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WHEN IT'S TIME TO GO:

REPLACE, REFURBISH, OR RE-ENGINEER IT?

WINDPOWER 2016 preview

AWEA

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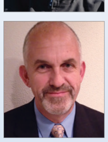
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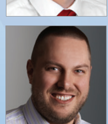
ZHANG


DAVID CLARK, CEO of CMS wind, has experience monitoring and analyzing wind turbines from 200 kW to megawatt-class units, and from several OEMs. In addition, he has 11 years of condition-monitoring experience in traditional markets, such as nuclear power, steel mills, and mining. Clark frequently writes for *Windpower Engineering & Development*.

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KARL FATRDLA has a degree in Mechanical Engineering from the Technical University in Vienna, Austria. He started out in the automotive industry as a Project Manager, and even received Project Management Professional (PMP) certification according PMI standards. In 2008, he joined the wind industry as a Director of Sales for Eastern Europe at Vestas. He's since moved to Switzerland for ROMO Wind, and is now Head of Sales as part of the company's young and dynamic wind team based at the Swiss ROMO Office. In this function, Fatrdla has built up sales entities for ROMO Wind in all major European countries.

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COLIN MCNICHOLS, a Senior Design Engineer, joined Romax in 2014 after five years of rotating machinery experience at General Electric. He has a degree in Mechanical Engineering from the University of Wisconsin–Madison, and a master's in Mechanical Engineering from the Georgia Institute of Technology. McNichols' most recent work has been on wind-turbine gearboxes, with a focus on structural component design and analysis. He specializes in mechanical engineering support of the Romax InSight product, including borescope inspection, vibration monitoring, design and prototyping of field solutions, and drivetrain failure analysis.

EMIL MOROZ has a deep understanding of wind energy from a system perspective, derived from roles in research, industry, development, operations, and consulting since 1992. Among other achievements, he has developed the site suitability evaluation process for two OEMs, played a pivotal role in the definition of the GE1.5sle, and is author on seven wind turbine technology related patents. *emoroz@att.net*

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BRIAN ROTH received a B.S. degree in Electrical and Computer Engineering from California Polytechnic University of Pomona. He has worked in a variety of engineering roles, and is currently the Marketing Product Engineer for industrial networking devices at Antaira Technologies.

DUSTIN J. SADLER has 16 years of mechanical design engineering experience, including co-inventor of AeroTorque's WindTC RTD device. He brings knowledge and background from multiple industries to the FMEA application and generation along with project management to aid in the creation of this technical document. *dsadler@aerotorque.com*

DR. ZHIWEI ZHANG is VP of Engineering for InSight, and he is responsible for Romax's InSight business in North America. He joined Romax in 2008, and led dynamic analysis and design work for multiple wind-turbine gearboxes. Dr. Zhang spent three years working in Asia, mainly on gearbox design and testing projects, and began work in the U.S. in 2014. His technical focus is drivetrain re-engineering and refurbishment, RCA, etc. Dr. Zhang has a PhD on dynamics from Loughborough University in the UK.

Karl Fatrdla
Head of Sales
ROMO Wind AG

A better anemometer gives more accurate wind measurements and monitoring

Although intended to measure wind speeds, conventional anemometers often provide imprecise data. On a wind turbine, these devices are mounted on the nacelle behind the rotor. But this placement can provide distorted measurements because of potential for wind effects from the rotor and nacelle. This makes attaining accurate wind speed, direction, and turbulence intensity measurements next to impossible. Reliable detection of yaw misalignment and performance monitoring are important for gaining insight into the wind, which is key to operating efficient and high-performance turbines.

Fortunately, a new ultrasonic device is available that can measure wind parameters that until now have proven difficult or impossible to measure accurately. The Spinner Anemometer (iSpin) measures wind speed and yaw misalignment in all wind sectors, and can increase the energy output of turbines by measuring and correcting yaw errors. iSpin sensors measure wind reaching the turbine at the spinner — where the wind hits the rotor. As such, the sensors can provide precise information about wind speeds, air pressure, and temperature.

The design

iSpin consists of three specially designed ultrasonic wind sensors installed at the front of a turbine, where the wind hits first. Here, wind is only influenced by the induction effect (slowing of the wind) caused by the turning rotor and its passage over the spinner and deflection on the symmetrical spinner body. These effects are predictable and correctable by means of calibration.

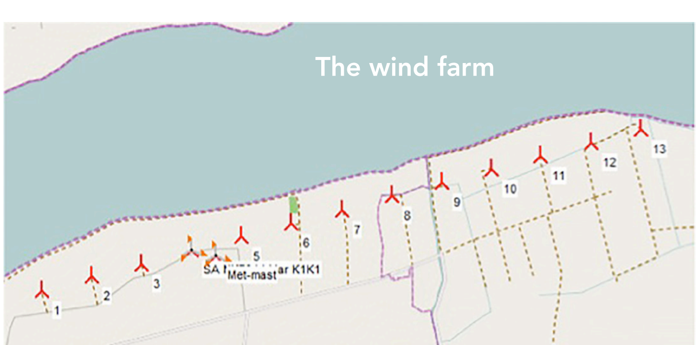
Simultaneous measurement of precise wind speed, yaw misalignment, inflow inclination angle, and turbulence intensity at the point of impact with the rotor are unique features of this system, not currently available from other anemometers on the market.

By detecting even small changes in power curves, iSpin can verify performance optimization measures (such as YMA corrections or rotor power-ups by applying vortex generators), and provide a continuous sequence of power-curve comparisons to enable reliable performance monitoring.

In a recent R&D project, together with the utility Vattenfall and the Technical University of Denmark (DTU), iSpin was verified against an IEC-compliant wind met mast to demonstrate that it can measure absolute power curves according to IEC 61400-12-2. The IEC, or the International Electrotechnical Commission, is the global standard and conformity assessment body for all fields of electrotechnology. IEC 61400-12 is the standard measurement procedure when assessing the power curve of a wind turbine.

The iSpin power curve of the investigated turbine showed only a 0.4% difference from the IEC-compliant wind met-mast measurement, based on a calculated annual energy production (AEP) for a site-typical wind climate. Power-curve measurements with the iSpin equipment on the other turbines at the site (unrelated to the met mast) showed an average power-curve deviation of 0.4% from IEC's met-mast measurements.

The demonstrated reliability of the iSpin's transfer function means it can transfer to other wind turbines without major losses to measurement data or quality. Through comparison measurements with a met mast (a free-standing meteorological tower), the iSpin showed an ability to measure wind speeds accurately in a 360° range around a wind turbine. Therefore, the device is not limited to undisturbed wind sectors only.



Anemometer comparisons took place on a Vattenfall's wind farm with this turbine arrangement.

When data was used without filtering for wake directions, the resulting AEP values from the iSpin power curves were still in the range of 0.1 % relative to the IEC-compliant met mast measurement results and with an average deviation of -0.3%.

The test

For the R&D project, evaluations took place at a Vattenfall wind farm that consists of 13 Siemens turbines with 2.3-MW rated power and 80-meter hub heights. The site is characterized by flat terrain and located on the southern coastline of the Limfjord area in Denmark.

All turbines were equipped with spinner anemometers to conduct power-curve measurements, according to IEC 61400-12-2. Additionally, a normal IEC 61400-12-1 power-curve measurement using a met mast was performed for verification purposes on one reference turbine (#4). The distance from the met mast to this reference turbine was IEC compliant at 234 meters.

The data for the IEC verification of the power curve has been limited to the free wind sector of the south (101° to 229°), where the upstream terrain is flat and without significant obstacles.

Sensor calibration

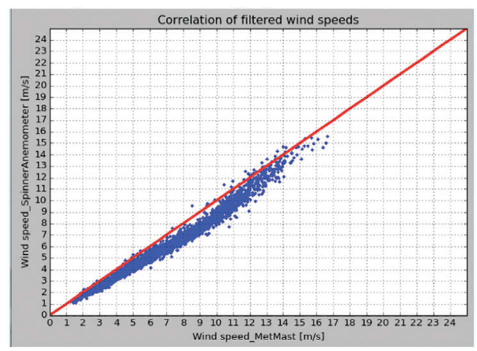
iSpin measures wind speed and direction on the surface of the spinner. This is influenced by the geometry of the spinner itself (deflecting the wind direction) and the induction effect of the rotor (slowing down the wind stream).

The wind direction measurement is easily calibrated without an external reference measurement. The aerodynamics around the spinner provide for self-calibration by introducing a sequence of controlled yaw angle errors to the turbine.

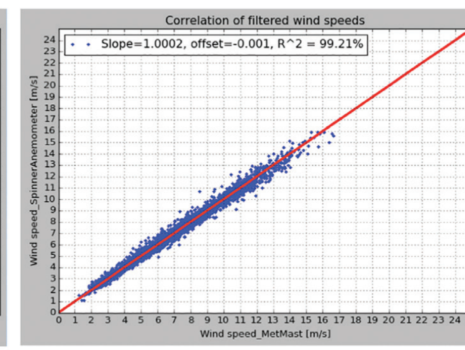
What proved interesting for the IEC power-curve measurement was calibration of the free wind speed measurements. These must be done once for a specific turbine type by conducting a comparison with a reliable reference measurement from an IEC-compliant wind met mast.

This transfer function describes the transition from "rotor wind speed" (as measured directly by the iSpin sensors) to "free wind speed" (as measured by the wind met mast), and is determined in two steps (see graphsbelow *Wind-speed correlation graphs*).

Wind-speed correlation graphs



Linear calibration of wind speeds for the high and low wind speeds only, and not the induction of the rotor. (Step 1)



Non-linear calibration by the methods of bins calibration, as described in IEC 61400-12-2. (Step 2)

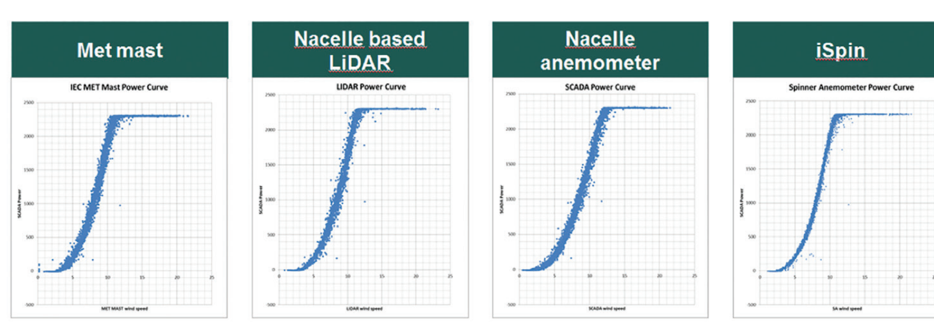
Power curves in undisturbed wind sectors

Power-curve measurements were conducted at the reference turbine (#4) for four wind-measurement systems: Met mast, nacelle-based LiDAR, nacelle anemometer, and iSpin. IEC standards were applied as necessary (for example, nacelle-based LiDAR's are not part of the IEC standard).

None of the power curves were corrected for turbulence intensity or wind shear, but were measured on the basis of a site-specific wind climate.

In this comparison, the iSpin power curve resulted in approximately 30% less scatter than all other measurement systems. Based on differences between the IEC met-mast power curve, warranted power curve (provided by the OEM), measured power curves of the LiDAR, and iSpin wind measurements, the results were derived for turbine #4 (see the

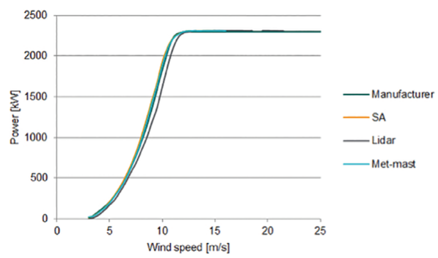
Comparison of wind measurement methods



Forward looking wind measurement

Local wind measurement

Comparison of power curves in the undisturbed wind sector



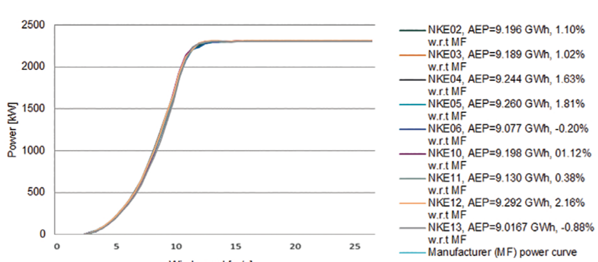
Comparison with the IEC met mast (MM) measurement:
iSpin to MM: Δ = 0.4 %
Lidar [1] to MM: Δ = -7.7 %

Comparison with the warranted power curve:
MM to PC_W: Δ = 1.2 %
iSpin to PC_W: Δ = 1.6 %
Lidar to PC_W: Δ = -6.5 %

Legend:
iSpin or SA (spinner anemometer): IEC compliant measurement with the iSpin equipment
MM: IEC compliant measurement with the wind met mast
LiDAR: Non-IEC (but following the rules) measurement with the Lidar
PCw: Warranted power curve provided by the OEM

Note: "Wind sectors" refers to the fact that following the IEC standard, it's only possible to measure power curves in so called "free wind sectors" or "undisturbed wind sectors," which need to be bare of any obstacle in the 2.5 RD distance from the turbines. So, each wind direction that does have an obstacle (such as trees, buildings, or other wind turbines nearby) must be excluded. Usually the 360° wind rose is segmented in 12 sectors with 30° each. The free wind speed range for this project was determined with 101° to 229° (south-east-east to south-south-west, approximately).

Comparison with other turbines: Undisturbed wind sectors only

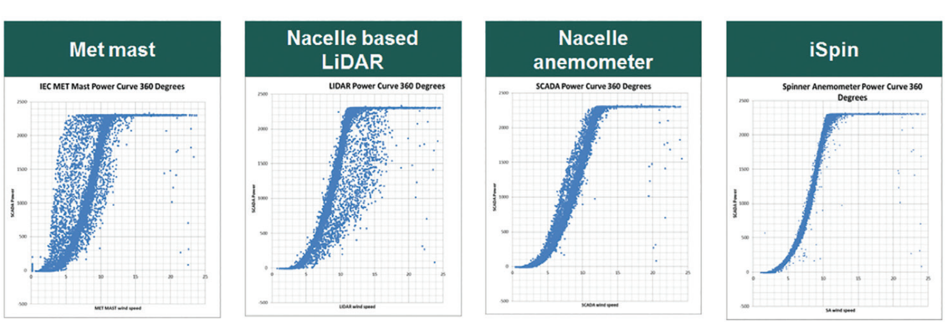


Measurement comparison with the IEC met mast:
iSpin to MM: $\Delta_{av.}$ = 0.4 %; Δ_{max} = 1.0 %

Comparison with the warranted power curve:
iSpin to PCw: $\Delta_{av.}$ = 1.3 %; Δ_{max} = 2.2 %

Legend: NKE 01 – 13 denominates each single wind turbine in Vattenfall's wind park Nørraeker Enge

Comparison between wind measurement methods in all wind sectors



Forward looking wind measurement **Local** wind measurement

Comparison of power curves in the undistributed wind sector graph). Note the nacelle-based anemometer was excluded because of high uncertainties.

To demonstrate the reliability of the transfer function of iSpin, it was essential to carefully and accurately employ the calibration factors and transfer function from the reference turbine to other turbines of the same type at the wind farm. The results of this comparison clearly showed that the iSpin transfer function and calibration factors (once determined for the turbine type based on a calibration with an IEC-compliant met mast) can reliably transfer to other wind turbines of the same type.

Full-range power curves

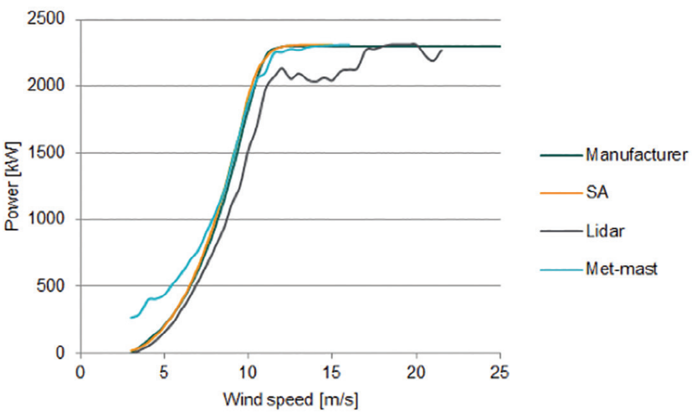
In contrast to met-mast and nacelle-based LiDAR systems, the spinner anemometer has an ability to measure the correct wind at hub height and in wake conditions. Forward-measuring devices, such as met masts or LiDARs face a challenge, especially in wake effects: the measured wind speed cannot be considered free wind speed (which becomes deteriorated from the turbine in front) and, therefore, are not comparable in non-free wind sectors.

But iSpin wind measurements have proven much less prone to deteriorations from these influences. Why? The calibration procedure with an IEC-compliant met mast first stores the information on a flat site that's undisturbed by obstacles (and stored in the iSpin controller). So, whenever iSpin is applied to the same turbine type in more complex terrain or higher winds, it is measured in the wake of the stored calibration factors. The transfer function then translates wind hitting the spinner into "free wind." This explains why iSpin can also determine power curves and turbine performance information in all wind sectors.

For this measurement, power curves for the reference turbine were calculated including data from all wind directions. For illustrative purposes, the met mast and LiDAR results are shown (in *Comparison between wind measurement methods in all wind sectors*), however, wind-speed measurements are misleading when a turbine or the met mast is in wake of another turbine.

By comparing the iSpin power curve with all wind sectors to the IEC-compliant met-mast power curve using only the free

Comparison of power curves in all wind sectors



Comparison with the IEC power curve measurement:

iSpin to MM*: Δ = 0.1 %

*IEC compliant met mast measurements in the free wind sectors only

Comparison with the warrantied power curve:

iSpin to PC_W*: Δ = 1.63 %

*IEC compliant in the free wind sectors only

sector demonstrates the unique capabilities of the iSpin system. The spinner anemometer's power curve does not materially alter when measuring wind speeds in all wind sectors.

In much the same way as for measurements in the undisturbed wind sectors, it's essential that the transfer function calibrated was reliable enough to be transferred to other turbines of the same type.

For further reading

[i] Refer to http://romowind.com/en/knowledge-centre/#performancemonitoring for detailed information on the test set-up.

[ii] See K-alpha calibration method in http://romowind.com/media/Calibration-of-a-spinner-anemometer-for-yaw-misalignment_we.1798.pdf

[iii] In regard to the LiDAR deviation, refer to the explanations given in http://romowind.com/en/knowledge-centre/#performancemonitoring