Influence of Wind Disturbance on Wind Measurement System

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Abstract. This paper conducts an in-depth exploration of the impact of flow disturbance on the accuracy of wind measurement for wind turbines. The flow disturbance generated by the rotation of turbine blades results in deviations between the data recorded by the anemometer at the nacelle tail and the actual wind speed, thereby affecting power generation performance. To validate this impact, the paper compares and analyzes the power curves of wind turbines before and after implementing yaw static deviation optimization, revealing that yaw misalignment influences wind speed. Specifically, flow disturbance significantly affects the accuracy of the wind measurement system, leading to errors in wind speed measurements. Through simulation and analysis of actual measurement data, the results indicate that as wind speed increases, the negative impact of flow disturbance on wind speed measurement intensifies.

Keywords: wind turbine; wind disturbance; wind measurement.

1 Introduction

Currently, with the continuous advancement of renewable energy technologies, wind power generation, as a vital component of clean energy, has seen its efficiency enhancement become a key focus of the industry. An increasing number of wind turbine manufacturers are striving to optimize turbine performance through intelligent means, such as implementing initialization parameter adjustments for wind speed, adopting unified scheduling and control systems for wind farms, or upgrading single-turbine control logic, with the aim of enabling turbines to align more precisely with the wind and thus improve power generation efficiency[1]. However, a non-negligible issue in actual operation is that the data measured by anemometers located at the nacelle tail often fail to accurately reflect the actual wind speed due to the disturbance caused by the rotation of turbine blades which affects the turbine's power generation effectiveness. Therefore, this paper aims to delve deeply into the extent of the impact of wind disturbance on wind measurement accuracy. Through comprehensive data analysis, combined with field validation using high-precision wind measurement devices such as laser radars, the paper seeks to accurately assess whether the turbine truly achieves

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maximum kinetic energy when directly facing the wind, thereby providing a scientific basis for further enhancing wind power generation efficiency[2].

2 Terms and Definitions

The following terms and definitions apply to this document.

2.1 Yaw Static Deviation

Yaw static deviation refers to the angular deviation between the longitudinal axis of the nacelle and the wind direction in the stationary state of a wind turbine. This deviation leads to a reduction in the output power of the wind turbine, as the rotational speed and torque generated by the rotor decrease when it deviates from the optimal angle[3]. Long-term accumulation of yaw errors can also increase the fatigue loads on the turbine, affecting its lifespan and reliability, and indirectly impacting its output power.

3 Influence of wind Disturbance on Yaw Static Deviation Optimizing

The primary objective of this study is to conduct detailed testing and analysis of the specific impact of the yaw static misalignment optimization scheme on wind turbine performance. To achieve this goal, the research team selected a representative prototype as the test subject. Initially, a baseline power curve test was conducted on this prototype to comprehensively understand its original performance status.

After obtaining the baseline data, the research team adopted an advanced yaw static misalignment optimization scheme and implemented a comprehensive optimization and retrofit of the wind turbine's control and measurement system[4]. Following the completion of the optimization work, a rigorous power curve test was again conducted on the prototype to scientifically evaluate the actual effect of the optimization scheme.

Through comparative analysis of the two sets of test results before and after optimization, the research team observed a significant phenomenon: after adopting the yaw static misalignment optimization scheme, the power curve of the wind turbine showed a notable improvement compared to the pre-optimization state, with a specific improvement amplitude of up to 15%(shown in Figure 1 and Figure 2). This finding fully demonstrates the significant effectiveness of the yaw static misalignment optimization scheme in enhancing wind turbine performance.

However, when comparing the wind speed-power curves obtained from the wind measurement tower and the nacelle, the research team observed an interesting phenomenon[5]. Specifically, from the perspective of the wind speed-power curve of the wind measurement tower, the changes before and after compensation were not significant, and even showed a decreasing trend in some local areas. However, from the perspective of the wind speed-power curve of the nacelle, the power curve after compensation showed significant improvement. This difference may stem from the actual impact of the compensation angle on the nacelle wind speed, leading to different results when evaluating the power curve compared to the wind speed at the wind measurement tower.

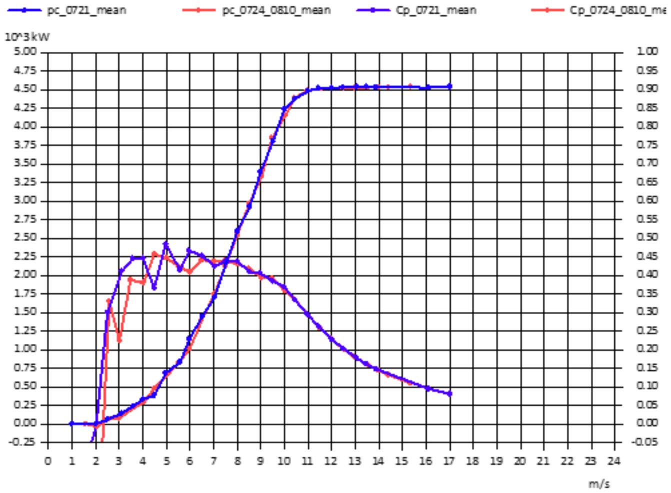

Fig. 1. Comparison of Wind Speed-Power Curves for Wind Measurement Tower (Blue: Before Compensation, Red: After Compensation)

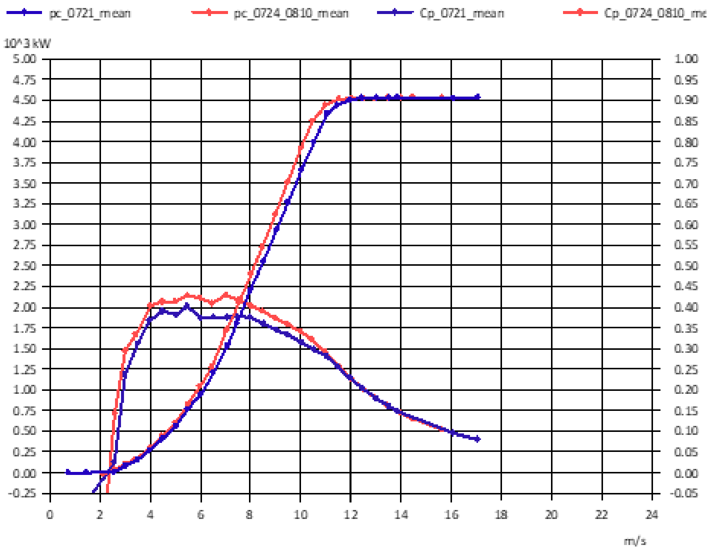

Fig. 2. Comparison of nacelle wind speed power curves (Blue_Before compensation, Red_After compensation)

Considering the adjustment of the wind turbine's yaw angle before and after compensation, this paper hypothesizes that the turbine's wake effect may exert an influence on the accuracy of the wind measurement system, consequently introducing a certain range of errors into the measured wind speed values[6]. To validate this hypothesis, we simulated the linear correlation between the wind speeds measured before and after turbine compensation and those recorded by the same wind measurement tower. The analysis results indicate that the wind speeds recorded by the nacelle anemometer after compensation exhibit a certain degree of decrease compared to those before compensation(shown in Figure 3). This phenomenon offers a plausible explanation for the significant improvement observed in the power curves plotted using nacelle wind speeds after compensation.

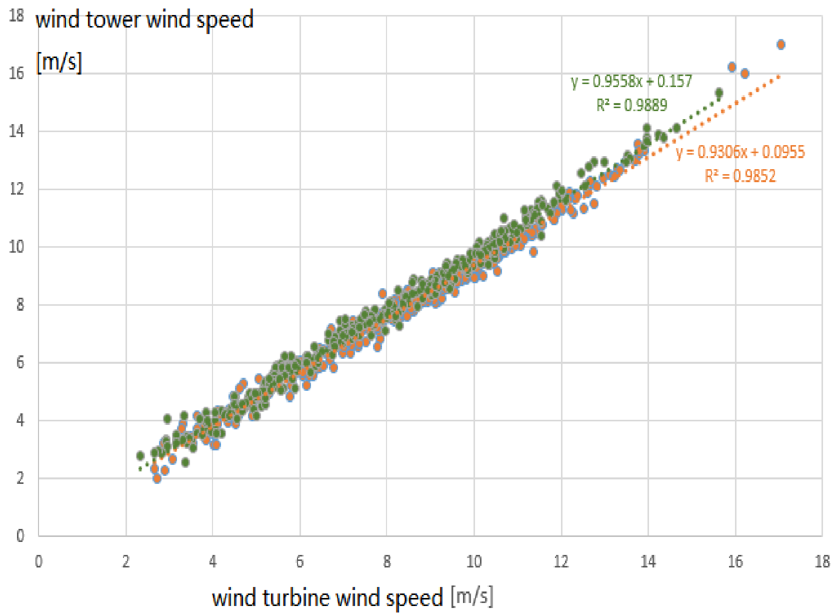

Fig. 3. The transfer function between nacelle wind speed and wind measurement tower wind speed (orange - before compensation, green - after compensation)

In summary, the yaw static misalignment optimization scheme has demonstrated certain potential in enhancing wind turbine performance[7]. However, in practical applications, it is necessary to comprehensively consider the influence of various factors to ensure the accuracy and reliability of the optimization effect. In the future, the research team will further deepen their research to fully reveal the profound impact of the yaw static misalignment optimization scheme on wind turbine performance

4 Influence of Wind Disturbance on Wind Speed Measurement

4.1 Simulation Calculation

Based on the data obtained from simulations, the following conclusions are drawn.

1.Impact of wind disturbance on wind speed measurement: As wind speed increases, the negative impact of wind disturbance on the accuracy of wind speed measurements also gradually intensifies. This means that under high wind speed conditions, wind speed measurements may exhibit greater errors due to the presence of wind disturbance.

2.Relationship between incoming wind speed and nacelle wind speed: With the incoming wind speed remaining constant, the nacelle wind speed changes as the yaw misalignment (i.e., the angle between the wind direction and the wind turbine plane) increases. Specifically, when the yaw misalignment is small, the increase in nacelle wind speed is relatively slow; however, as the yaw misalignment further increases, the rate of increase in nacelle wind speed accelerates significantly. This finding indicates that yaw misalignment is one of the important factors affecting nacelle wind speed, and its impact trend exhibits a characteristic of initial slow increase followed by rapid acceleration(shown in Figure 4).

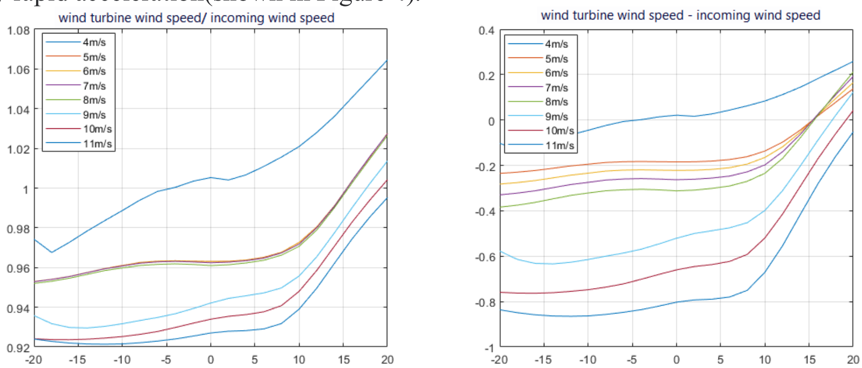

Fig. 4. The ratio and difference between the wind turbine wind speed and the incoming wind speed.

4.2 The Influence of Disturbed Flow on Wind Speed Measurement in Prototype Testing

In this study, a detailed exploration was conducted on the wind measurement tower and radar data analysis within specific time periods. Specifically, the analysis of data from the wind measurement tower was focused on August, while the radar data was analyzed over the time span from 00:00 on July 24th, to 23:50 on August 10th. It is worth noting that both sets of data have undergone yaw optimization compensation to ensure their accuracy and reliability.

During the data analysis process, reference wind speed and reference wind direction were used as the benchmarks for binning. The wind speed range was set at [3.75m/s, 9.75m/s], and bins were created with 0.5m/s intervals, resulting in a total of 12 wind speed bins. For wind direction, a range of ±30° was considered, and bins were created with a precision of 0.25°, yielding 240 wind direction bins. Based on this, the mean differences between the nacelle wind speed and the reference wind speed were calculated.

Through in-depth analysis of the data, an interesting phenomenon was observed: regardless of whether the reference wind speed was based on the wind measurement tower or the radar, the nacelle wind speed increased monotonically with the increase in reference yaw misalignment, but this trend was particularly significant within a misalignment range of less than 10°. When the misalignment angle exceeded 10°, due to the relatively small amount of data, the scatter points exhibited greater dispersion and did not show the rapid increase trend observed in the simulation figures(shown in Figure 5). This phenomenon provides an important reference for subsequent wind turbine performance optimization.

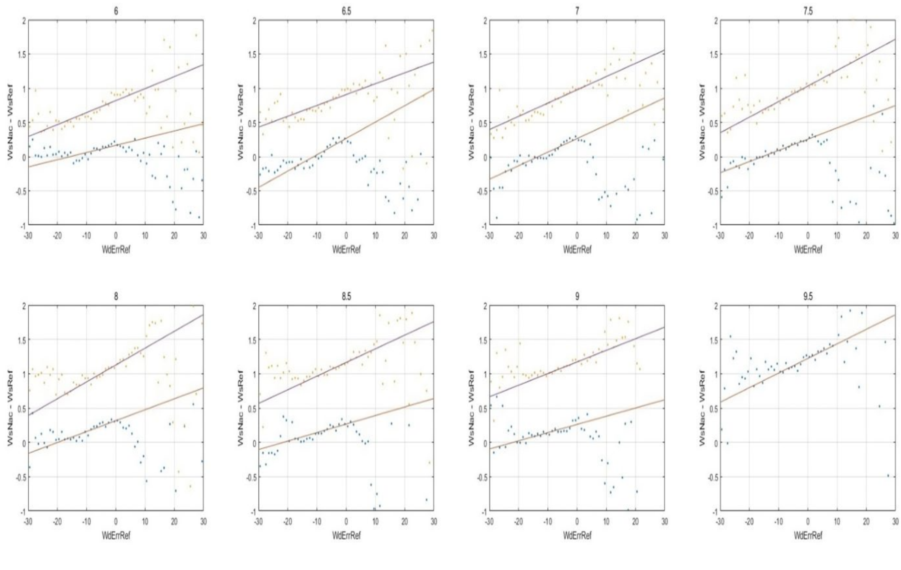

Fig. 5. The difference between the wind turbine wind speed, the wind measurement tower and the radar wind speed

In a study focusing on another wind turbine generator (with data collected from June to October), the same binning statistical method was employed as used for the prototype. Notably, as the yaw misalignment varied, the difference between the nacelle wind speed and the radar wind speed exhibited a specific trend: the difference initially increased monotonically, then gradually decreased, with a distinct maximum point in the wind speed difference observed during this process(shown in Figure 6).

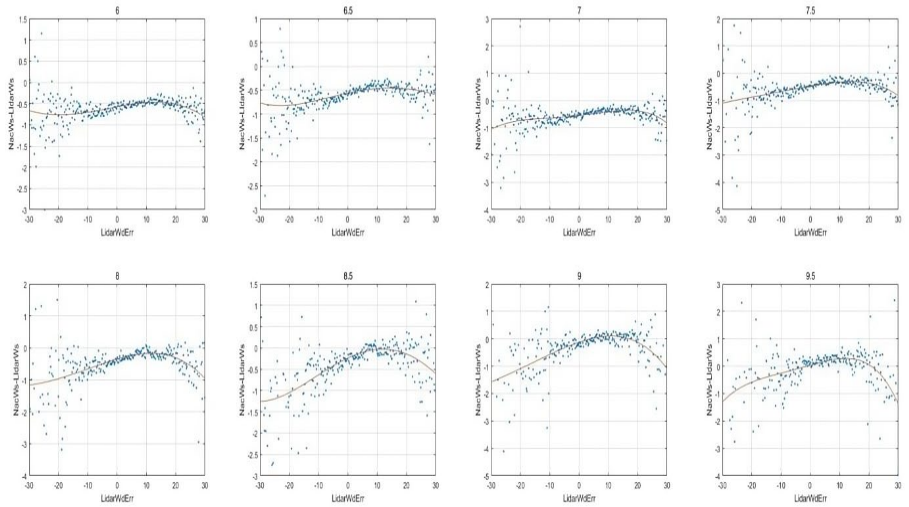

Fig. 6. The difference between the wind turbine wind speed and radar wind speed

4.3 Conclusion

Under the condition of the same incoming wind speed, the wind speed within the nacelle is significantly influenced by wind disturbance factors. Specifically, when the external incoming wind speed remains constant and the yaw angle between the nacelle and the wind direction changes, the measured wind speed within the nacelle exhibits noticeable differences. This variation indicates that the intensity of the wind disturbance effect differs at various yaw angles, leading to fluctuations in the nacelle wind speed.

On the other hand, when the wind speed within the nacelle is maintained at a constant level, the external incoming wind speed is not evenly distributed. Under different yaw angle conditions, even if the measured nacelle wind speed is the same, the external incoming wind speed may vary significantly. This further confirms the uneven impact of wind disturbance on wind speed distribution and the complex and variable relationship between the incoming wind speed and the nacelle wind speed at different yaw angles.

5 The Influence of Wind Disturbance on Wind Direction

The nacelle wind speed and nacelle wind direction were segmented into bins. The wind speed range was set to [2.75, 9.75] m/s, subdivided at 0.5 m/s intervals, resulting in 14 wind speed bins. The wind direction range was set to ±30°, with a 0.2° step, yielding a total of 300 wind direction bins. Based on this segmentation, the wind directions corresponding to the maximum values of radar wind speed, nacelle wind speed, and power were recorded(shown in Figure 7). The results indicated that the distribution of power scatter points was highly consistent with that of radar wind speed scatter points, and the wind directions corresponding to their maximum points were also basically aligned. Further analysis revealed that wind disturbance had a significant impact on wind speed measurements, becoming the dominant factor in yaw optimization. The wind direction value corresponding to the maximum radar wind speed could be approximately equated to the yaw optimization value obtained through power optimization.

Based on the above analysis, an important conclusion can be drawn: the disturbance of the wind turbine impeller has almost no influence on the wind direction measurement.

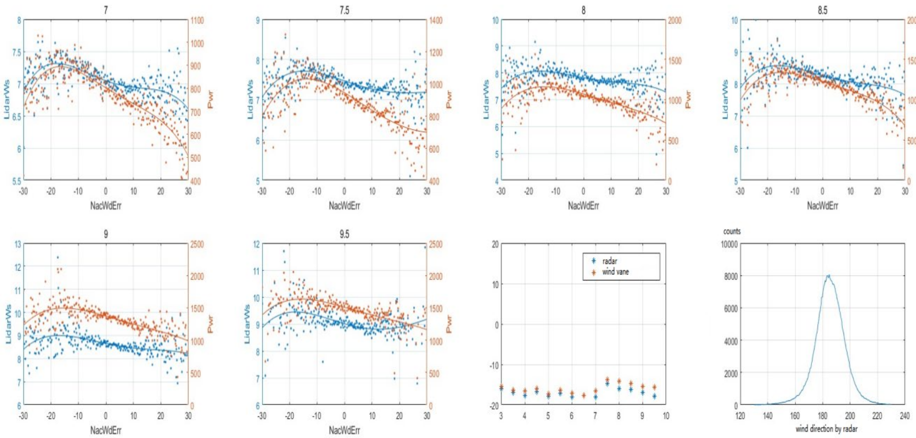

Fig. 7. The scatter plot of power versus wind speed of nacelle and radar

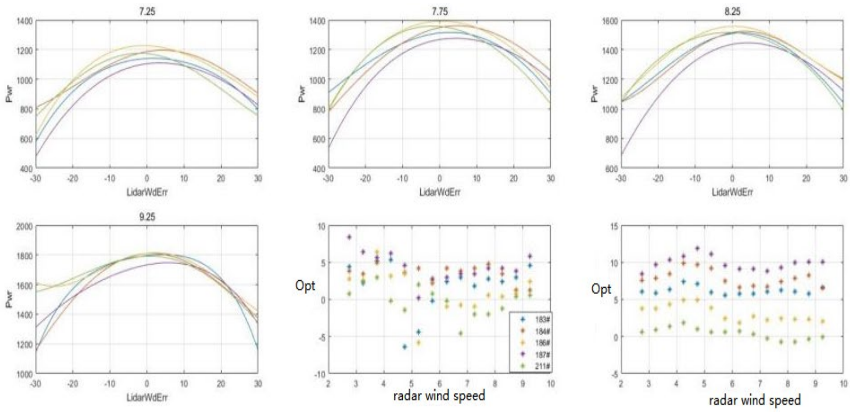

Fig. 8. Maximum power optimization by using radar

When using the wind speed and direction measured by radar for maximum power optimization, theoretically facing the wind coming from the front, the highest power can be obtained, and the optimization result should be 0°. However, through the test of five wind turbines, the optimization value measured by the radar is generally positive (that is, greater than 0°), and usually within 5°. This means that when the airflow slightly to the right enters the radar, it can make the wind turbine produce higher power(shown in Figure 8).

6 Conclusion

The occurrence of blade flow disturbance and subtle adjustments to the wind angle both significantly and notably affect the accuracy of wind speed measurements in wind turbines. Specifically, when the blades encounter external factors such as atmospheric turbulence or obstructions during operation, resulting in the generation of flow disturbance effects, or when there are slight deviations in the angle between the blades and the wind direction (i.e., the wind angle), these changes directly lead to pronounced fluctuations in the wind speed measurements of the wind turbine.

In contrast, although blade flow disturbance and changes in the wind angle also exist in the wind direction measurement environment of wind turbines, their direct impact on the wind direction measurement results is relatively small. Although these external factors can cause a certain degree of interference to the wind direction measurement, resulting in small fluctuations in the measurement values within a local range, the overall wind direction measurement results of the wind turbine can still maintain a relatively stable interval, showing good consistency and repeatability. This phenomenon indicates that the wind direction measurement system has strong anti-interference ability and robustness.

Further observation and analysis reveal that when the wind turbine is directly facing the wind, it does not reach the maximum power output as expected. Instead, the peak power output occurs when the wind turbine is slightly to the right (relative to directly facing the wind). This phenomenon reveals the complexity and non-linearity of wind turbines in actual operation, suggesting that we need to more carefully consider the interaction between wind direction, wind speed, and wind turbine structure during wind turbine design, installation, and operational optimization to maximize the energy conversion efficiency and power output of the wind turbine.

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