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ZX Lidars

Accurate Wind Measurements Using Nacelle-Mounted Lidars for IEC Power Performance Measurements

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ZX Lidars

By reviewing this paper, professionals in the wind energy sector will learn:

- The advantages of using a Nacelle Mounted Lidar for precise wind speed measurement at turbine hub heights, offering a reliable alternative to traditional anemometry.
- The benefits of Continuous Wave Doppler Lidar technology, including its Spectral Averaging Turbulence Intensity and wind shear/veer measurement configuration.
- Compliance with IEC 61400-50-3 standards and validation through independent calibration tests.
- Practical applications of ZX TM data in optimising wind farm performance, including resource assessment, turbine monitoring and load analysis.
- The cost and operational efficiencies achievable by deploying ZX TM technology in real-world wind energy projects

Introduction

Accurate wind speed measurement at wind turbine hub heights is critical for performance verification under IEC 61400-50-3 and IEC 61400-12-1 standards. Traditional meteorological masts with cup anemometers become increasingly impractical due to rising turbine heights and associated costs. This study evaluates the performance of ZX TM, a nacelle-mounted, Continuous Wave (CW) Doppler Lidar, as a high-accuracy alternative for power performance assessment [8]. By eliminating the need for tall met masts, nacelle-mounted Lidars streamline the testing process and provide robust data for wind turbine performance validation.

This paper is designed to be a **practical guide** for using nacelle-mounted Lidar in IEC-compliant power performance tests. By referencing a **core set of validation documents and procedures**, as well as showcasing **evidence from the industry** supporting the adoption of such technologies, this work aims to provide clarity and confidence to wind farm operators and turbine manufacturers considering Lidar-based measurements.

Nacelle-mounted Lidar technology allows remote sensing of the wind field at ranges from **10m up to 550+m** upstream of a turbine. This provides direct measurement of the wind conditions prior to interaction with the turbine rotor, allowing precise determination of turbine performance. Many years of trials and testing have demonstrated that these systems can optimise energy capture, mitigate structural fatigue and enhance turbine control [7].

Background and supporting evidence

Measurements from the ZX TM Lidar have been systematically compared against traditional cup anemometers mounted on meteorological masts across multiple onshore and offshore sites.

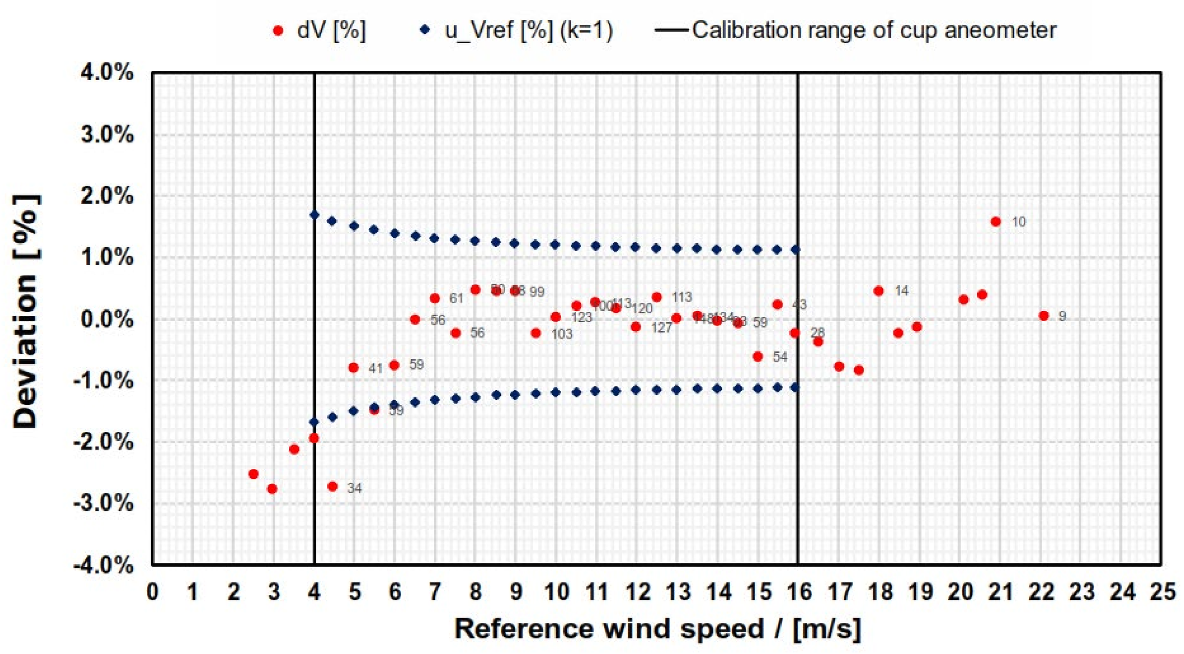
Assessments of wind speed accuracy, turbulence intensity and wind shear in real-world conditions have been observed.

Calibration and validation of ZX TM ensures compliance with IEC 61400-50-3 requirements. ZX TM has been tested at the Janneby test site under DNV oversight [1], where calibration procedures aligned with industry standards. Additional validations were conducted by DTU at the Høvsøre test site [2], further reinforcing confidence in the Lidar's accuracy and reliability.

ZX TMs undergoing 50-3 compliant calibration at DNV's Janneby test site, Germany.
Image courtesy of DNV.

Turbulence intensity has also been considered, as it directly impacts turbine loads and energy yield predictions. A novel approach, Spectral Averaging Turbulence Intensity (SATI), is introduced with ZX TM to provide a cup-anemometer-equivalent measurement of turbulence intensity [3]. Environmental factors, including temperature, air pressure and humidity have also been accounted for, ensuring robust performance across diverse operational conditions.

The ZX TM Lidar has repeatedly demonstrated high accuracy in wind speed measurements, with deviations from traditional calibrated anemometers of **less than 1%.**



On-turbine, 50-3 compliant, ZX TM calibration check, with a reference metmast at 610 m range. Image courtesy of DNV

Turbulence intensity measurements using ZX TM provided highly reliable data, aligning closely with established industry benchmarks. The ability of the ZX TM to assess wind shear also proved critical for turbine load evaluation and power curve adjustments, enhancing the accuracy of performance assessments.

In terms of industry compliance, independent evaluations confirmed that the ZX TM fully meets IEC 61400-50-3 criteria, further supporting its role as an alternative to traditional met mast-based measurements [1].

The industry adoption of ZX TM continues to grow, with major players such as Siemens Gamesa and GE Renewable Energy integrating the technology into their power performance verification protocols. Siemens Gamesa has approved the ZX TM for medium- and long-range power performance testing, affirming its accuracy and reliability [5]. GE Renewable Energy has similarly endorsed its use for onshore wind turbine verification, cementing its place as a viable alternative to conventional methods [6].

Practical Steps for Conducting a Power Curve Test with ZX TM

Key considerations for conducting a power curve test compliant with IEC 61400-12-1 using wind speed measurements made by a ZX TM, in accordance with IEC 61400-50-3 are as follows [4]:

<u>Site Selection & Preparation:</u>
- Identify a test site with minimal terrain complexity to avoid flow distortion
- Ensure the nacelle-mounted Lidar has an unobstructed field of view
- Verify that site conditions align with IEC requirements for measurement sectors

<u>Lidar Installation & Configuration:</u>
- Mount the ZX TM securely on the nacelle, ensuring proper alignment with the turbine axis
- Set Lidar inclination and roll to ensure horizontal deployment, using the Lidar's internal sensors

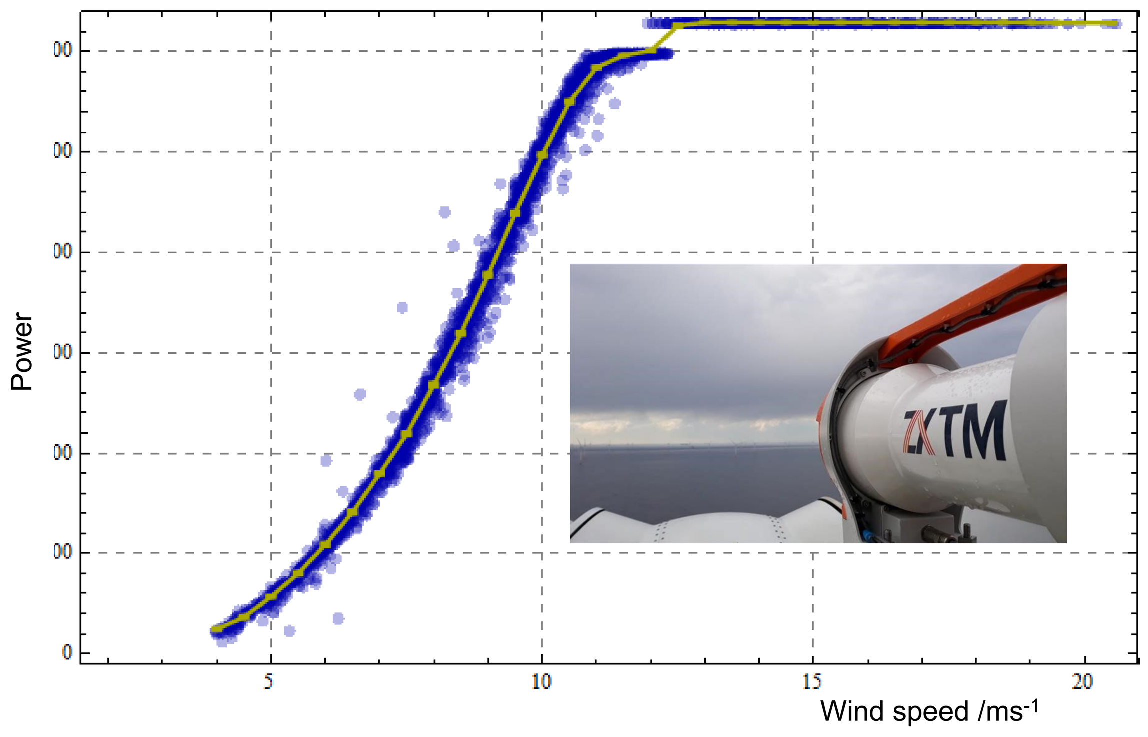
<u>Measurement Setup & Data Acquisition:</u>
- Configure measurement distances at 2 to 4 rotor diameters upwind from the turbine
- Define a measurement period with sufficient data capture to establish statistical robustness
- Collect real-time wind speed and turbulence data in 10-minute intervals

<u>Data Processing & Filtering</u>
- Apply filtering methods to exclude periods of wake interference and complex flow conditions. In addition to sector filtering, the Lidars own flow complexity measurements can be used to identify homogenous turbine inflow
- Use standardized algorithms to process wind speed data and align with IEC-defined uncertainties

<u>Uncertainty Analysis & Validation</u>
- Quantify measurement uncertainties using IEC 61400-50-3 guidelines
- Compare results with reference anemometry to ensure accuracy
- Validate findings through independent expert review and calibration reports

By following these steps, wind farm operators and turbine manufacturers can confidently utilize ZX TM for power performance assessment, ensuring reliable and repeatable results.

IEC 61400-50-3 is limited to simple terrain. However, several campaigns have demonstrated the value of ZX TM measurements on wind farms on more complex sites.



Example power curve measurement result, using a ZX TM, following IEC 50-3 and 61400-21-1 standards

Conclusion & Industry Impact

- ZX TM offers a non-intrusive, precise alternative to traditional anemometry.
- Enhanced operational insights: Improves turbine performance monitoring, power curve verification, and wind resource assessment.
- IEC standard compliance ensures credibility and widespread industry adoption.
- Greater efficiency in power curve testing: Reduces costs and complexity, enabling more frequent and accurate performance validation.
- Industry-Wide Benefit: Establishing a standardized, validated approach for nacelle-mounted Lidar in power performance assessments can lead to greater trust, wider adoption, and ultimately, more efficient wind energy production at a reduced cost.

References

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[4] *ZX Lidars, ZX TM Powercurve Procedure, 2019.*
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