© Veja Mate

Nacelle-mounted lidar for accurate measurement of turbulence intensity

Words: Zhi Liang, Application Manager, WindCube Nacelle, Vaisala.

With global wind capacity set to exceed 1 terawatt by the end of the year, the demand for accurate, reliable wind data will only increase in the future, powered by clean energy sources. As wind turbines sky higher and wind farms covering more expansive areas spring up, on and offshore, the accuracy of lidar technology in harnessing wind power helps optimise turbine performance and power output.

Ground-based and nacelle-mounted lidars are popular across the wind energy industry for delivering useful information and measurements across the life cycle, from prospecting and development through operations and life management. Whether helping with site prospection, Wind Resource Assessment (WRA), or providing accurate and complete Power Performance Testing (PPT), lidar has evolved into the industrywide gold standard for wind measurement.

Recent lidar advancements have equipped stakeholders with more accurate, bankable data and helped drive research into and the development of valuable innovations like turbulence intensity (TI) measurement.

Lidar technology and turbulence intensity

Quick and easy to deploy and operate, lidar instruments can help predict wind turbine energy production performance and address challenges, such as nacelle yaw misalignment, abnormal shears, or high turbulence intensities.

Turbulence intensity is one of the most important and widely used wind-related parameters in many applications, such as PPT verification, wind turbine generator load estimation, and turbine micrositing. Turbulence can manifest as gusts, eddies and fluctuations in wind speed that affect the performance and efficiency of wind turbines. High TI levels can increase mechanical stress on turbine components, resulting in higher maintenance costs and reduced turbine lifespan.

Nacelle-mounted lidar has gained wide acceptance with the release of the IEC 61400-50-3 standard and the formalisation of the PPT procedure. Given the high cost of constructing met masts, nacelle-mounted lidar is a natural solution for PPT, easily deployed on different turbines across the wind park to provide highly accurate wind measurements.

New research from Vaisala proves nacelle-mounted lidar's capability to collect accurate TI measurement data suitable for wind energy applications. For radial wind speed measurement, nacelle-mounted lidar uses horizontal laser beams to measure TI by line of sight. The horizontal angle of two beams at each height, upper or lower, is 30° and the vertical angle is 10°.

The lidar used in this new research, Vaisala WindCube Nacelle, can measure along the horizontal distance from 50 to 700 meters in front of the turbine, with up to a maximum of 20 measurement points and an accuracy of 0.1 m/s for wind speed and of 0.5° for wind direction. A calibration study conducted by the Technical University of Denmark showed that the uncertainty of the lidar's wind speed measurement was in the range of 2% to 3.5% compared to the anemometer tower.

To calculate wind turbulence intensity (TI), WindCube Nacelle leverages a newly developed algorithm summarised in the following four steps. The first step is to compute a 10-minute averaged wind speed and standard deviation for all four beams using 1Hz data. Secondly, divide standard deviation by line of sight mean wind speed to calculate the TI for each beam. Next, compute TI+ and TI- using the mean TI from the two upper and lower beams. Finally, calculate TI at hub height from TI+ and TI- using a logarithmic interpolation law.

This algorithm aims to effectively eliminate wind speed outliers and

improve TI measurement accuracy. Field measurements help drive an understanding of the capability and accuracy of TI by wind lidar. There are two typical approaches to compare the lidar TI measurement with a wind sensor: white box comparison (WBC) and black box comparison (BBC). WBC can be used to evaluate the direct capability of TI measurement of the laser itself, whereas BBC provides the final TI accuracy after the reconstruction algorithm. The 10-minute averaged wind speed and TI are widely used for wind energy applications.

White box comparison

In this test, nacelle-mounted lidar measures wind speed and TI at line of sight (TI LOS). When the lidar beam points directly to a met mast anemometer, it is possible to directly compare TI LOS with a reference TI from the anemometer. The measurement at line of sight is the raw lidar data, and this comparison can exclude uncertainty from the reconstruction algorithm.

Black box comparison

For BBC, TI is reconstructed at hub height by measuring LOS. The nacelle-mounted lidar usually faces the wind direction to provide a complete and accurate picture of wind conditions in front of the rotor. Consequently, if the angle between LOS and wind direction is not too large, the TI of horizontal wind speed could be equal to the TI at LOS. To compare reconstructed TI at hub height, nacelle-mounted lidar should measure toward the reference wind measuring device and then compare TI with the reference TI.

WBC measurement and results

Conducted in one verification site in north Germany, the WBC measurement project site featured: (1) two met masts of 30-meter height as the reference for wind speed and (2) one platform at the 30m height on the top of a lattice tower for the lidar installation. Both met masts were equipped with the calibrated reference sensors, and two laser beams at the same height verified simultaneously reduce measurement duration. The interval width of the wind sector is selected 20 degrees.

Measurement began in February 2021, using a 4-beam nacelle-mounted lidar, and IEC-compliant calibrations were performed at this test site for 11 months. The raw data illustrated good capability of nacelle-mounted lidar on TI measurement. Further analysis revealed the results of turbulence intensity measurement by lidar are quite promising.

The WindCube Nacelle measures wind speed and turbulence along the LOS and could provide 1Hz data, which provides more information for the spatial and temporal structure of the wind field.

BBC measurement and results

Two projects were used to study the nacelle-mounted lidar TI measurement at hub height. The test site of project one was a wind turbine test field in Denmark, with measurements collected between June 2019 and February 2020.

A WindCube Nacelle was installed on an 8-megawatt 167-meter diameter, 120-meter hub height offshore wind turbine and compared to a 120-meter IEC met mast and two WindCube ground-based lidars.

The second test site was an operational wind farm in the United States on flat, onshore terrain for three months. The lidar was installed on a wind turbine in this test and was compared to one IEC met mast and a WindCube ground-based lidar.

The result of TI at hub height by BBC revealed the following. The correlation coefficient was 0.916 and 0.932 with slopes of 0.951 and 1.029. The data coverage percent of valid TI was high: 83.7% and 71.9%. The global accuracy of TI measurements was high, with bias within 4.9%.

Conclusion

The high measurement accuracy and data coverage of TI using nacelle-mounted lidar is an important step in increasing lidar acceptance and usability for wind energy applications. By using TI data collected by nacelle-mounted lidar during PPT, end users can validate whether the turbines meet the required performance specifications, and make necessary adjustments if needed.

As the wind energy sector continues its remarkable growth, lidar technology empowers the industry to make critical decisions and harness the full potential of wind power.

www.vaisala.com

About the author

Zhi Liang, an application manager at Vaisala since 2017, focuses on WindCube Nacelle for algorithm development, data analysis and wind-related applications. With a solid knowledge background and Ph.D. in atmospheric physics and atmospheric environment, he has concentrated on Wind Resource Assessment in wind energy since 2012.