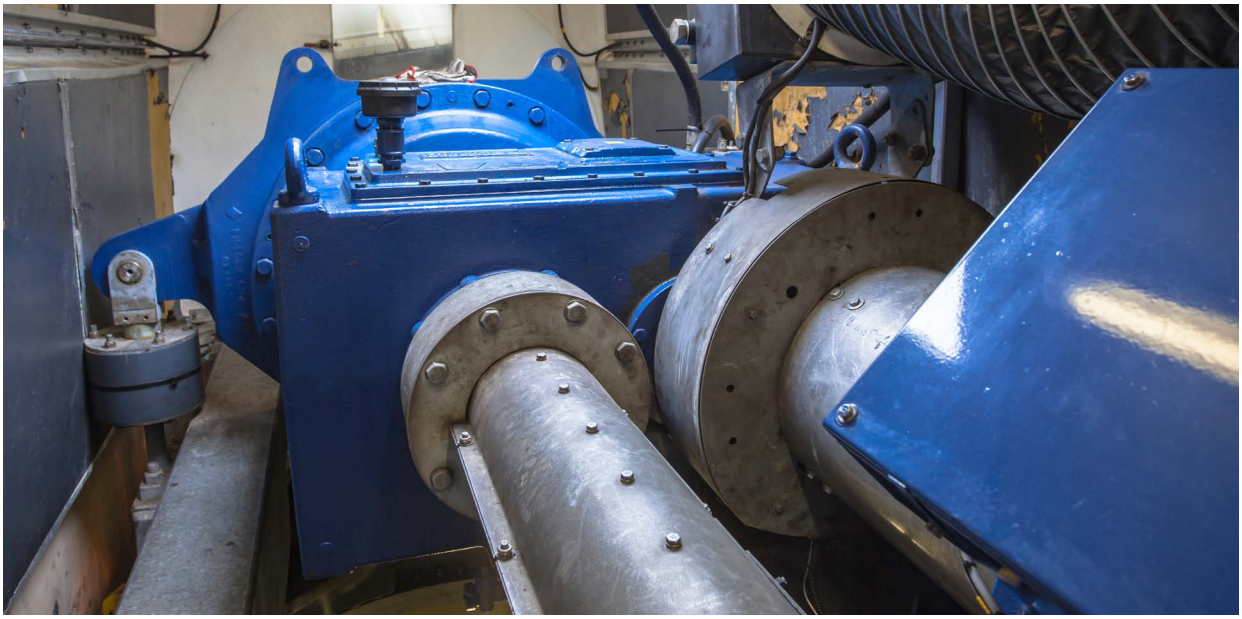
Tuesday, May 19				
7:30 am –5:30 pm	Registration Open (South exhibit hall)			
7:30 am –8:30 am	Kick-off Exclusive Networking Breakfast for Session Attendees (South concourse)			
8:30 am –10:00 am	WINDPOWER 2015 - Welcome and Opening General Session (Open to all attendees) (South exhibit hall SA1)			
	Power Sessions			
10:30 am –11:45 pm	U.S. Wind Energy Market Forecasts: Where, When and How Much? (Room S320A)		Future of O&M – The Technology Impact and Lessons Learned (Room S310E)	
11:45 am –12:00 pm	Knowledge Hub: Meet the Speaker			
12:00 pm –1:30 pm	Networking Lunch in Exhibit Hall			
1:30 pm –2:45 pm	The Next Frontier for Wind: Four Competing Cases from Leading Developers (Room S320A)	Scientific Advancements in Wind, as Told by Industry Experts (Scientific) (Room S310E)	Innovations in Wind PowerIntegration (Room S320A)	Turbine Transportation and Infrastructure Considerations (Room S310A)
2:45 pm –3:00 pm	Knowledge Hub: Meet the Speaker			
3:15 pm –4:30 pm	Opportunities & Challenges in Resource & Performance Assessment (Room S320A)	Advances in Turbine Components and Subsystems R&D (Scientific) (Room S310E)	Potential and Planned Transmission Solutions. What is Next? (Room S320E)	Wind Power in the New Congress: A Medium and Long-Term View of How Federal Policy Will Shape the Future of Wind (Room S310A)
4:30 pm –4:45 pm	Knowledge Hub: Meet the Speaker			

Wednesday, May 20				
7:30 am – 5:30 pm	Registration Open			
7:30 am – 8:30 am	Day Two Exclusive Networking Breakfast for Session Attendees(South concourse)			
8:30 am – 10:00 am	General Session: Wind Industry Leaders Panel & Keynote Speaker Address (Open to all attendees) (South exhibit hall SA1)			
	Power Sessions			
10:30 am – 11:45 am	YieldCos and IPOs – Why New Public Structures Are Adding New Owners for Wind Projects (Room S310E)		Wind Vision: An Opportunity to Rally the Public Around a Future of Abundant Clean Energy (Room S320A)	
11:45 am – 12:00 pm	Knowledge Hub: Meet the Speaker			
12:00 pm – 1:30 pm	Networking Lunch in Exhibit Hall			
1:30 pm – 2:45 pm	Wind Demand: Offense and Defense (Room S320A)	Turbine Maintenance Marathon or Sprint? (Room S310E)	Stakeholder Engagement: Ensure Your Online Messaging is Targeted and Received (Room S320E)	Supply Chain Evolutions to Support Technology Trends (Room S310A)
2:45 pm – 3:00 pm	Knowledge Hub: Meet the Speaker			
3:15 pm – 4:30 pm	Navigating Federal Wildlife Permitting at Greenfield and Operating Wind Farms (Room S320A)	The "Mostly Wind" Grid – Implications for Reliability, Markets and Storage (Room S310E)	International Market Update: Opportunities and Challenges (Room S320E)	Offshore Wind in the U.S. – Past, Present, and Future (Room S310A)
4:30 pm – 4:45 pm	Knowledge Hub: Meet the Speaker			
4:30 pm – 6:00 pm	Poster Reception (South exhibit halls, Poster presentation area)			

Thursday, May 21				
8:00 am – 1:00 pm	Registration Open (South exhibit hall)			
8:00 am – 9:00 am	Day Three Exclusive Networking Breakfast for Session Attendees (South Foyer, Level 2)			
9:00 am – 10:15 am	Innovations in Reliability and Performance of Today's Wind Turbines (Room S320A)	Health and Safety Regulation Updates – How They Affect Design and Operations on Wind Turbine Projects (Room S310E)	Connecting the Dots: Understanding the Value of Improved Wind Energy Forecasts (Scientific) (Room S320E)	New Distributed and Community Wind – Success Stories and Strategies (Room S310A)
10:15 am – 10:30 am	Knowledge Hub: Meet the Speaker			
11:30 am – 1:00 pm	Networking Lunch in Exhibit Hall - Last chance to visit the exhibition			
1:30 pm – 2:45 pm	Closing Session: Large Turbine Manufacturer Forum (Open to all attendees) (Room S320A)			
2:45 pm – 3:00 pm	Knowledge Hub: Meet the Speakers			

Validation of journal bearings for use in wind turbine gearboxes

By Thomas Meyer
Winergy



Maximum reliability and low life-cycle costs are the decisive key factors for systems operators in nearly all areas of industry, including the windpower industry. That also applies to gearboxes in windpower turbines functioning as the main constituent of the drive train. Journal bearings now offer a technology that is already being used successfully in other areas of industry and is further enhancing the availability of windpower systems.

Experience shows that journal bearings make a very good alternative to the roller bearings so far used in windpower gearboxes. The area of application for journal bearings is very varied: for large, heavy-duty applications hydrodynamic journal bearings in particular are worth considering. In the past such applications have been mainly large industrial gear units for driving mills and ships. In these applications journal bearings stand out for their high reliability. Because of this experience journal bearings are also a highly promising alternative for use in the drive systems of windpower systems, particularly in gearboxes.

The development and design of bearings in windpower gearboxes represent an increasing challenge as gearboxes get larger and their load and deformation conditions change accordingly. Positive experience made with journal bearings in industrial applications can be used to good effect in the windpower sector, if windpower-specific limiting conditions are taken into consideration. The high loads at low sliding velocities are a particular example here.

For the use of journal bearings in windpower-specific applications special operating conditions must be taken into consideration. Such conditions include low-temperature operation, the idling condition, emergency stops and all part-load operating conditions.

Tests on journal-bearing test rigs

To validate their suitability for operation in windpower gearboxes, Winergy subjected journal bearings to exhaustive tests. To estimate the limits to the loads on and use of journal bearings in windpower gearboxes, tests can first be conducted on bearing test rigs. For this, a test rig of the kind shown in Figure 1 was built. This test rig has a bearing holder to receive a radial journal bearing with a nominal diameter of 120 mm. This is roughly equivalent to the bearing size of a two-megawatt windpower gearbox on the high-speed generator shaft (HSS).

The test rig is fitted with a friction balance to enable the friction torque in the journal bearing to be directly measured.

Various metallic bearing materials were tested under windpower-specific conditions. High torques occur, particularly when braking a turbine, until the system comes to a

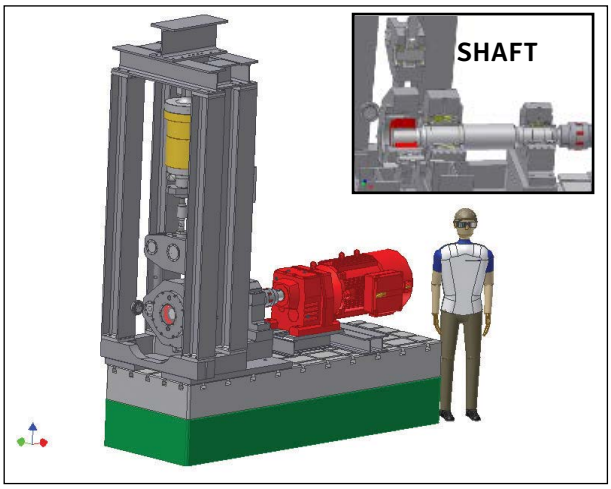


Fig. 1: 120 mm journal-bearing test rig. Source: Institute for Machine Elements and Machine Design at RWTH Aachen University, Germany

standstill. These emergency stop tests were repeated 2 000 times without measurable wear being found. Only run-in wear of the order of magnitude of < 1 µm was visible.

The Stribeck curves on Figure 2 clearly show that the level of friction after run-in is below that of roller bearings. At the same time the friction minimum at very low sliding

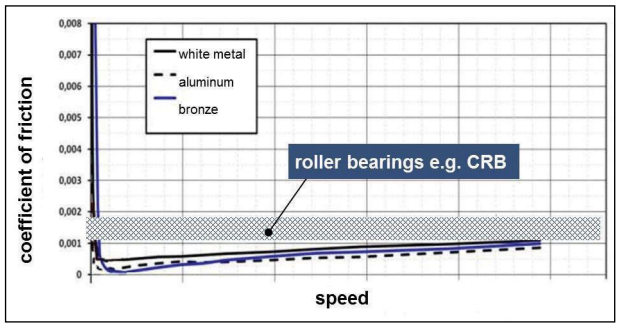


Fig. 2: Stribeck curve pattern at the end of the test cycle for various material groups.

velocities is less than 0.2 m/sec. Since rated operating velocities are considerably higher, hydrodynamic operation is possible in the rotor side of the gearbox.

Tests on gearbox test rigs

Further validation of the use of journal bearings in windpower gearboxes is based on a two megawatt gearbox fitted with roller bearings in series. The aim here was to use the space required for roller bearings for the use of journal bearings. The gear used was a three-stage planetary cylindrical-gearbox comprising a planetary stage on the rotor side and two cylindrical gear stages to follow. The plane-

tary stage was driven via the planetary carrier, while output was via the central sun pinion with a fixed hollow gear. This gearbox was fitted entirely with journal bearings. The only exception was carrier bearings 256 and 255, as shown on Figure 3.

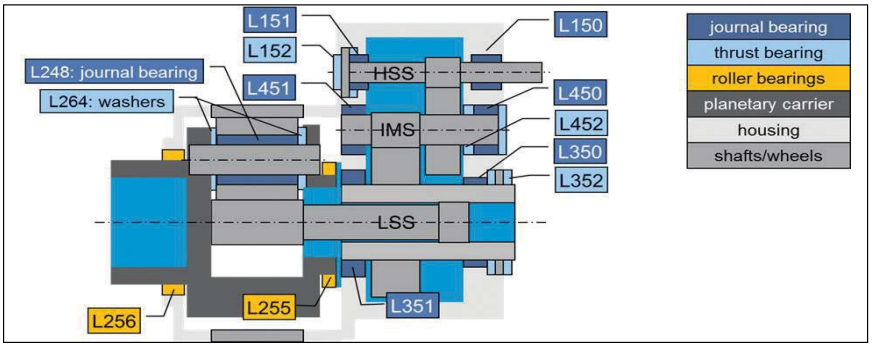


Fig. 3: Schematic view of a three-stage 2 MW gearbox

The gearbox was subjected to various tests on the test rig. Tests were conducted with part, nominal and overload, in idle operation under cold weather conditions, as well as various special tests. Figure 4 shows a complete overview of the tests conducted.

The tests were conducted sequentially on the same gearbox. On completion of the tests the bearings were inspected and measured. The journal bearings were found to be in a faultfree condition – no damage had occurred. Subsequent 3D measurement of the journal bearings showed that the bearings had not undergone any deformation and so no wear occurred.

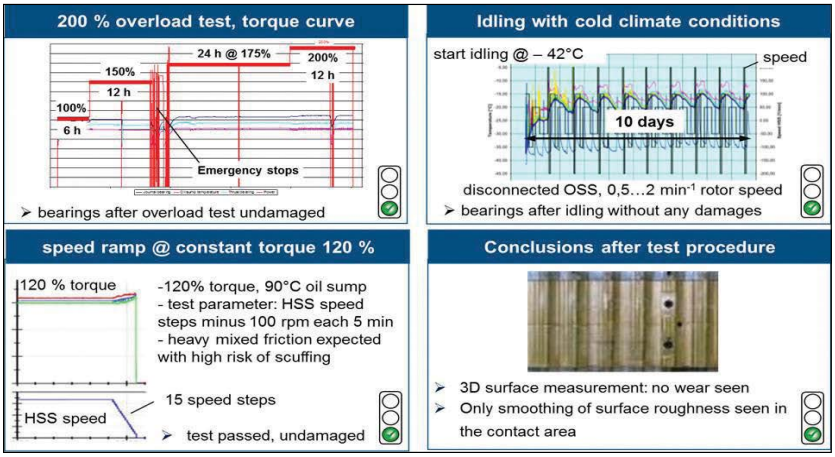


Fig. 4: Overview of gearbox test – 2 MW gearbox

The test rig tests also showed that the power losses on the gearbox variant fitted with journal bearings were no higher than those on the variant with roller bearings. In the low-speed range of the gearbox lower power losses occur on the low-speed shaft (LSS), whereas in the high-speed range slightly higher power losses of the journal bearings occur on the HSS. No increase in the cooling capacity of the gearbox or in the volumetric oil flow is necessary.

A 10-day idle test under cold conditions was conducted at – 40°C. Here too no abnormalities occurred. The emergency running properties of the material used for the bearings are adequate for such conditions.

As expected, structure-borne sound vibration was reduced in comparison with the roller-bearing variant because of the excellent damping properties of the journal bearings at all gearbox stages.

Prototype field validation

After successfully passing the tests on the test rig, the gearbox was installed in a Vestas V90 series turbine; it has been running faultlessly for two years; behaving in the turbine the same way as it does on the test rig. The good noise characteristics were confirmed, and the oil analyses conducted during running time show no impurities from wear.

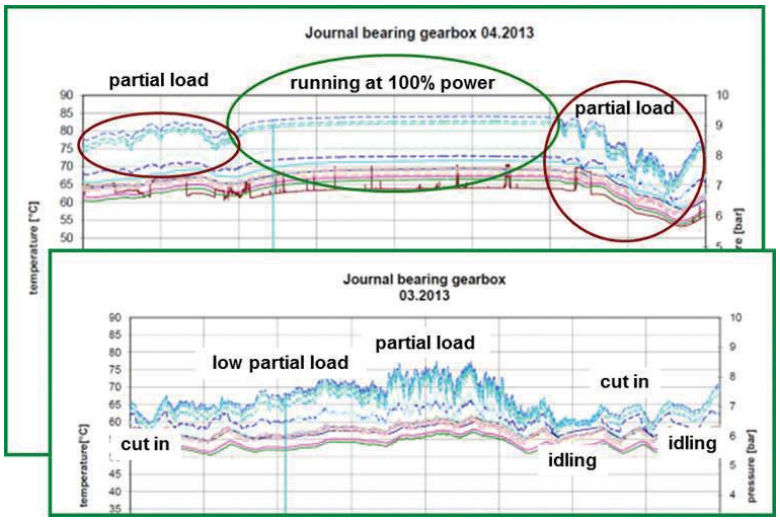


Fig. 5: Temperature measurements for journal bearings, 24-hr records

This behavior too can be assessed by monitoring the temperature of the journal bearings. Figure 5, for example, shows the daily records of temperature measurements. These show clearly the link between current operating condition and the corresponding temperature level.

The nominal load condition is marked by an even operating temperature of the journal bearings. The different part-load conditions under constantly changing wind conditions express themselves in changing temperatures.

Summary and conclusions

As previously mentioned, application-specific investigations have shown the use of journal bearings in windpower gearboxes offers a very good alternative to roller bearings. The advantages that journal bearings already show in other applications also show clearly in the windpower sector.

Test-rig tests have confirmed journal bearings can be operated hydrodynamically in windpower gearboxes without causing wear. This finding is supported by the successful field operation of the prototype fitted with journal bearings that has been faultlessly in operation for two years now. Journal bearings also behave very well during operation in windpower-specific conditions. Also special operating conditions like prolonged idling and emergency braking are borne by journal bearings without any problem. It was also found that windpower gearboxes fitted with journal bearings show low sound radiation because of the greater damping capacity of hydrodynamic journal bearings. Since journal bearings take up less fitting space, gearboxes fitted with journal bearings can also be built more compactly and more cost-effectively.

Vaisala to present on assessment methodology in Orlando

For the last decade, the wind industry has exhibited vast underperformance by all, including the top consultants, and a massive effort has been underway to understand where performance losses occurred. These investigations have already revealed that more sophisticated assessment methods are required to improve energy estimates.

Vaisala will be presenting and exhibiting at WINDPOWER 2015 to discuss a better approach to energy assessment. Attendees can join the discussion by visiting Booth 4221 and attending its speaker presentation, "Validation of Pre-construction Energy and Uncertainty Assessments" given by Vaisala Sr. Scientist, Mark Stoelinga.

A few years ago, aware of shortcomings in the classical uncertainty models, Vaisala developed the Energy Risk Framework, an innovative approach designed to calculate uncertainty sensitivities no other model can capture. With the advantages in both modeling technique and risk characterization, Vaisala has gained respect with a number of global banks and investors, often being their preferred opinion. Today, the company is in regular outreach with key banks, and is working toward universal acceptance of our approach.

To demonstrate its accuracy, Vaisala is investing in a significant validation study to prove skill and calibration of its methods. This study will create the beginning of a database that will be continually updated as the company expands on its extensive experience.

There are three basic goals for this study:

1. Prove that Vaisala's methods can accurately predict P50s in a standard pre-construction estimate.
2. Demonstrate that its Energy Risk Framework calculates uncertainties that actually relate to the prediction error.
3. Establish that Vaisala has a well-documented, robust process that clients and investors can trust to repeatedly achieve trustworthy results at projects going forward.

While Vaisala's validation effort is a key part of demonstrating its approach and accuracy for energy estimates, it is only the beginning. A core value at Vaisala is continuous improvement, and this study is just the first cycle of a feedback loop that will be maintained indefinitely. As technology changes require the adaptation of new and more sophisticated methodologies, this ongoing feedback process will ensure Vaisala continues to lead with the most scientific and accurate process.

— Source: Vaisala

Airway Services Inc.

Since 2009, this independent service provider has built its reputation on safety, professionalism, and quality

By Stephen Sisk

In this 21st-century age of growing skepticism, agendas, and distrust, it's often refreshing to hear a voice that cuts through all the noise and tells it like it is.

It may even seem like a novel concept, but straight-talk and truth have an almost uncanny way of building trust.

For Airway Services Inc., a full-service provider of operations, repair, maintenance, and staffing services for the utility-scale wind energy industry, that kind of transparency is far from a novel concept. It's one of the core values influencing how they do business.

Founded in 2009 in response to the rapidly increasing demand for wind energy service providers during the exponential growth of the U.S. wind energy industry, the young company has grown in step with the industry and now serves customers in 41 states, three provinces in Canada, Puerto Rico, Chile, and Brazil.

That growth is due in large part to the company's commitment to customer service. This is evidenced by its professionalism and ethical dealings with customers, as well as through employing best practices and maintaining a high level of proficiency in the services they offer.

"We're very transparent with our customer," said Chase Hord, CEO of Airway Services. "If we tell them we can do something, we do it. If we say we can't, it means that we don't have the technical pool to do so."

Customers, Hord said, appreciate that brand of honesty, which leads to a solid reputation within the wind service community.

"If we mess something up, we're the first ones to raise our hands and say 'let's make sure we learn from this experience,'" Hord said. "Then we'll all sit down and see where our

AIRWAY SERVICES INC. SERVICE PORTFOLIO

PREVENTATIVE MAINTENANCE AND INSPECTION
- Component inspection
- Fluid level inspection
- Oil replacement and filter change
- Cleaning inspection and physical inspection
- Tower cleaning and punch-list services

WARRANTY SUPPORT SERVICES
- Coordination of wind turbine generator replacement including:
- Disassembly of nacelle
- Generator replacement
- Nacelle reassembly
- Electrical
- Crane path optimization and final completion of generator replacements
- Perform inspections on all incoming components
- Provide alignment of generator/gearbox couplings to OEM specifications
- Perform construction, final walk-down and end-of-warranty inspections

SCHEDULED PREVENTATIVE MAINTENANCE (PM)
- Servicing the Turbine reoccurring maintenance program including:
- Hydraulic torque and tensioning
- Base tower and structural components
- Up tower mechanical components
- Perform tower cleaning and PM punch-list services
- Supply technical PM on demand site support or independent staffing

ON-DEMAND STAFFING & LABOR SUPPORT
TECHNICAL
- O&M Technicians
- Supervision
- Health & Safety

SKILLED LABOR
- Wind Turbine Technicians
- Riggers
- Electrical
- Construction

PROFESSIONAL AND ADMINISTRATIVE
- Project Management
- Spare Parts Procurement
- Health & Safety Management
- Training
- QA/QC
- Installation
- Electrical
- Mechanical
- Field

INSTALLATION AND GENERAL CONSTRUCTION SUPPORT
- Torque & Tensioning
- Final Cleanup
- Inspection
- Receiving
- Project Punch-List
- Project Walk-down

lessons learned are and move forward in a positive direction."

According to Hord, it's easy in the wind industry to over-commit to a project. This can often lead to inferior service. Considering the tight-knit, family nature of the O&M segment of the industry, having that kind of reputation can be costly.

While professionalism and ethical dealings with customers are priorities for the company, they are only part of its operating philosophy.

Complementing these elements is Airway Services' strong commitment to providing its customers with the highest quality services possible. The company is able to achieve this level of quality due to the extensive knowledge and experience of its technical staff. Additionally, the company uses a Best Practices approach to maintaining a high-level of quality and workmanship in the services it offers.

With its field technician staff of around 185 — more than 92 percent of its total workforce — Airway Services has the capabilities, knowledge, and expertise to handle a wide range of needs sought by wind farm owner-operators and other industry stakeholders. Airway Services maintains its technical expertise throughout all areas of the O&M market segment through ongoing training, and the hiring of pre-qualified personnel.

Service areas within the Airway Services portfolio include turbine inspection, O&M tasks, warranty support, preventative maintenance, major component changeouts, on-demand staffing (technical and general labor), construction support, and administrative/professional support. (For a complete list of services, see the table accompanying this article.)

Airway Services' primary concern in its daily operations is the safety of its employees and the people around them — above all else. Its goal is to have zero incidents every day technicians are out in the field. The commitment to that goal is evidenced by measures the company takes to emphasize and encourage a strong safety culture throughout its ranks.

Those measures include an extensive, ongoing safety training program intended to maintain a safety-first attitude in the minds of its employees — to the point where it's second nature. Additionally, the company utilizes the latest safety technology, and evaluates its safety program and procedures on a perpetual basis.

Regarding the future for the San Angelo, Texas-based company, Hord expects the O&M market to grow steadily in the years ahead, as wind farm owner-operators continue to re-think and re-structure their O&M strategies.

While some owner-operators choose to self-staff and others choose to use the OEMs for sites under warranty, a different approach may be on the horizon.

"In the next couple of years, I think you're going to see a lot of the service providers take more of a blended approach to the business," Hord said. "You're going to see owners try to skeleton-staff their sites and run more of a leaner machine than what's been done in the past."

If that's the case, demand for service providers will likely increase, leading to more growth in the segment, and more opportunities for Airway Services to build even further on its reputation as a safe, honest, provider of high-quality services.

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Can you tell us the history of the company?

PSI began in 1967 as a hydraulic repair company specializing in the repair of servo valves for the automotive industry. From there, we evolved into supporting production machinery in military, aerospace, steel, and other industries. Over the last decade, we have supported the wind energy and mass transit industries.

What are some of the services that PSI offers?

We specialize in remanufacturing high power electronic components. Engineering Services is what separates PSI from other ISPs. This portion of our service provides root cause analysis (RCA), corrective action and upgrades to components experiencing a high rate of failure.

Are there advantages in using repaired parts vs. new parts from the manufacturer?

We do not perform what would be termed a "typical" repair. We isolate hard failures, but we also study parts that have been impacted by the application in which they operate in the turbines. By replacing not only the hard failed parts, but also the stressed or degraded parts, we provide a component that performs as good as, or better than, a new unit for a fraction of the price.

How about when compared to aftermarket parts?

Our services include repair, remanufacturing, upgrading and RCA. Aftermarket products provide the same design that will experience the same failure rate in the application.

Talk a little about the upgradability aspect of repairing parts.

This involves incorporating newer generation technology into the original design. This improves efficiency and reliability. This starts with root cause analysis and corrective action. We look at the trends of failure over several components through reverse engineering. The result involves a form, fit, function replacement that will run cooler, last longer and increase the mean time between failures.

How do repaired parts fit into a wind farm's maintenance schedule?

Repaired parts are kept as spares at the site and when there is a failure in the turbine the maintenance staff will pull from the repair inventory and start the cycle of repair by shipping out the failed component. A repair will be a fraction of the price for new so maintenance budgets are reduced, providing additional funding that can be used for predictive maintenance.

What is it that makes PSI unique?

We have a diverse service portfolio in comparison to other ISPs. We repair electronics, hydraulics and electro-mechanical components. Our customers also value our ability to engineer an upgrade to their OEM components. They want to know why components fail and what can we do to improve the MTBFs. We are a solution provider to our customer's dissatisfaction with the OEM design.

What service do you provide that meets the current need in the wind industry?

Companies in the wind industry are working to improve turbine reliability. The OEM promised a 20-year life, but users are having failures in fractions of that time. We provide end-of-life analysis on numerous electronic components. Technology gains result in components becoming obsolete as manufacturers discontinue support. OEMs integrate a wide range of manufacturer's assemblies into their controls. We have been able to bridge the gap when manufacturers are not meeting the customer expectations. They value our Engineering Services Division's role in assuming support when the OEM original warranty contract expires.

One example that we have seen involves a pitch drive from a large turbine OEM. This part experienced a high rate of failure. The customer came to us to improve the component. Through RCA, we found that the capacitors and switching transistors were not robust enough to handle the trauma in the application. We installed a higher grade of capacitors, redesigned the bus board and selected switching transistors that better matched the 18,000 per second switching frequency. As a result, the drive ran cooler and our customer realized an 81% reduction in failures.