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Torque loading: Standards have limits

Part 1: How drivetrain loads are important in analyzing component performance.

By Paul Baker and Doug Herr

Editor's note: *This article on torque loading is presented in two parts. Part 2 will discuss the specific industry standards for wind-turbine drivetrains and will appear in the February issue.*

As wind energy has moved from a niche market to mainstream, the industry has focused more on the lowest cost of energy or LCOE. Technological improvements and larger rotor sizes have moved the industry forward, frequently positioning wind as the lowest cost energy source.

Recently more attention has been focused on controlling the cost of turbine damage, downtime, and component failures to improve the LCOE. To gain control, a more thorough understanding of why major components, such as gearboxes, are failing prematurely is needed.

For bearing and gear designs, manufacturers require high fidelity load cases from the OEMs to optimize their designs for performance, costs, and life. Load cases are coming under renewed scrutiny, as components reach the end of service life prior to the predicted life calculations. New detailed design standards have improved turbine reliability, but more may be needed to achieve the component design life targets.

UNDERSTANDING LOADS

Loads are a significant consideration when analyzing drivetrain component performance. Knowing what loads were present, and if the bearing or gear is overloaded, help identify the root cause of reduced component life.

Rolling Contact Fatigue analyzes when normal loading will lead to a "wear-out" condition. It is an estimation of when average useful life is reached. This analysis is straightforward, as long as you have an accurate load estimate and the time at load conditions. In bearings, loads are important; just a 23 percent increase in loads will reduce the predicted bearing life by a factor of two.

Transient loads are more difficult to model or to build into wind-turbine design standards and other equipment with variable conditions. Transients are extreme peak loads or rapidly shifting loads that occur in the drivetrain, which may be two-to-three times higher than the nominal loads. However, these loads may only make up 0.05 percent of the total lifetime in the load spectrum. Because component durability is so dependent on the loading, extreme transient loads may result in the difference between 20 years or 20 months of component life. It is essentially guaranteed that turbines will experience some level of transient loads because they see highly variable locations, frequency of wind gusts, grid fault frequency, turbulence, control systems, frequency of sensor failures, and other variables.

With so many variables and differences in loading between turbines in the same site and from site-to-site around the world, it is challenging to fully understand the loading conditions to use in the calculation models.

OPERATING LOADS DEFINED

The large number of premature failures in gearboxes in the late 1980s prompted an investigation into high-torque transients that occur during stopping events. In 1990, Brian McNiff, Walt Musial, and Robert Errichello published a report sponsored by SERI (Solar Energy Research Institute) that stated:

"As mentioned, the undampened

Transient loads are more difficult to model or to build into wind-turbine design standards and other equipment with variable conditions. (Courtesy: AeroTorque)

mechanical brakes stop a wind turbine abruptly. In such severe stops, and even in the damped version, some of the kinetic energy is stored momentarily as elastic strain energy in the gears, shafts, and couplings. After the rotor has stopped, the strain energy is released when these drive train elements torsionally unwind. During this period, the gear teeth unload, travel through the backlash, and impact on their backsides. They then rebound, travel through the backlash, and impact on their front sides. These rapid torque reversals may be repeated several times while the transient vibration decays. Impact may cause very high stresses on the gear teeth. Again, gear life is probably overestimated for both mechanical brakes by the model due to

ALSO IN THIS SECTION

the inability of the present analysis to include these torque reversals. The impact stresses could be determined in a future study with a nonlinear, dynamic analysis and/or actual measurement."

This work led to the first AGMA/AWEA meeting in 1993. In 1996, the first U.S. wind-specific design information sheet, AGMA/AWEA 921-A97 was published. This guideline defined operating loads for the first time.

OPERATING LOADS:

As defined by this standard, operating loads are as follows:

- Long periods of small oscillations while the unit is stopped by the parking brake and the rotor is buffeted by wind.
- Long periods of low-speed, low loads during light winds.
- Long periods of high-speed, low loads when winds are below the cut-in speed (minimum speed at which a turbine can connect to the utility's power grid and start generating power).
- High transient loads when the generator connects to the power grid.
- Rapid load fluctuations during normal operation.
- High transient loads during braking. Such loads, although infrequent, can be damaging.

Defining the load spectrum for each condition is a difficult task due to the uncertainty of predicting loads. However, it was thought at the time that experience made these predictions more reliable. AGMA/AWEA 921 tells how to assemble load spectra that include both wind loads and transient loads that occur during start-up (connection to the power grid), rapid blade pitch change, and braking.

The standard provided guidelines for material properties and metallurgies and specified that wind gear sets meet the AGMA 901-A92 standards. It further defined recommended practices on bearing fitting and preferred bearing types. Lubrication, quality assurance, and maintenance practices were also defined, creating a standard with a better understanding of how to design better turbines. The standard mentions severe transient loads, but did not directly address them.

As wind energy has moved from a niche market to mainstream, the industry has focused more on the lowest cost of energy or LCOE. (Courtesy: AeroTorque)

DESIGN STANDARDS APPROVED

Fast forward to early 2000s, and even with standards, gearboxes were not meeting design lifetime requirements. A true design standard was needed.

In 2003, ANSI/AGMA/AWEA 6006-A03 was approved, and became an official American National Standard in 2004. The standard requires all transient loads be included in a load description document as annotated time series. It states:

"The torque spectrum shall include all fatigue loads, including all external transient loads such as brake loads, if applicable." It provides several examples of transient load cases, including: transient starting loads due to generator control actions; loads due to motoring; transient stopping loads from aerodynamic and mechanical brakes; rotor mass imbalance or aerodynamic imbalance due to blade pitch differences; and fault induced control actions.

Standard 6006-A03 specifically makes an important distinction between extreme torque/extreme loads, and extreme events. It states in part:

"Extreme torque shall be specified by the wind-turbine manufacturer: torque level; number of occurrences; source, such as rotor, generator or brake. Extreme loads shall not be included in the load spectrum … The extreme load is that load from any source, either operating or non-operating, that is the largest single load that the gearbox will see during its design life beyond which the gearbox no longer satisfies the design requirements … The maximum one-time load event for a gearbox is likely to be a consequence of other events such as an emergency brake stop, generator short circuit fault or utility grid event. The wind-turbine designer should determine the likely magnitude and probability of this maximum load and specify it separately to the gearbox designer."

This requires the designers to consider extreme transient loads in the load spectrum, but to evaluate extreme events separately. This may be the best approach available, but it does magnify the importance of correctly and conservatively estimating the number of such extreme events. In 2009, Francisco Oyague published an NREL Technical Report titled Gearbox Modeling and Load Simulation of a Baseline 750-kW Wind Turbine Using State-of-the-Art Simulation Codes. The report offered a few hypotheses to explain gearbox failure, including:

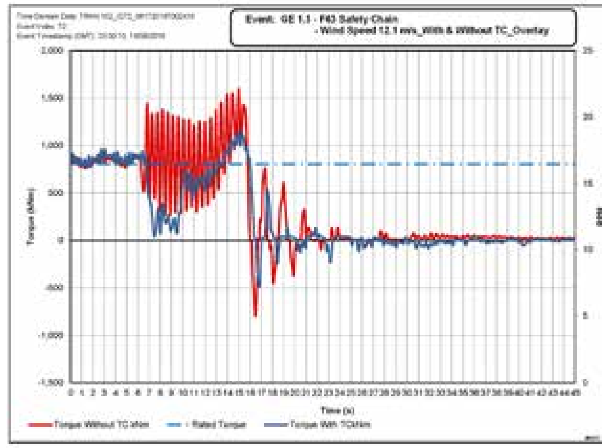
- Absence of a number of load cases, relevant to the design process.
- Transfer of non-torsional loads between drivetrain components.
- The lack of standardized bearing-life calculations.
- Poor communication between non-integrated engineering teams for various key components.

The report discussed revealing

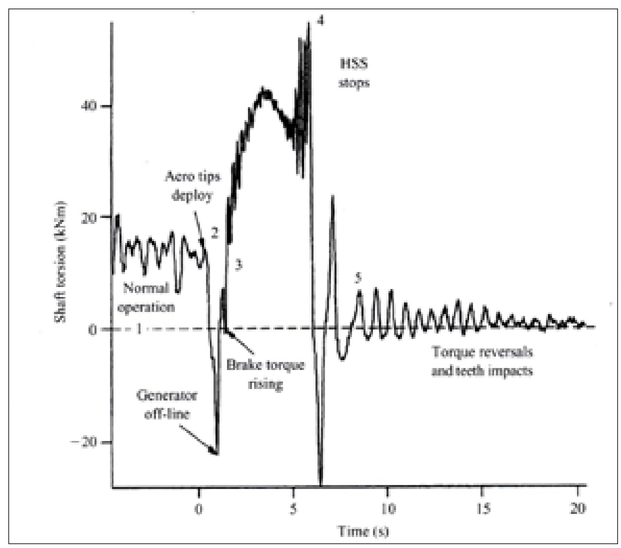
missing load conditions by development of a number of analytical models that sequentially increase in complexity, which are capable of reproducing the dynamic behavior of the internal components of the drivetrain. The models developed were offered freely to improve information sharing and ultimately increasing the transparency of the design process.

SOURCES:

1. AGMA/AWEA. (1996). *Recommended Practices for Design and Specification of Gearboxes for Wind Turbine Generator Systems.* AGMA/AWEA 921-A97
2. ANSI/AGMA/AWEA. (2003). *Standard for Design and Specification of Gearboxes for Wind Turbines.* ANSI/AGMA/AWEA 6006-A03
3. IEC. (2012). *Wind turbines - Part 4: Design requirements for wind turbine gearboxes.* IEC standard 61400-4:2012
4. McNiff, B., Errichello, R., (1997) *New guidelines promise reliable wind-Turbine gearboxes: What they mandate.* http://www.machinedesign.com/Sustainable-Engineering/New-Guidelines-Promise-Reliable-Wind-Turbine-Gearboxes-What-They-Mandate. [Accessed 8 Dec. 2017].
5. McNiff, B., Musial, W., Errichello, R., (1990) *Variations in Fatigue Life for Different Wind Turbine Braking Strategies* SERI/TP-257-3984. Available at: www.nrel.gov/docs/legosti/old/3984.pdf [Accessed 8 Dec. 2017].
6. Nappi, G., *Introduction of the new gearbox design standard for wind turbine generators: a gap analysis between IEC 61400-4 and ISO 81400-4.* proceedings.ewea.org/annual2014/conference/posters/PO_036_EWEApresentation2014.pdf
7. Oyague, F. (2009). *Gearbox Modeling and Load Simulation of a Baseline 750-kW Wind Turbine Using State-of-the-Art Simulation Codes.* [online] Nrel.gov. Available at: www.nrel.gov/docs/fy09osti/41160.pdf [Accessed 8 Dec. 2017].



Transient loads in a modern wind turbine. The red line is a standard drivetrain with a standard torque limiter. The blue line shows the reduction in loads from a torque control devise. (Courtesy: AeroTorque)



A typical record of rotor shaft torque during a HSS brake stop. (Courtesy: AGMA/AWEA 921-A97)

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Doug Herr is vice president of Sales and Marketing for AeroTorque. He joined PT Tech/AeroTorque in 2007 and has 20 years of industrial drivetrain experience. He began working in the wind industry in 2009, and he was deeply involved in the launch of AeroTorque. His early experience in the wind industry included significant up-tower work and monitoring of wind-turbine drivetrains, working to further develop the unique equipment AeroTorque uses for field data acquisition and field validation of the WindTC torque control. He has had papers published in numerous international industry magazines and has presented at conferences in the U.S. and Canada on the subjects of transient loads, their causes, and how they can reduce drivetrain reliability. He is a graduate of Juniata College.

The critical component for torque equipment? ISO 17025

From OEMs to tower installers to service contractors, any group that uses torque equipment should be using ISO 17025 calibrated equipment.

A battery torque wrench being calibrated at Maxpro. (Courtesy: Maxpro)

By Tom Macey

There are thousands of bolted connections in each wind turbine. Whether it's the largest tower bolts or the smallest electrical box connections, every bolt and application has a torque specification. Choosing which tool to use to calibrate those bolts may seem to be the most important decision, but it's not. For both safety reasons and the long term cost of maintenance of wind turbines, the really critical, but often overlooked, consideration is the quality of the calibration of the torque tool being used. It's time for the wind industry to standardize the requirement that all torque equipment be calibrated by an ISO 17025 accredited calibration lab.

ISO 17025 already is required by the defense and pharmaceutical industries, and other ones such as the pipeline and transmission industries are considering requiring that standard as well. Due to the fact that wind turbines have large rotating blades hundreds of feet in the air, there is tremendous stress on all bolted connections. When failures have occurred in the past, investigators of the bolts often cite improperly applied torques as the reason for their problems. However, while the investigators may check that the tool used had been calibrated, they have not necessarily looked more deeply to determine how or by whom it was calibrated. Unfortunately, there are many companies/individuals using substandard calibration methods and apply calibration stickers on torque tools and equipment with little or no accreditation behind them. When conducting root cause analysis of a failure, more attention needs to be heeded to the firm that calibrated the torque equipment used on the job during the failure.

The variety of torque tools and equipment used on wind-turbine sites can be large and include hydraulic torque wrenches, ERAD electric torque tools, manual click and dial torque wrenches, and torque measurement equipment such as torque transducers and testers. All of this equipment is subject to measurement, which makes it vulnerable to changes in accuracy. Thus, it should be put into the proper calibration cycle by a properly accredited vendor.

ISO 17025 accredited calibration labs are independently audited by firms such as A2LA or NVLAP that hold them to the strictest quality standards to ensure proper calibration protocols are in place.

Using an ISO 17025 accredited calibration lab ensures the following points:

- All technicians who perform the work pass tests of technical competence to show they are fully qualified.
- All standards used are traceable back to a known calibrated standard.
- The lab has a defined management system in place.
- It has a documented continuous improvement policy.
- There is a proscribed recordkeeping and software management policy.
- They use a corrective action plan when potential non-conformance issues arise.
- They perform ongoing internal audits and maintain a written quality manual.

In addition, it is important that when wind-turbine management sends out its out torque equipment to be calibrated, that it select a high-quality lab to do the work. Here are 10 points to consider when making that selection:

1. Is your calibration lab ISO 17025 accredited by a reputable firm such as A2LA or NVLAP?
2. Have you checked to ensure that the equipment is on the calibration lab's Scope of Accreditation? Ask to have the vendor email you its "Scope of Accreditation" for review.

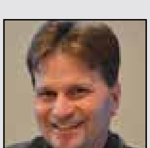
3. Have you identified and informed your calibration lab of the interval for calibration?
4. Does the tool/equipment that you are using for your torque applications have the range/tolerances to meet your application specifications?
5. What are the calibration lab's measurement uncertainties calculations?
6. Are you receiving recall notices for your equipment that you are sending out?
7. Are your calibration certs available immediately and on demand via a QR sticker code that the vendor adheres to your equipment?
8. Are you receiving the calibration certs in detail to ensure compliance with your set objective (see additional calibration cert information below)?
9. Can the lab meet your delivery/timeframe requirement?
10. Does the lab have the ability to repair, overhaul, and replace the equipment being serviced?

If your torque calibration vendor cannot produce the above information upon request, you should seriously consider another vendor. The final calibration certification that is returned with the piece of equipment should contain the following information:

- As found/as returned calibration data.
- Pass/fail data of the manufacturer's or owner's required tolerances.
- Uncertainty budget of the calibration lab performing the test.
- Environmental factors, such as temperature and humidity, during the testing.
- Standards used, along with the calibration due date of those standards.
- Method used for the calibration per a written standard operating procedure (SOP).
- Calibration certificate document number.

From OEMs to tower installers to service contractors, any group that uses torque equipment should be using ISO 17025 calibrated equipment. This will ensure unwavering traceability all the way back to the source and will result in fewer failures and a safer, less costly environment for the units. That is why it is time to standardize ISO 17025 for the wind-turbine industry.

One of the most common torque tools used in the wind industry is the ERAD-3000 being calibrated at Maxpro. (Courtesy: Maxpro)



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The role of Lidar in offshore wind measurement

Insights into the rise of Lidar as the primary measurement system used in the offshore industry.

Lidars are set to replace met masts for offshore applications and to be systematically used in wind farms at one or multiple stages of their life cycle. (Courtesy: Leosphere)

By Florian Rebeyrat and Peter Spencer

The advanced wind-measurement capabilities of Lidar have unleashed tremendous opportunities for the offshore wind industry. After years of successful validation campaigns, offshore professionals are now favoring Lidar over met masts for wind-resource assessment, power-performance verification and wind-farm optimization.

Gathered at a Lidar User Seminar hosted by Leosphere at the Offshore Wind Conference 2017, leading wind-measurement experts from Deutsche WindGuard, ECN, EDF EN, MHI Vestas Offshore Wind, RES, Siemens, SSE, and UL DEWI shared their experiences of using Lidar technology for a broad range of offshore applications. In this paper, we draw on the industry's practical experience to offer a unique Lidar user perspective on the role of this technology in the rapidly evolving offshore market.

FROM R&D TO COMMERCIALIZATION

The wind industry has resolutely stepped forward into a new era of adopting Lidar technologies in commercial projects. Multiple deployments in significant offshore wind farms have effectively set the stage for their widespread use and expected primacy over traditional measurement technologies.

After more than a decade of successful validation campaigns performed throughout the world, Lidar technology has secured a high level of confidence among wind-power experts who recognize its technological maturity and reliability for effective commercialization in offshore as well as onshore projects in simple or moderately complex terrain conditions. Lidar is now accepted as a proven technology by the wind industry from a practical, contractual and, increasingly, from an industry standards' perspective.

Offshore, Lidar is completely replacing met masts, enabling significant project development and operational cost reductions. It has been instrumental in addressing the critical installation, cost reduction, and safety challenges associated with offshore mast installations. Thanks to those advantages, Lidar is emerging as the main wind-measurement technology used by industry professionals for offshore wind resource assessment as well as plant optimization purposes. Lidars offer a broad range of benefits that add considerable value to projects. They are a cost-effective solution to deliver accurate and reliable measurements quickly, enabling users to save precious time on their campaign, and providing them with the bankable data they need. They are easy to install, require little maintenance and are extremely competitive on cost.

Over the last decade, the practices of major turbine suppliers such as Siemens Gamesa have evolved to include the use of Lidar for an increasingly broad range of applications. The ground-based Windcube has been deployed for wind resource assessment, prototype power curve validation, or site calibration, whereas the nacelle-mounted Wind Iris has been used for wind-turbine performance monitoring or prototype and warranty power curve assessments. But these are just the most commonly used applications. As these practices are becoming mainstream, other high-potential Lidar applications such as site calibration after turbine erection or turbine control also are being actively developed and implemented.

Over the last decade, the practices of major turbine suppliers such as Siemens Gamesa have evolved to include the use of Lidar for an increasingly broad range of applications. (Courtesy: Leosphere)

SECURING BANKABLE DATA

Precise and reliable wind resource measurements are critical for developers to increase project value. These measurements provide the essential data used to calculate the potential energy yield from a project, which in turns dictates the terms of the project financing.

Just a few years ago, met masts were still the only bankable wind-measurement tool available to the industry at the project-development stage. This is no longer the case. In the challenging offshore environment, standalone Lidars are extensively used to provide trusted data for a broad range of development requirements. These include better estimation and comprehension of the meteorological conditions across the offshore area, preliminary estimations of the AEP, and preliminary site condition assessments.

As always in the offshore industry, cost plays a critical role. Lidars can be deployed at a fraction of the price of a met mast, whose installation can cost more than 10 million euros, an investment that largely exceeds today's average development budget. Several offshore projects have secured financial closing using Lidar-based energy yield assessments alone.

Recent examples include the Beatrice offshore wind farm, a £2.6 billion, 588-MW project developed by Beatrice Offshore Windfarm Ltd in Scotland, or the 500 MW St-Brieuc Offshore Wind Project in France developed by RES and Iberdrola. For St-Brieuc or Beatrice, the use of stand-alone Lidars has led to multi-million euro savings compared to the cost of installing a met mast, while delivering the essential bankable data needed for these multi-billion offshore projects.

In the Netherlands, ECN has

deployed the standalone Windcube in its measurement network to provide bankable data to support the Dutch government's ambitious offshore wind installation targets. Depending on the specific project conditions and location, different types of Lidar technologies and setups are available to deliver accurate meteorological condition measurements for robust project development. Scanning Lidars such as the Windcube 100S/200S/400S are used for mapping the wind from the shore at up to 10 kilometers. They can perform a full 3D mapping of the atmosphere to provide enhanced measurements of wind speed and direction.

In January 2016, The Offshore Wind Accelerator program (OWA) launched the world's largest offshore trial of scanning Lidar systems. The four-month trial showed phenomenal accuracy at long ranges, as well as uncertainty reductions of the P90/P50 ratio by between 1 percent to 2 percent, therefore proving the technology's ability to significantly lower the LCOE offshore.

The appropriate deployment and siting of Lidars will vary depending on the distance of the site from the shore, and its specific configuration. For wind farms located far offshore, the Windcube enables the accurate measurement of wind on stable offshore platforms, as demonstrated at the St-Brieuc and Beatrice projects. When platforms are not available or cannot be built, floating Lidars installed on a buoy are the most effective wind resource assessment tools.

In 2013, floating Lidars were tested and validated as part of the U.K.'s Carbon Trust Offshore Wind Accelerator program. Because of the current absence of normative standards defining how a floating Lidar should be deployed, the OWA has published a set of recommendations to give the industry the formal framework it needs to accelerate the commercial deployment of the technology while standards are being developed.

In 2015, EDF EN performed a four-month validation campaign of the floating Lidar in compliance with the Carbon Trust recommendations at the Fécamp platform, where a met mast and a Windcube were installed. Following this test campaign, they found an uncertainty coefficient of less than 4 percent, lower than the Carbon Trust's uncertainty recommendations (4 percent to 7 percent). EDF EN also pointed out that an important part of the floating Lidar uncertainties were actually due to the reference uncertainties. There is a strong consensus in the industry that floating Lidar is an effective and reliable technology, and developers such as EDF EN are hard at work to swiftly bring floating Lidar to a commercial deployment stage.

Scanning Lidars such as the Windcube 100S/200S/400S are used for mapping the wind from the shore at up to 10 kilometers. (Courtesy: Leosphere)

IMPROVING ASSET PERFORMANCE

For operational wind farms, Lidars are used to monitor turbine performance and optimize the project. Thanks to their ability to measure, log, and characterize the approaching wind across the entire rotor span, in addition to measuring at hub height, they are key to improving energy production as well as the operator's understanding of its asset performance. They are used for several applications including power-curve measurements, yaw error correction, and wind sector management.

Nacelle-Lidars such as the Wind Iris are firmly established as a powerful tool for contractual power curve testing. They provide a precise evaluation of the correlation between the measured wind speed and the turbine output, which is essential to verify the turbine's performance against the warranted contractual power curve. Although nacelle-Lidar measurements are not yet covered by IEC standards, developers are requesting that nacelle-mounted LIDARs be selected as a cost-effective alternative to met masts as part of the Turbine Supply Agreement.

According to Deutsche WindGuard, demands for the inclusion of nacelle-mounted Lidar for power curve test in turbine agreements occur in about half of the projects. Since 2013, the German independent consulting firm highlighted that power curve warranties based on two- and four-beam nacelle Lidar power curve verification already have been successfully created by three of the leading turbine suppliers.

The wind industry has stepped forward into a new era of adopting Lidar technologies in commercial projects. (Courtesy: Leosphere)

For offshore wind farms, delivering contractual power curve verification tests according to IEC 61400-1-12 standards remains highly impractical. Indeed, the standards implicitly require the installation of a met mast, a costly option that, in addition, allows for the testing of only one turbine. On the other hand, nacelle-Lidar can deliver accurate measurements for multiple turbines with high availability and low uncertainties.

Nacelle-Lidar measurements are now a method accepted by all established turbine manufacturers for verifying warranted power curves offshore. In addition, scanning Lidars also generate strong confidence among users. Both technologies have been proven to deliver accurate power curve measurements, as demonstrated at the Greater Gabbard 504 MW offshore wind farm developed by SSE and RWE Innogy. For this project built 23 kilometers off the coast of Suffolk in England, a Wind Iris was installed on a nacelle. The setup was completed with a scanning Lidar, which was installed on a transition piece of a turbine. This power curve verification campaign demonstrated that Lidar-based power curve testing was as accurate as mast-based campaigns. Similar conclusions were reached in a campaign developed by Deutsche WindGuard, which showed excellent agreement between the power curve measurements performed with the nacelle-Lidar and scanning Lidar for the same turbine and measurement period. The high correlation of the results, obtained with two entirely different and independent Lidar systems, are confirming the strong capabilities of each technology.

Deutsche WindGuard's validation campaigns showed the Lidar-based power curve test's total uncertainty is similar to best practice cup anemometry. This is true both offshore and onshore in simple terrain, two contexts in which Lidar technology is anticipated to be included in projects as a matter of course.

What is more, nacelle-Lidars become increasingly relevant as the power ratings and rotor diameters of offshore wind turbines keep growing. This is because they can measure horizontal wind speed at a significant distance from the rotor plane. It is, for example, the MHI Vestas Offshore Wind ESTAS V-164 8.0MW, which sports a 164-meter rotor diameter, requires the use of a system that can measure out at a distance of minimum 410 meters. Although the Wind Iris is specified up to 450 meters, such distances are beyond the scope of most other devices on the market.

In 2015, MHI Vestas Offshore Wind ran a power-curve verification test campaign at the Østerild site to collect the data and experience needed for the preparation of their commercial offering. The campaign concluded that the Wind Iris nacelle-Lidar was able to measure wind speed out to 454 meters, with a precision similar to that of a met mast. In response to customer request, the Danish manufacturer went on to develop a nacelle-based power curve verification method based on the Wind Iris 2-beam for large rotors, which was independently reviewed by DTU Wind Energy. The procedure is easily applicable for the Wind Iris 4-beam as well.

Eventually, nacelle-Lidar power curve verifications are expected to be generalized on all operating wind farms to improve the understanding of potential turbine underperformances globally. Siemens is at the forefront of that trend. This leading offshore player is already including the bracket design for nacelle-Lidar on the turbines design specifications, which enables the company to offer the Wind Iris as an option in its standard turbine contracts as well as optimize Lidar siting. At the same time, they are developing a nacelle-Lidar power curve verification method based on the Wind Iris 4-beam device. From a developer's perspective, the result of these power-curve measurements can be used to negotiate the contractual warranty level and to adapt losses applied on annual energy assessments.

FUTURE CHALLENGES

Today, Lidars have moved from the margin to the mainstream. They are set to replace met masts entirely for offshore applications and to be systematically used in wind farms at one or multiple stages of their life cycle. They already are recognized by the wind-measurement community as truly operational, maintainable, and reliable tools to deliver bankable results for offshore and onshore wind-feasibility studies and warranted power-curve verification tests. For these applications, they will most likely be deployed universally in the short term. At the same time, the industry is working hard to adapt IEC Standards and speed up the deployment of Lidars for commercial projects. However, the industry is far from done exploiting the full range of capabilities offered by Lidar. This versatile technology also continues to be developed and validated for a broad range of other critical applications. Indeed, Lidars already have displayed great potential to help improve turbine control and load management, wake-effect measurements, wind-sector management, site calibration, and power forecasting.

As vertical wind profiler and nacelle-Lidars already have achieved widespread industry acceptance and effective commercial deployment, scanning and floating Lidars have rapidly been building their own track record in offshore wind. Industry specialists expect them to quickly become a prominent technology with the required maturity for large-scale commercialization.

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Florian Rebeyrat has extensive experience in the wind industry in Europe, Asia, and North America. Rebeyrat leads the product management function for Leosphere's core vertical profiler and nacelle-mounted precision measurement product lines. Previously, he held management roles in key account management, market analysis, and communications. He has a strong track record of bringing cutting-edge technology products to market.