WEP Warwick Evans Publishing

International Journal of Computer Science and Information Technology
ISSN: 3005-9682 (Print), ISSN: 3005-7140 (Online) | Volume 3, Number 2, Year 2024
DOI: https://doi.org/10.62051/ijcsit.v3n2.37
Journal homepage: https://wepub.org/index.php/IJCSIT/index

Comparison Technology of Wind Speed and Direction Anemometer for Wind Turbines Based on Doppler Lidar

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ABSTRACT

This paper focuses on the importance of sensors in wind turbines and the limitations of the current calibration method. It introduces a new technology based on Doppler lidar combined with numerical simulation to achieve in-situ and real-time calibration of the wind speed and direction sensor. The technology aims to evaluate the sensor's working status, quantify the influence of impeller interference, and improve the power generation efficiency of the unit. The key is to use numerical simulation modeling for direct comparison and evaluation. The research contents include quantifying the interference factors of the wind speed and direction sensor using numerical simulation and researching the use of Doppler lidar for sensor calibration. This technology offers advantages such as efficient status evaluation, in-depth result analysis, and reduced unit downtime, filling the technical gap in the wind power industry.

KEYWORDS

Wind Turbines; Calibration Method; Doppler Lidar

1. INTRODUCTION

In wind turbines, sensors such as wind speed and direction sensors, vibration sensors, temperature sensors, inclination sensors, and displacement sensors are very important components of the entire power generation system. The current calibration method mainly adopts the approach of randomly inspecting 1 - 2 units per year, which is unable to determine the actual operating status. Moreover, the process of disassembly and installation is troublesome, the calibration transportation process is time-consuming, and the signal transmission and analysis system cannot be calibrated. In addition, since the wind speed and direction sensor are installed behind the impeller, the data deviation caused by the interference of the impeller cannot be evaluated through the existing calibration methods. Inaccurate or incorrect sensor signals not only reduce the efficiency of the wind turbine but also affect the safe operation of the wind turbine and the lifespan of other components.

After the warranty period expires and the wind power operation and maintenance are taken over by the power station, the maintenance and calibration requirements of the above-mentioned sensors will increase significantly. However, the current situation of the enterprise is that there are few operation and maintenance personnel, and the coverage of professional skills is incomplete, which cannot meet the on-site needs.

This paper adopts Doppler lidar technology to achieve on-site and real-time calibration of the wind speed and direction sensor without the need for disassembly. At the same time, combined with numerical simulation technology, the inherent deviation of the wind speed and direction sensor and the data deviation caused by the impeller influence are quantified. Finally, the in-situ calibration of the wind speed and direction sensor is realized, and the power generation efficiency of the unit is improved by correcting the data deviation of the wind speed and direction sensor.

This project will realize the transformation from the traditional sensor delivery and inspection method to the direction of judging the real-time working status of the sensor, aiming at the ultimate safe and efficient production of the object, achieving a true object-oriented measurement, and making the measurement serve the object.

The purpose of this technology is to develop a sensor status evaluation technology that meets the actual needs of the wind power industry, transforming the sensor status evaluation work from labor-intensive to intelligent, reducing manual operations, lowering the implementation difficulty, improving the operability, and solving the contradiction between the high requirements for status monitoring and the practical implementation difficulties in the existing wind power generation, filling the technical gap in the wind power industry.

2. TECHNICAL SOLUTION

This technology is based on Doppler lidar technology, combined with numerical simulation model analysis, to achieve in-situ static and dynamic calibration of the wind direction and speed sensor of the wind turbine and evaluate the correct working status of the unit's wind direction and speed sensor.

2.1. Wind Speed and Direction Sensor Status Evaluation

Doppler lidar can retrieve the radial wind speed by detecting the backscattering signal of aerosol particles and the Doppler frequency shift of the system local oscillator light. It has the characteristics of high temporal and spatial resolution and high measurement accuracy. It is one of the most effective means to measure the wind turbine performance curve and has been applied in the pre-engineering wind measurement, wind turbine curve testing, and post-evaluation of wind farms in many domestic and international wind farms.

This technology has not yet been applied in the field of wind turbine wind speed and direction sensor measurement. Due to installation errors, mechanical wear, and wake effects, errors in traditional wind speed and direction sensors will occur. Simply comparing the measurement results of the lidar with the unit data cannot determine whether the deviation is caused by equipment failure or blade wake.

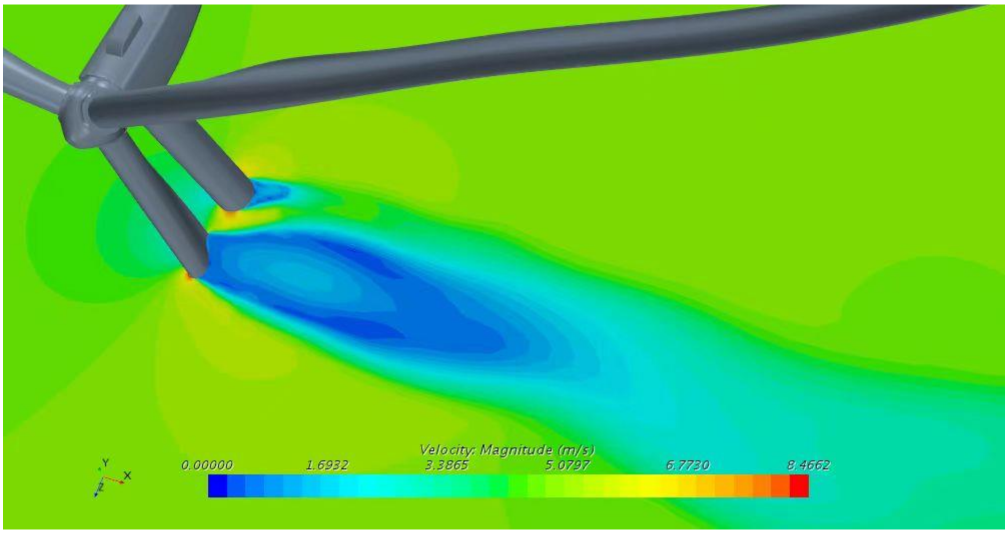

Figure 1. Numerical simulation of the influence of the impeller on the wind speed and direction sensor

This technology uses numerical simulation modeling to calculate the influence of the wake on the wind speed and direction sensor. The input conditions include wind speed, wind direction, wind density, etc., and a matrix database is formed for the lidar to call the data.

Compared with the existing technology, this technology has the following advantages:

(1) Efficient status evaluation. By using the laser Doppler lidar technology, the labor cost can be greatly saved. The actual working status of the wind speed and direction sensor can be evaluated without the need for manual climbing, disassembly, transportation, and installation. The test accuracy and efficiency are greatly improved.

(2) In-depth result analysis. Combining direct measurement with numerical simulation, in addition to judging the status of the unit's wind speed and direction sensor, the influence of installation errors, mechanical wear, and blade wake on the wind speed and direction sensor can be detected, and a retrofit plan can be provided to improve the power generation efficiency of the unit.

(3) Reducing unit downtime. A phased screening method for problem equipment is adopted. In the first stage, the wind turbine unit does not need to be shut down to complete the initial screening of the problem unit. In the second stage, the problem unit is shut down for high-precision detection to lock the problem unit equipment. This can avoid the power generation loss caused by the long-term shutdown in the existing technology.

The key of this technology is to use numerical simulation modeling to realize the direct comparison between the Doppler lidar and the unit's wind speed and direction sensor and evaluate the influence of the impeller interference on the wind speed and direction sensor.

Since the wind speed and direction sensor is installed behind the impeller, the data deviation caused by the impeller interference cannot be evaluated through the existing calibration methods, and this part of the deviation will have a significant impact on the efficiency and safety of the wind turbine. At the same time, combined with numerical simulation technology, the inherent deviation of the wind speed and direction sensor and the data deviation caused by the impeller influence are quantified. Finally, the in-situ calibration of the wind speed and direction sensor is realized, and the power generation efficiency of the unit is improved by correcting the data deviation of the wind speed and direction sensor.

3. RESEARCH CONTENTS

3.1. Research on Quantifying the Interference Factors of the Wind Speed and Direction Sensor Using Numerical Simulation

Simply comparing the Doppler lidar equipment with the wind speed and direction sensor cannot accurately evaluate the status of the wind speed and direction sensor. It is necessary to further clarify other interference factors, including the influence of the impeller rotation under the operating state and the impeller structure under the Y-type shutdown state on the wind speed and direction sensor, in order to analyze the initial yaw value of the wind direction sensor and optimize the unit operation.

Hypermesh is used for geometric cleaning and mesh generation, and the STAR-CCM + solver is used for calculation. A geometric model of the wind turbine is established. The input initial data includes the geometry of the wind turbine blade, nacelle, tower, wind direction sensor installation position, and wind direction sensor installation location. The model is used for numerical simulation calculation. The input condition is the wind speed. The output is the correction coefficient of the wind turbine wind direction sensor disturbed by the impeller. It includes: the correction coefficient of the wind turbine wind direction sensor disturbed by the impeller corresponding to different wind speeds under the non-stop state; the correction coefficient of the wind turbine wind direction sensor disturbed by the impeller corresponding to different wind speeds under the blade Y-type shutdown state.

Through numerical simulation, the influence of the impeller on the wind speed and direction sensor can be calculated. Taking the 37.5m blade model as an example (Figure 2), due to the interference of the impeller, at a wind speed of 11m/s, the wind speed data measured at the position of the wind speed sensor on the nacelle fluctuates periodically, as shown in Figure 5. The wind speed sensor results are always in a state of being too small, with the detection value fluctuating between 8.5 - 10m/s, with a deviation of 10 - 23% from the incoming wind speed of 11m/s.

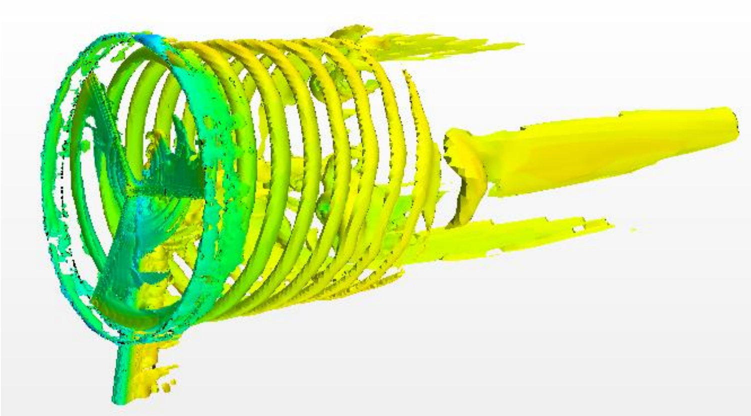

Figure 2. 37.5m blade model building (vorticity = 0.8 iso-surface view)

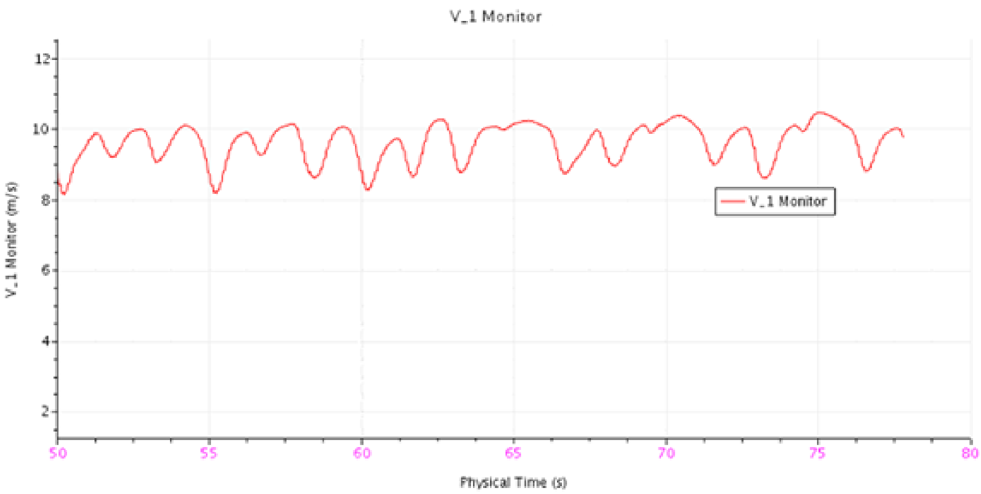

Figure 3. Existing wind speed sensor wind speed results (11m/s)

As shown in Figure 3, when the theoretical wind direction sensor should be at 0°, due to the interference of the impeller, the wind direction sensor also has a certain angle deviation. Through big data analysis, it is usually found that due to the interference of the impeller, the wind direction sensor deviation is about 4° - 10°.

This part of the research content belongs to theoretical calculation research and is an important means to establish the impeller interference database through calculation. It is an important reference basis for the comparison between the measured data of the Doppler lidar and the wind speed and direction sensor.

3.2. Research on the Use of Doppler Lidar for the Calibration of Wind Speed and Direction Sensors

Carry out research on the calibration method of Doppler lidar, focusing on the layout method, scanning method, dynamic screening process, and static screening process of the lidar; develop the corresponding software operating system. Develop a wind speed and direction sensor status screening method for the operating wind turbine; develop a wind speed and direction sensor status screening method under the Y-type shutdown state to form a complete dynamic + static wind speed and direction sensor status screening process.

The current Doppler lidar calibration technology is carried out in accordance with the International Electrotechnical Commission standard IEC61400 - 12 - 1 (2017). The equipment accessories used in this technology have undergone rigorous tests in Germany. The measurement data is compared with the data measured by the international IEC standard Type 1 cup anemometer. The correlation between the two at any height layer is as high as 99% or more, and the verification results are excellent. In this technology, the numerical simulation wind speed accuracy can reach 0.05m/s, the wind direction measurement accuracy can reach 0.1°, the lidar wind speed measurement accuracy can reach 0.1m/s, and the wind direction measurement accuracy can reach 1°. The accuracy fully meets the technical requirements of this project.

Based on big data analysis, determining the correction method for the wind direction sensor and wind speed sensor, determining the yaw correction angle of the wind direction sensor can achieve quality and efficiency improvement in wind alignment optimization. After determining the correction speed of the wind speed sensor, it can ensure the accuracy of the cut-in and cut-out wind speeds, achieve accurate cut-in to ensure the power generation utilization hours of the unit; achieve accurate cut-out and vibration monitoring to ensure the safe operation of the unit. In addition, the wind direction deviation has a greater impact on the unit efficiency, and in the shutdown state, the low-frequency vibration caused by the yaw affects the safety of the wind turbine.

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