Research and Application of Intelligent Monitoring Technology for Long Blades of Wind Turbine Tower

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Abstract

This article addresses the safety issues of high tower and long blades in wind turbines. By analyzing the causes of tower collapse and blade breakage, a multi state intelligent monitoring method for wind turbines that integrates vibration, load, tilt, and acoustics is proposed. And through practical application in wind farms, the effectiveness of monitoring data was verified and the application effect was analyzed. The results showed that this method is accurate, reliable, and technically feasible.

Keywords

Wind turbines; High tower; Long leaves; Intelligent Monitoring.

1. Introduction

The hub height of modern wind turbines generally exceeds 100 meters, and even reaches 160 meters. As wind turbine towers become taller and impellers become larger, safety based stability assessment of the entire machine becomes increasingly important [1].

However, the higher the tower, the greater the safety risk. For wind turbine towers above a height of 120m, there is a risk of resonance collapse of the tower due to the coupling vibration of the first and second frequencies with the impeller speeds of 1P, 3P, 6P, and higher-order frequencies. At the same time, the operating environment of wind turbines is complex and ever-changing, and the tower must withstand various complex loads such as self weight, wind pressure, and blade forces, resulting in a certain degree of sway and distortion. At this point, slight uneven settlement of the foundation will cause significant horizontal displacement at the top of the wind turbine. Under further external loads such as wind pressure and hub yaw, the tower will be subjected to severe eccentric bending moments, leading to surface overload cracking, tilting, bolt loosening, bending deformation, and a series of other problems. These phenomena will cause greater horizontal displacement at the top of the wind turbine, exacerbating damage to the tower and ultimately causing tower collapse.

In addition, wind turbine blades work in complex natural conditions, enduring harsh environments such as strong wind loads, sand erosion, atmospheric oxidation, lightning strikes, and humid air corrosion for a long time. During operation, they are also subjected to alternating loads. Therefore, wind turbine blades may experience various faults, such as air holes, cracks, wear, corrosion, carbonization, etc. If these faults cannot be detected and treated in a timely manner, the blades will be more severely damaged or even broken, which will lead to unit shutdown and cause serious economic losses [2-3].

In summary, it is very important to carry out intelligent monitoring and early warning for the long blades of wind turbine towers.

2. Technical Routes

By establishing wind turbine load, blade load, anchor cable load, tower vibration, optical monitoring module, foundation monitoring module, and noise detection module, and establishing corresponding calculation models, fault diagnosis, and warning models, intelligent monitoring and technical analysis of wind turbine foundation deformation, yaw load, blade status, and tower vibration can be achieved.

By monitoring the deformation of wind turbine blades, tower vibration, and load, potential faults in blades, tower, foundation, and steel cables are identified. The causes of blade noise, tower vibration, and foundation hazards are analyzed, and their fatigue life and safety are evaluated. This provides a load basis for optimizing wind turbine control strategies and verifies the effectiveness of optimized control. To conduct health assessments for in-service wind turbines in wind farms, provide technical support for fault analysis and safety warnings, reduce downtime and frequency of wind turbine failures, and improve economic benefits, as shown in Figure 1.

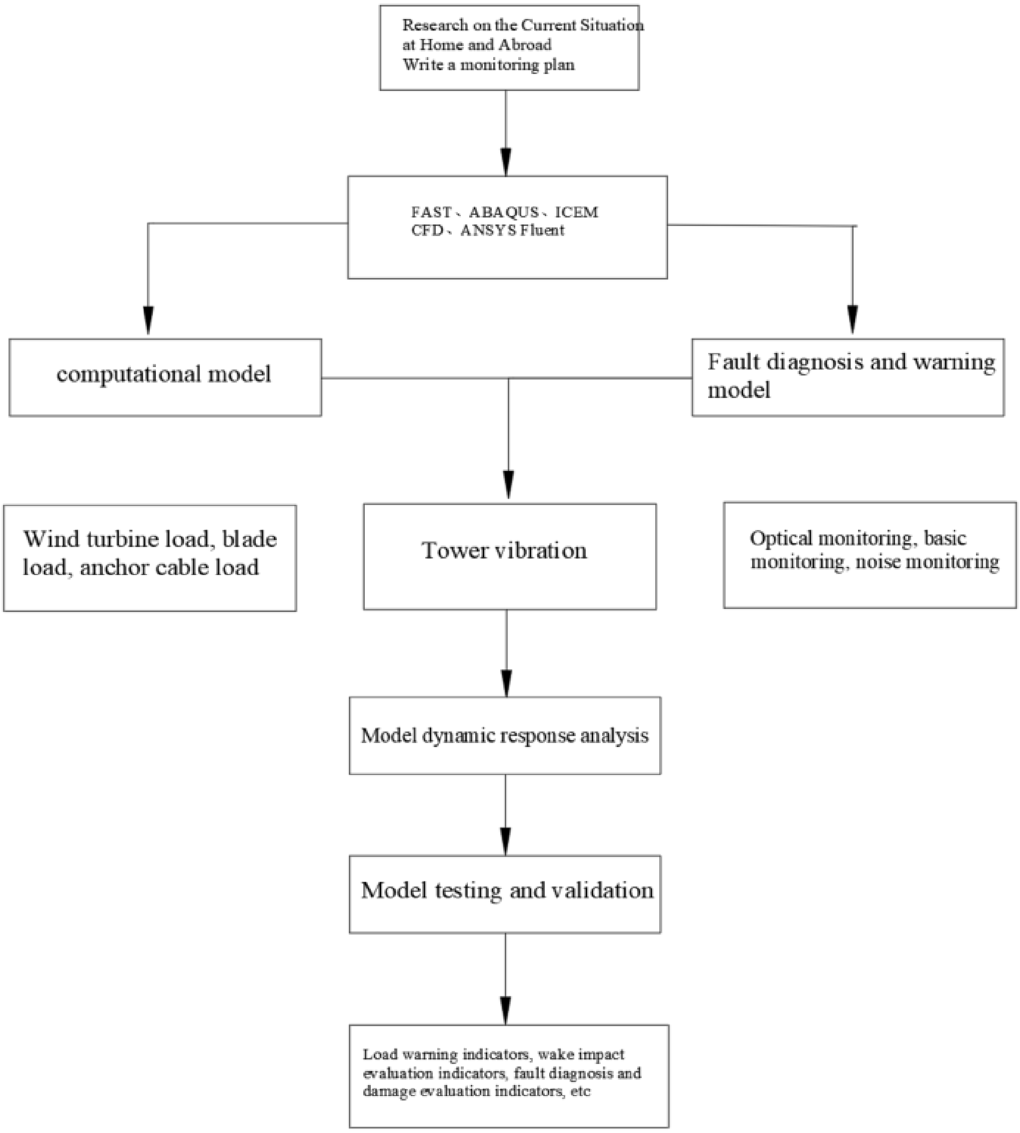


Figure 1. Overall Technical Roadmap

2.1. Layout of measuring points for intelligent monitoring equipment

The intelligent monitoring of a single wind turbine unit includes tilt monitoring, vibration monitoring, load monitoring, and optical monitoring. The distribution of measuring points is shown in Figure 2, and the types of measuring points are shown in Table 1.

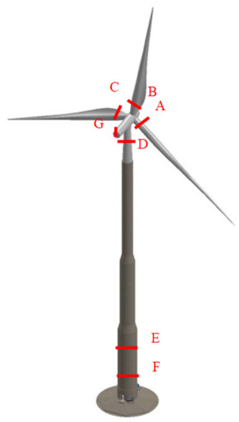


Figure 2. Distribution of Intelligent Monitoring Points for Wind Turbine Units

Table 1. Types of Measurement Points

measuring point location	Monitoring type		
Measurement points A/B/C	load	tilt	/
Measurement point D	load	tilt	vibration
Measurement point E	tilt	/	/
Measurement point F	load	/	/
Measurement point G	optical	/	/

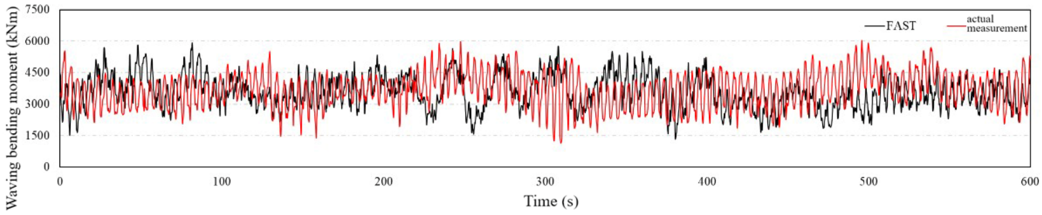
2.2. Numerical Calculation

Based on FAST software, wind turbine dynamic response calculations under different conditions are carried out to comprehensively grasp the characteristics of the wind turbines used in this project from the model calculation level, providing a basis for monitoring data verification and setting warning indicators. Based on the model, calculate variables such as blade root load, tower load, tower vibration and deformation in typical environments as a reference for data validation.

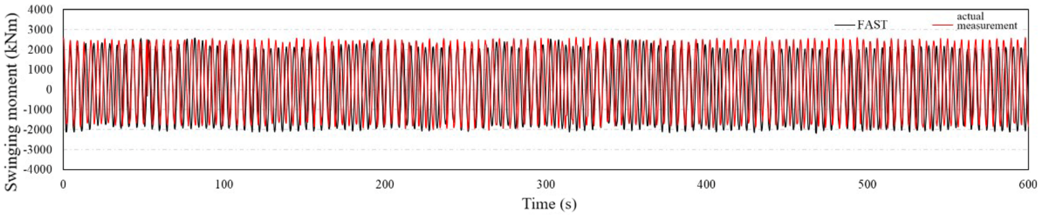
2.3. Data Validation

By comparing the test results with the model calculation results, the rationality and accuracy of the test data are verified, indicating that this technical solution can truly reflect the dynamic response of the wind turbine, achieve intelligent monitoring of the high tower and long blades of the wind turbine, and provide data support for wind turbine fault warning.

Select the period when the wind turbine is stably maintained near the rated power for blade root load verification, and use FAST software to calculate the dynamic response of the wind turbine under the same wind speed conditions. Compare the blade root swing bending moment and oscillation bending moment output by FAST with the monitoring results, as shown in Figure 3. The measured values of the blade root bending moment are in good agreement with the simulated values, with only small errors. The maximum value and variation range of the load are relatively consistent. The results can demonstrate the accuracy of the measured load.



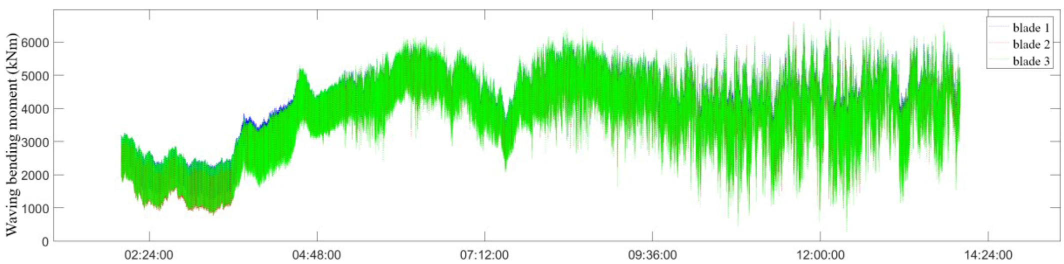
(a) Waving bending moment



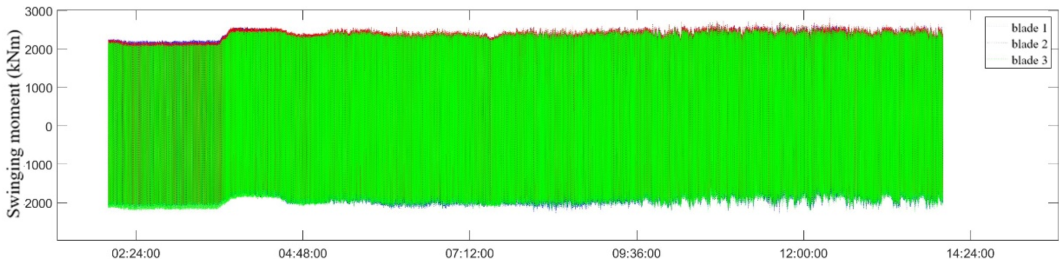
(b) Oscillation bending moment

Figure 3. Verification of blade bending moment

Extracting the root load time history of three blades during a certain period of time, covering the process of wind turbine from low power generation to full power generation, analyzing the load situation of the three blades during wind turbine operation, as shown in Figure 4. The swing bending moment and oscillation bending moment of the three blades are relatively consistent. Combined with the simulation model verification, it shows that the monitoring results can truly reflect the load state of the three blades.



(a) Waving bending moment



(b) Oscillation bending moment

Figure 4. Verification of blade load

3. Application Cases

A technology application was carried out in a certain wind farm, and an intelligent monitoring system was deployed to achieve dynamic load, vibration, tilt and other state monitoring of wind turbine blades and towers. It can accurately calculate and perceive the state changes of wind turbines under different operating conditions and provide timely fault warnings.

The operation effect after the system is put into operation is shown in Figure 5, Figure 6, and Figure 7.

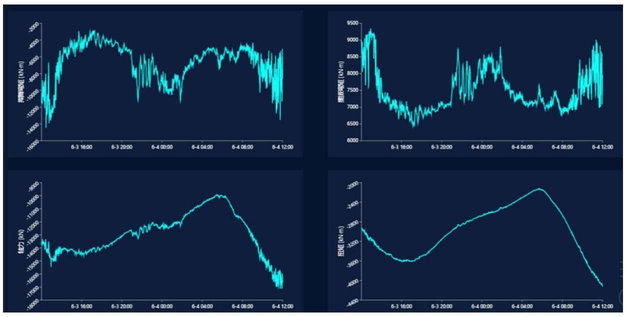


Figure 5. Blade Monitoring Results

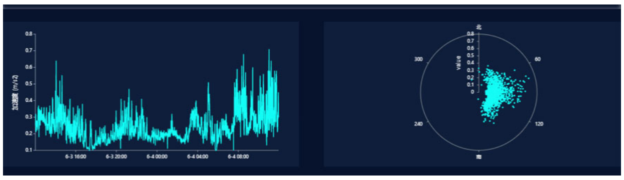


Figure 6. Tower Monitoring Results

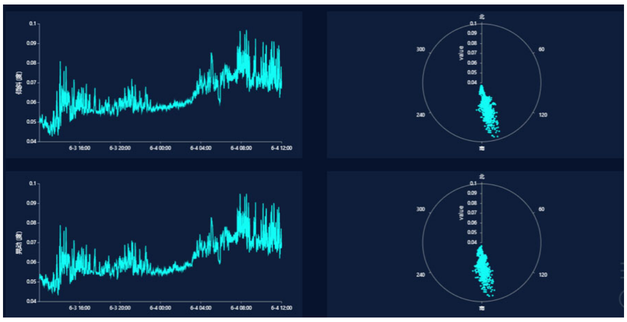


Figure 7. Tower foundation monitoring results

From the monitoring results of wind turbines, it can be seen that the system operates stably and the monitoring results are accurate. It can reflect the real-time operating status of wind turbine blades and towers in real time, indicating that the intelligent monitoring technology route for high tower and long blade of wind turbines proposed in this paper is feasible.

4. Conclusion

This article proposes a multi state intelligent monitoring method for wind turbines that integrates vibration, load, tilt, and acoustics to address the issue of missing state monitoring of high tower blades and long blades. Based on FAST software, the dynamic response of wind turbines was calculated, and the effectiveness of the monitoring data was verified. The method was found to be accurate and reliable, ultimately achieving real-time monitoring and fault warning of key operating parameters of wind turbine leader blades and high tower blades. This provides a feasible technical route for the safety protection of high tower blades and long blades in the future large-scale development of wind turbines.

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