



Review on Wind Resistance, Seismic Resistance and Vibration Control of Wind Power Structures

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Abstract

As an important structure supporting the wind turbine, the wind power tower is faced with the complex environmental impact of wind load and seismic load during operation. This paper reviews the current research progress and methods on wind resistance, seismic resistance and vibration control of wind power tower structures. The purpose is to provide reference for the structural design and related technical research of wind power tower.

Subject Areas

Civil Engineering

Keywords

Wind Power Structure, Wind Load, Seismic Performance, Vibration Control

1. Introduction

With the increasing global dependence on renewable energy, wind power, as one of the representatives of green energy, has an increasing proportion in the power system. However, the wind power structure is often affected by a variety of dynamic loads in its operation, among which wind load and seismic load are important factors that cannot be ignored. The structural vibration and damage caused by it will not only affect the normal operation of the wind power system, but also may even lead to serious structural damage and economic losses. How to ensure the anti-vibration safety of wind power structures and establish feasible vibration control schemes is still a challenge for scholars at home and abroad. At present, there are still deficiencies in the research on wind, seismic and vibration control of wind power structures in terms of accurate simulation of complex environments, research on considering the coupling effect of multi-

ple factors, and research and development of new vibration control strategies. The purpose of this paper is to systematically summarize and analyze the research results of the existing wind power tower structure in wind resistance, seismic resistance and vibration control, and put forward the direction and suggestions for further optimization design and performance improvement, so as to provide reference for research and engineering practice in related fields.

2. Research on Wind Resistance Performance of Wind Power Structure

Wind load is an important factor that must be considered in the design and operation of wind power tower. Wind load characteristics mainly include wind speed, wind direction, turbulence and its dynamic effects on the structure. The size and distribution of wind load directly affect the design and safety performance of wind power tower. With the increase of the height of the tower, the structure becomes flexible, the vibration frequency decreases continuously, and it is more sensitive to wind load, which is prone to vibration fatigue damage and collapse damage under extreme conditions [1].

In view of this phenomenon, He Guangling [2] combined the integrated finite element analysis model to analyze the wind-induced dynamic response of reinforced concrete wind power tower. The results show that the wind-induced dynamic amplification effect has a significant impact on the structure. Cheng Youliang *et al.* [3] established a tower blade coupling structure model, combined with the fluctuating wind speed spectrum, and used the two-way fluid-solid coupling method to analyze the dynamic parameter changes of the tower blade coupling structure. The results show that the first and second modes of the tower are shimmy and the third mode is flapping when the offshore wind power tower is in normal operation. Ke Shitang *et al.* [4] established the whole finite element model of wind power generation structure considering SSI effect and blade centrifugal force, simulated the fluctuating wind field of wind power generation structure, and analyzed the wind-induced dynamic response of wind power tower. Studies have shown that considering the SSI effect will increase the wind vibration coefficient of the blade. Li Wangrun *et al.* [5] established a wind power tower structure model considering the rotation effect of blades, and analyzed its response under wind-seismic coupling. The results show that the influence of wind-seismic coupling on tower top displacement is smaller than that under wind load alone.

3. Study on Seismic Performance of Wind Power Structure

Wind power structure has the characteristics of high flexibility, high towering and strong dynamic characteristics. These characteristics determine that the response of wind power structure under earthquake is more complex and intense, and the wind power structure is facing huge earthquake risk. Therefore, it has aroused the in-depth study of scholars.

Considering the coupling effect between the tower and the foundation, Lavas-

sas *et al.* [6] carried out static, fatigue and seismic dynamic response analysis of a 1 MW steel wind power tower. Taddei *et al.* [7] compared a simplified SSI model with an accurate generalized soil spring-based finite element method. The results show that the spring model considering SSI effect can explain all the most important dynamic characteristics of the entire turbine-soil system in the case of a softer layer on a harder half-space. Natale *et al.* [8] established a comparative model for seismic response analysis under SSI effect. The results show that the influence of SSI effect on the dynamic response of blades is more significant.

The research on seismic reduction of wind power structures in China started relatively late, but has made remarkable progress in recent years. Based on the total probability theory, Dai Kaoshan *et al.* [9] analyzed the structural damage of the wind power tower. It was found that the wind power tower structure was easier to enter the first and second damage states under the action of earthquake, and the wind power tower could not generate electricity normally. Based on the finite element software and time history analysis method, Song Bo *et al.* [10] analyzed the seismic dynamic response of wind power structure. The study found that compared with other ground motions, the dynamic response of plate boundary ground motion to wind power tower structure is dominant. Li Dayong *et al.* [11] studied the seismic response characteristics of wind power hollow conical foundation through numerical simulation, and found that the conical foundation can mobilize more soil-based seismic performance services.

4. Experimental Study on Wind Power Structure

4.1. Wind Tunnel Test Research

In the wind-resistant design of wind power tower, wind tunnel test is a crucial analysis method, which can effectively evaluate and optimize the wind-resistant performance of wind power tower.

Wind tunnel test is a common experimental method to simulate the effect of natural wind on wind power tower. The scale model is usually used to simulate the actual wind power tower. The model design should strictly follow the similarity law to ensure that the experimental results can accurately reflect the actual situation. By simulating different wind speed, wind direction and turbulence intensity in the wind tunnel, researchers can observe and record the response of the wind power tower under various wind conditions. The results of the wind tunnel test are not only used to evaluate the wind resistance of the structure, but also to verify the accuracy and reliability of the numerical simulation. By comparing the wind tunnel test data with the numerical simulation results, the designer can correct the model parameters to ensure the accuracy of the simulation results. Tian De *et al.* [12] found different characteristics of impellers with constant cross-section and variable cross-section through wind tunnel tests.

4.2. Shaking Table Test Research

Shaking table test is a method to test the dynamic performance of the structure

by simulating the external vibration environment such as earthquake. Through the shaking table test, the dynamic characteristics, seismic performance, collapse failure mechanism and possible weak links of the wind power structure can be understood, which provides a basis for structural design and optimization. It is also an important means to verify the accuracy of seismic theory and numerical simulation of wind power tower.

Xu Yazhou *et al.* [13] studied the response characteristics of wind turbine tower model structure under random earthquake through shaking table test. Shen Minyu *et al.* [14] carried out a series of tests on the tripod structure model of offshore wind power tower by using the shaking table, and studied the dynamic characteristics of the model structure. Based on the p-y pile-soil calculation model, Song Bo *et al.* [15] compared and analyzed the numerical simulation results and experimental results, and verified the correctness of the model and numerical simulation method.

5. Vibration Control Technology of Wind Power Structure

5.1. Improvement of Vibration Reduction Technology of Wind Power Structure

The vibration reduction technology of wind power structure has also received extensive attention and research in recent years. In addition to improving the overall anti-vibration performance of wind power structures through reasonable design and construction, optimizing the selection and use of structural materials is also an important improvement method. Choosing high strength and good durability materials, such as high performance concrete, high strength steel, etc., can effectively improve the vibration resistance of the structure and reduce the deformation and damage of the structure.

In addition, the vibration control method is also a commonly used vibration reduction method. Structural vibration control refers to the technology of passively or actively applying control force to the structure or adjusting the dynamic characteristics of the structure by setting some kind of isolation device, some kind of energy dissipation mechanism or some kind of substructure in a specific part of the engineering structure, so as to reduce or suppress the dynamic response of the structure caused by dynamic load, without special enhancement of the structure itself [16]. The vibration control of wind power structure has been deeply studied at home and abroad, and it has been applied and paid more and more attention in practical engineering.

5.2. Research Status of Wind Power Structure Vibration Control

In engineering practice, it is very important to understand and master the basic theory of structural vibration for the design of stable and safe structures. The generation of structural vibration is closely related to external excitation. External excitation can be from earthquake, wind load, mechanical vibration and other factors, these factors in the role of the structure will cause the response of

the structure vibration. The control of structural vibration is to reduce or eliminate the negative effects of structural vibration, so as to improve its performance and service life. Common vibration control methods include passive control, active control and semi-active control.

5.2.1. Research Status of Passive Control of Wind Power Structure

Passive control is widely used in wind power structures in practical engineering. Passive control consumes vibration energy and reduces the vibration response of the structure by increasing damping, adjusting mass distribution and stiffness. Common methods include the use of shock absorbers, isolators and damping materials. The advantages of passive control are simple system, low cost, convenient maintenance, stable performance, high reliability and no external energy supply. However, its control effect is limited by the changes of system parameters and external environment, and it is impossible to adjust the complex vibration in real time.

Tuned mass damper (TMD) is currently the most widely used device in vibration control of wind power structures. In recent years, many scholars have proposed a variety of passive vibration reduction technologies and devices for wind power structures. The research results are as follows: Liu Gang *et al.* [17] proposed a new type of passive prestressed tuned mass damping device (PS-TMD). Through theoretical analysis and finite element simulation, it is concluded that compared with the traditional TMD under the same conditions, PS-TMD can more effectively suppress the resonance of the tower structure. Zhu Dazhuang *et al.* [18] proposed a frequency modulation damping device-rotary tuned inertial mass damper (RITMD). The results show that the damper has a good effect in suppressing the wind-induced vibration response of the wind power tower. Taking a 2 MW wind turbine tower as an example, Su Yi *et al.* [19] proposed a fixed mass damper (FMD), and analyzed the dynamic response of fluid-solid coupling under wind load. The results show that it has obvious control effect on the dynamic response of the tower in the height direction.

It is not difficult to see that the passive vibration reduction technology and device proposed by most scholars are mainly to improve the problems of limited internal space of the tower and difficult installation of the control device when the traditional TMD structure is applied to the wind power tower. Due to the limitation of space, the swing or vibration displacement amplitude of the traditional TMD structure is limited, and the vibration reduction effect is greatly restricted. Therefore, it is necessary to carry out deeper research on passive energy dissipation devices.

5.2.2. Research Status of Active Control of Wind Power Structure

Active control is to realize real-time monitoring and adjustment of vibration through external energy input. The active control system includes a sensor, a controller and an actuator. The vibration signal is collected in real time by the sensor. The controller processes the signal according to the preset algorithm and

outputs the control command. The actuator exerts a reaction force according to the control command to suppress the vibration. Active control can accurately adjust the system parameters, has strong adaptability, and can effectively control complex vibration problems. However, the active control system is complex, costly, and requires external energy support, and its reliability and stability are susceptible to environmental and system failures.

Yongoon *et al.* [20] proposed a new control algorithm for floating offshore wind turbines. Through modeling and simulation, it is concluded that the control algorithm improves the output performance and reduces the tower load at different wind speeds above the rated wind speed. Mahmudur *et al.* [21] used ant colony optimization (ACO) to optimize the parameters of PID controller to study its effectiveness in reducing the vibration of wind power tower. The experimental results show that the optimized active vibration controller is superior to the traditional method in terms of vibration reduction rate, frequency change adaptability and calculation time. Bai Jiulin *et al.* [22] studied the control of the forward and backward acceleration response of the wind power tower based on the active mass damper (AMD) based on the linear quadratic regulator (LQR) algorithm. The results show that the AMD based on the LQR control algorithm can better suppress the forward and backward acceleration response of the tower top, and its control performance is significantly improved compared with TMD.

Compared with passive control vibration reduction, active control vibration reduction is less studied in wind power structure, but active control is superior in essence. With the development of science and the maturity of technology, this technology has a wide application prospect in wind power structure vibration resistance.

5.2.3. Research Status of Semi-Active Control of Wind Power Structure

Semi-active control is between passive control and active control, which changes the vibration characteristics by adjusting the system parameters without directly inputting external energy. The commonly used methods of semi-active control include magnetorheological dampers and variable stiffness devices. The magnetorheological damper changes the physical properties of the damping material through the magnetic field, thereby achieving semi-active control of vibration. The variable stiffness device changes the vibration characteristics of the system by adjusting the structural stiffness. Semi-active control dampers can be widely used in building structures, bridges, high-rise buildings, seismic response analysis and other fields. Compared with passive control, semi-active control has higher adaptability and flexibility, but there is still a certain gap between its control effect and active control.

Mroz *et al.* [23] studied and introduced a new type of connection between the cone and the tower, which was optimized by semi-active control of the connection parameters. Through numerical research, the effectiveness of the new method was preliminarily estimated. Caterino *et al.* [24] used magnetorheologi-

cal (MR) dampers to semi-actively control the wind-induced vibration of wind turbine tower model. The results show that even in the worst case, the proposed control technique is effective in reducing the stress demand on the foundation. Lian Jijian *et al.* [25] studied a new type of eddy current-tuned mass damper (EC-TMD) and applied it to the actual engineering simulation of the structure. The results show that the EC-TMD damping effect is obvious under extreme wind load.

With the rapid development of wind turbines in the direction of high power, the length of blades and the height of hubs have also increased significantly, and the influence of vibration load on them cannot be ignored. Based on this, there is still a lot of room for development in the research of wind power structure vibration reduction technology. Further research is needed in the future.

6. Conclusions and Prospects

As an important part of wind energy utilization, the research on wind resistance and seismic performance and vibration control technology of wind power tower is very important to improve the safety and reliability of wind power generation system. Through the review of the existing research, it can be found that the performance of wind power tower under different loads and its improvement methods have made remarkable progress. However, the wind power structure has unique structural characteristics, and it still needs to be further studied in combination with these characteristics.

1) In the aspect of wind resistance design, the characteristics of wind load are complex and changeable, which has a significant impact on the fatigue and damage accumulation of the structure. However, the current wind field simulation technology cannot fully and accurately simulate the wind field characteristics under complex terrain and climatic conditions, which leads to a certain error in the evaluation of wind resistance performance of wind power structures in real environments.

2) For the study of the seismic performance of wind power structures, the propagation mechanism of seismic waves still needs to be deeply understood. In addition, most of the existing studies only consider the situation of earthquake or wind alone, but in practice, the two often exist at the same time and interact, which has a complex coupling effect on the wind power structure, and there are relatively few studies in this regard.

3) Structural vibration control technology will develop in the direction of intelligence and integration. The traditional vibration control method is mostly passive control. Although it is simple and reliable, the adjustment ability is limited. In the future, active control and semi-active control technology will be widely used.

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Dai, K.S., Wang, Y., Huang, Y.C., *et al.* (2015) Research on Wind and Earthquake Resistance, Health Monitoring and Vibration Control of Wind Power Generation Tower Structure. *Special Structures*, **32**, 91-100. (In Chinese)
- [2] He, G.L. (2011) Wind-Induced Dynamic Response Analysis of Reinforced Concrete Wind Turbine Tower. *Wind Energy*, No. 5, 48-52. (In Chinese)
- [3] Cheng, Y.L., Qu, J.M. and Li, S.L. (2017) Analysis of Wind-Induced Response Characteristics of Offshore Wind Power Tower Based on Two-Way Fluid-Solid Coupling. *Renewable Energy*, **35**, 1835-1840. (In Chinese)
- [4] Ke, S.T., Wang, T.G., Cao, J.F., *et al.* (2015) Wind-Induced Response Analysis of Large-Scale Wind Power Structures Considering Soil-Structure Interaction. *Journal of Civil Engineering*, **48**, 18-25. <https://doi.org/10.15951/j.tmgcxb.2015.02.005>
- [5] Li, W.R., Fan, K.Y. and Du, Y.F. (2023) Wind-Seismic Coupling Response Analysis of Wind Turbine Tower Structure Considering Blade Rotation Effect. *Engineering Mechanics*, **40**, 193-204+256. (In Chinese)
- [6] Lavassas, I., Nikolaidis, G., Zervas, P., Efthimiou, E., Doudoumis, I.N. and Baniotopoulos, C.C. (2003) Analysis and Design of the Prototype of a Steel 1-MW Wind Turbine Tower. *Engineering Structures*, **25**, 1097-1106. [https://doi.org/10.1016/s0141-0296\(03\)00059-2](https://doi.org/10.1016/s0141-0296(03)00059-2)
- [7] Taddei, F. and Meskouris, K. (2013) Seismic Analysis of Onshore Wind Turbine Including Soil-Structure Interaction Effects. In: Klinkel, S., Butenweg, C., Lin, G. and Holtschoppen, B., Eds., *Seismic Design of Industrial Facilities*, Springer Fachmedien Wiesbaden, 511-522. https://doi.org/10.1007/978-3-658-02810-7_43
- [8] Alati, N., Failla, G. and Arena, F. (2015) Seismic Analysis of Offshore Wind Turbines on Bottom-Fixed Support Structures. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, **373**, Article ID: 20140086. <https://doi.org/10.1098/rsta.2014.0086>
- [9] Dai, K.S., Yi, L.D., Liu, Y., *et al.* (2015) Performance-Based Seismic Analysis of a Wind Turbine Tower. *Structural Engineer*, **31**, 96-102. (In Chinese)
- [10] Song, B. and Zeng, J. (2013) Nonlinear Seismic DYNAMIC response Law and Limit Value Evaluation of Wind Power Tower. *Journal of Beijing University of Science and Technology*, **35**, 1382-1389. (In Chinese)
- [11] Li, D.Y., Hu, J.Y., Zhang, Y.K., *et al.* (2023) Analysis of Seismic Response Characteristics of Hollow Cone Foundation of Land Wind Power. *Journal of Shandong University of Science and Technology (Natural Science Edition)*, **42**, 57-68. (In Chinese)
- [12] Tian, D., Diao, M.G. and Wang, H.K. (2007) Wind Tunnel Experimental Study on Three-Blade and Four-Blade Impellers of Concentrated Wind Turbine. *Journal of Solar Energy*, No. 1, 74-80. (In Chinese)
- [13] Xu, Y.Z., Yu, M.Y., Ren, Q.Q., *et al.* (2021) Shaking Table Test of Wind Turbine Tower Structure under Random Near-Field Earthquake. *Vibration and Shock*, **40**, 309-316. (In Chinese)
- [14] Shen, M.Y., Zhu, L., Jia, J.B., *et al.* (2022) Shaking Table Test Study on Structural Model of Offshore Wind Tower. *Engineering Mechanics*, **39**, 85-95. (In Chinese)
- [15] Song, B., Huang, F.T. and Zeng, J. (2015) Damage Characteristics and Shaking Table Test of Wind Turbine Tower under Strong Earthquake. *Earthquake Engineering and Engineering Vibration*, **35**, 137-143. (In Chinese) <https://doi.org/10.13197/j.eeev.2015.05.137.songb.021>

- [16] Xu, Y.H., Li, A.Q., Xuan, P., *et al.* (2017) Semi-Active Control and Installation and Commissioning Technology of High-Rise Structures. *Industrial Buildings*, **47**, 131-134+150. (In Chinese)
- [17] Liu, G., Lei, Z.B., Yang, W., *et al.* (2021) Mechanism Analysis and Parameter Tuning Optimization of PS-TMD Passive Control Device for wind Turbine Tower. *Engineering Mechanics*, **38**, 137-146. (In Chinese)
- [18] Zhu, D.Z. and Xiong, S.S. (2021) Research on Vibration Reduction of Wind Power Tower by Rotating Inertia Tuned Mass Damper. *Engineering Construction and Design*, No. 23, 31-33+36. (In Chinese)
- [19] Su, Y., Ren, S.K. and Shi, H. (2021) Research on Wind-Induced Vibration Control of Wind Turbine Tower with Fixed Mass Damper. *Special Structures*, **38**, 47-51. (In Chinese)
- [20] Oh, Y., Kim, K., Kim, H. and Paek, I. (2015) Control Algorithm of a Floating Wind Turbine for Reduction of Tower Loads and Power Fluctuation. *International Journal of Precision Engineering and Manufacturing*, **16**, 2041-2048. <https://doi.org/10.1007/s12541-015-0265-0>
- [21] Rahman, M., Ong, Z.C., Chong, W.T., Julai, S. and Ng, X.W. (2018) Wind Turbine Tower Modeling and Vibration Control under Different Types of Loads Using Ant Colony Optimized PID Controller. *Arabian Journal for Science and Engineering*, **44**, 707-720. <https://doi.org/10.1007/s13369-018-3190-6>
- [22] Bai, J.L., Li, C.H. and Wang, Y.H. (2023) Vibration Control of Active Mass Damper for Offshore Wind Turbine Structures Considering RNA Operation. *Vibration and Impact*, **42**, 183-191. (In Chinese)
- [23] Mróz, A., Holnicki-Szulc, J. and Kärnä, T. (2008) Mitigation of Ice Loading on Off-Shore Wind Turbines: Feasibility Study of a Semi-Active Solution. *Computers & Structures*, **86**, 217-226. <https://doi.org/10.1016/j.compstruc.2007.01.039>
- [24] Caterino, N. (2015) Semi-Active Control of a Wind Turbine via Magnetorheological Dampers. *Journal of Sound and Vibration*, **345**, 1-17. <https://doi.org/10.1016/j.jsv.2015.01.022>
- [25] Lian, J.J., Zhao, Y., Lian, C., *et al.* (2019) Research on Vibration Reduction of Off-shore Wind Turbine Bucket Foundation Structure Based on Eddy Current-Tuned Mass Damper. *Vibration and Shock*, **38**, 20-25. (In Chinese)