Structural response analysis of wind turbine under different wind speeds

Qian Huo

Department of Civil Engineering, Lanzhou University of Technology, Lanzhou, Gansu 730050, China

Corresponding author’s e-mail: 2326518993@qq.com

Abstract: Taking a 2 MW horizontal axis wind turbine in a wind farm in Northwest China as the research object, the structural response analysis of wind turbine considering fluid structure coupling effect under different inflow was carried out by using ANSYS Workbench software. The results show that when the incoming wind speed is cut-in wind speed, the displacement and stress change slightly; when the incoming wind speed is between the cut-in and cut-out wind speed, the structural response law of the wind turbine is the same. The maximum of displacement and stress increase with the increase of wind speed, and the maximum displacement of the blade is located in the tip, and the maximum stress of the blade is concentrated in the middle of the blade; The maximum displacement of the tower is located at the top, and the maximum stress of the tower is concentrated at the bottom. The results have important reference value for the design and safe operation of wind turbine.

1. Introduction

With the increasing improvement of wind turbine power generation technology, wind turbine is developing in the direction of large-scale. Under the action of different incoming flow, the wind turbine produces deformation and stress concentration, which makes the wind turbine fatigue and reduces its working life. Therefore, it is of great significance to study the structural response of wind turbine under different incoming flows for its safe operation.

At present, many scholars have carried out a large number of wind turbine deformation research. Hao Wu et al. [1] used CFD simulation method to study the vibration mode and displacement curve of NREL phase VI blade under different wind speeds, and the results show that the aerodynamic loading on the blade increase with increasing of wind speed. A study of the structural stress distribution of a wind turbine under different wind speed and tip ratio with a fluid structure coupling method by Yuanxing Zhao et al. [2]. Jianping Zhang et al. [3] used ANSYS software to study the dynamic response of offshore wind turbine tower under different average wind speeds. Taking a 2.5MW wind turbine as the research object, Yuan Li et al. [4] used weak coupling method to study the blade load distribution and aerodynamic performance under different shear inflow conditions. By comparing the aeroelastic structural response of wind turbine under shear wind speed and uniform wind speed, Wenping Zhou et al. [5] provided reference for structural optimization design of wind turbine.

Based on the above research, there is less researchs on the structural response of wind turbine model under different incoming wind speeds. Therefore, this paper takes the 2MW horizontal axis wind turbine in Northwest China as the research object, and uses the unidirectional fluid-structure coupling method to study displacement and stress at the typical position on wind turbine structure under different wind speeds, which has guiding significance for the safe operation of wind turbine.
2. numerical simulation

2.1. Modeling and meshing
In this paper, the solid and fluid domains of wind turbine are established by Solidworks software. ICEM software is used to divide the grid, and the type is unstructured grid because of shape of blade surface is distorted and complex. The fluid flow around the rotating domain is complex and changeable. In order to simulate the flow characteristics of wind turbine accurately, the grid in the rotating domain is encrypted, especially the blade surface needs to be refined and local encryption. The size of the static grid is enlarged appropriately for reducing the number of grid generation. After the above grid division, a total of 5million unstructured grids are obtained, and the fluid field is shown in Figure 1.

![Figure 1. Fluid domain meshing.](image)

2.2 Computing method
The fluid flow is set as an incompressible steady flow, and a SIMPLE solver is used for double precision and steady-state calculation. The standard $k-\varepsilon$ turbulence model is selected, and multiple reference frame model is used for data transfer between rotating domain and stationary domain.

3. Simulation results and analysis
Three typical curves of wind turbine are selected as the research object, one of which is composed of the same position points on each blade element along the blade direction; The other two curves are composed of the points on the windward side and leeward side of the tower along the axis of tower.

The incoming wind speed is 6m/s of cut-in wind speed, 11m/s of rated wind speed, 15m/s and 20m/s of cut-out wind speed respectively. The total displacement of blade is shown in Figure 2. It can be seen that the starting point of the four curves represents displacement of the blade root and is not zero, which corresponds to the displacement of the top of tower. The end point of the four curves represents the displacement on the blade tip, which is the most deformed position on the whole blade. When the incoming wind speed is 6m/s, the deformation of the blade is not obvious, and the displacement growth is only 0.0349m, which indicates that influence on the deformation of blade is small when the incoming wind speed is low. When the wind speed is between 6m/s and 20m/s, the three displacement curves increase exponentially, and the increment of blade deformation from root to tip increases with the increase of wind speed. When the wind speed is 20m/s, the maximum increment of blade deformation is 0.5583m, which is 16 times of increment of blade deformation under cut-in wind. It shows that the aerodynamic force will increase with the increasing of the incoming wind speed, and the influence on blade deformation is also increasing.

Figure 3 shows the shimmy displacement of blade. It can be seen that the shimmy deformation of blade tip is the largest under different wind speeds. When the wind speed more than 6m/s, the blade shimmy will swing in opposite direction. When the wind speed is 20m/s, the maximum shimmy displacement increment of the blade reaches 0.0405m, which is 2.94 times of the shimmy displacement increment under cut-in wind speed, indicating that the aerodynamic force has little effect on the shimmy displacement of blade.
Figure 4 shows the flapping displacement of blade. It can be seen that the flapping deformation of blade is in the same direction under different wind speeds, and the deformation at tip is the largest. When the wind speed is 20 m/s, the maximum blade flapping deformation increment is 0.5609 m, which is 15.7 times of blade flapping deformation increment under cut-in wind speed, indicating that the aerodynamic force has a great influence on the blade flapping displacement.

Figure 5 shows the spanwise displacement of blade, and it is seen that deformation near the root has hardly changed. In the section including the connecting area of the root and the blade body and the tip area, the deformation shrinks. In the blade body area, displacement will not change. Overall, the amount of blade deformation is negligible.

Figure 6 shows the stress distribution of blade. It can be seen that the stress variation law of blade under different wind speeds is basically the same, the stress from blade root to blade body joint decreases gradually. In blade body and tip region, the stress first increases and then decreases. With the increase of incoming wind speed, the maximum stress increases gradually, and the maximum stress position moves to the root direction. When the wind speed is 20 m/s, the maximum stress of the blade is $9.47 \times 10^7$ Pa, which is 4.28 times of maximum stress under cut-in wind speed.

Figure 7 shows the displacement variation of wind turbine tower. It can be seen that the displacement variation is the same under different wind speeds. the total increment of tower displacement increases with the increasing of wind speeds. When the wind speed is cut-in wind speed, the displacement increment is the smallest. When the wind speed is 20 m/s, the maximum displacement of tower top reaches 0.233 m, which is 4.44 times of maximum displacement under cut-in wind speed. It shows that aerodynamic force has a great influence on the deformation of wind turbine tower.
Figure 8 shows the stress distribution on the windward side of tower. It can be seen that when the wind speed is 6 m/s, the stress increases gradually from the bottom to the top of tower. When the wind speed is greater than 6 m/s, the variation of stress is similar under different wind speeds. Stress concentration occurs at the bottom and top of tower. The stress of tower body first decreases and then increases. With the increase of wind speed, the position of the minimum stress on the tower gradually moves to the top, and the maximum stress of tower gradually increases. When the wind speed is 20 m/s, the maximum stress is $3.56 \times 10^7$ pa, which is 4.44 times of maximum stress under cut-in wind speed.

Figure 9 shows the stress distribution on the leeward side of tower. It can be seen that when the wind speed is 6 m/s, the tower stress first decreases and then increases, and the overall change amplitude of stress is small. When the wind speed more than 6 m/s, the stress law of the leeward side of tower is similar to that of the windward side. The difference is that the position of the minimum stress turning point and the maximum stress on the leeward side are higher than those on the windward side. When the wind speed is 20 m/s, the maximum stress is $4.64 \times 10^7$ pa, which is 4.06 times of maximum stress under cut-in wind speed.

### 4 Conclusions

In this paper, a 2MW horizontal axis wind turbine in a northwest wind farm is taken as the research object, and the structural response characteristics under different wind speeds are studied by using ANSYS Workbench software. The results are as follows:

1. When the wind speed is cut-in wind speed, small aerodynamic force has little effect on the deformation of wind turbine.
When the wind speed is between the cut-in and cut-out wind speed, the structural response of wind turbine is completely consistent. With the increase of wind speed, the stress and deformation scale of gradually increase, and there is stress concentration in the middle of blade and the middle of tower, which has an important impact on the safe operation of wind turbine.

References

[1] Wu, H., Lai, Y.B., Wang, L., et al. (2018) Study on vibration characteristics of wind turbines under different wind speeds. Journal of Hebei University of Science and Technology, 39: 401-408.

[2] Zhao, Y.X., Wang, J.W., Zhang, L.R., et al. (2021) Research on influence of aerodynamic load and centrifugal load on wind-turbine-blade stress. Acta Energiae Solaris Sinica, 42: 225-232.

[3] Zhang, J.P., Gong, Z., Zhang, Z.W. (2019) Influence of Average wind speed on dynamic responses of offshore wind turbine tower. Journal of Shanghai University of Electric Power, 35: 27-30+52.

[4] Li, Y., Kang, S., Zhao, P., et al. (2014) Numerical simulation of fluid-structure coupling of 2.5MW wind turbine rotor in various wind speeds of shear inflow. Journal of Engineering Thermophysics, 35: 2192-2196.

[5] Zhou, W.P., Xiao, Y. (2016) Influence of wheel polygonization on vehicles dynamics. Mechanical Engineering & Automation, 05: 40-41+44.