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Structural Design and Research of Offshore Wind Turbine Towers

Guorong Yan

Yunda Energy Technology Group Co., LTD., Hangzhou, Zhejiang 310012

Abstract: The structural design and research of offshore wind turbine tower need to involve knowledge and technology in many fields, such as mechanical engineering, material science, fluid mechanics and so on. Through the research and optimization of tower structure, it can promote the development of related industries and improve the technical level and competitiveness of the whole industrial chain. The structural design and research of offshore wind turbine tower has important practical significance and application value. Through in-depth research and optimization of design, the performance and reliability of offshore wind turbines can be improved, and the rapid development of offshore wind power technology can be promoted.

Keywords: Offshore; Wind turbine; Group tower; Structural design

1. Preface

With the rapid development of the global economy, energy demand continues to grow. At the same time, the need for environmental protection and reduction of carbon emissions is becoming increasingly urgent. Wind energy, as a clean and renewable energy source, has great potential for development. Compared with onshore wind power, offshore wind power has the advantages of higher wind speed, more stability and less influence by terrain. In addition, offshore wind power can avoid occupying land resources and reduce damage to the environment. Therefore, the development of offshore wind power technology has become the priority choice of many countries and regions. With the development of material science, structural mechanics, computer science and other fields, the structural design of offshore wind turbine towers has also made significant progress. The application of new materials, the improvement of structural optimization methods and the introduction of digital design technology have all provided strong support for the design of offshore wind turbine towers.

However, the design of offshore wind turbine towers faces many challenges. The offshore environment is complex and variable, including the influence of waves, tides, currents and other factors, which requires the tower structure to have sufficient strength and stability. The height and weight of the tower are large, which requires consideration of material selection and structure optimization. In addition, the high installation and maintenance costs of offshore wind turbines also require the tower structure to have good transportability and maintainability.

2. Structural design of offshore wind turbine towers

The special characteristics of the offshore environment, such as strong winds, waves, currents and marine corrosion and other factors, put forward higher requirements for the structural design of the tower. Therefore, these factors need to be fully considered in the design process to ensure the safety and stability of the tower. The choice of materials for the tower is crucial. Considering the corrosiveness of the marine environment, high-strength steel with good corrosion resistance is usually selected. In addition, the fatigue performance, welding performance and impact resistance of the material are also factors to be considered. The structural design of the tower needs to meet the mechanical requirements, including withstanding wind loads, wave loads and the weight of the unit itself. Designers need to use finite element analysis and other engineering software to carry out detailed mechanical analysis of the tower to ensure its safety and stability under various working conditions.

In addition, the design of the tower also needs to consider the convenience of construction and maintenance. Offshore construction conditions are complex, so the design of the tower should simplify the construction process as much as possible to reduce construction costs. At the same time, in order to facilitate future maintenance and overhaul, the design of the tower should provide sufficient space and access.

The structural design process of offshore wind turbine towers is a complex and multi-step process involving knowledge and technology from several specialized fields.

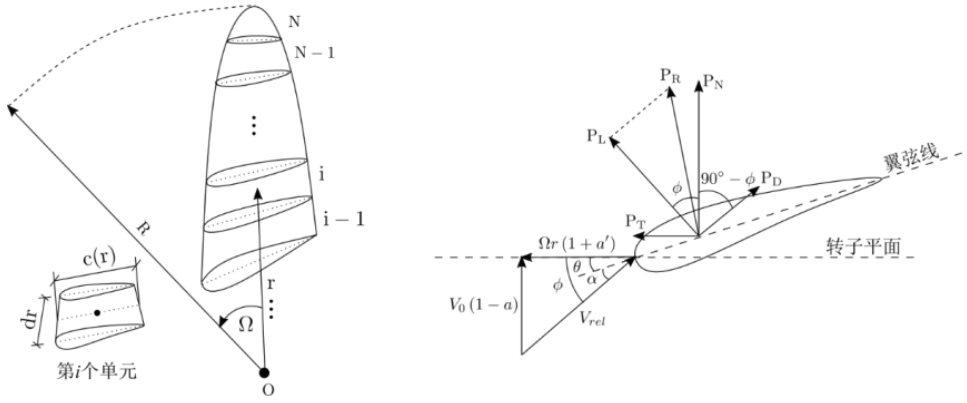

Figure 1. Leaves and units

First, determine the geographic location and environmental conditions of the project (e.g., wind speed, currents, water depth, soil conditions, etc.). Determine the technical specifications and performance requirements of the wind turbine (e.g., rated power, hub height, annual power generation, etc.), so as to set the objectives of the tower design, such as safety, economy, environmental impact, and maintainability.

Second, load analysis of offshore wind turbines is performed, including wind load, wave load, current load, and seismic load. Extreme weather conditions and design baseline events are considered to ensure that the tower can operate safely and stably in all environments.

Third, the preliminary design of the tower is carried out based on the results of the load analysis. The design should include the height, diameter, wall thickness, and material selection of the tower. The preliminary design should consider the overall stability of the tower, vibration characteristics, fatigue life and other factors.

Fourth, on the basis of the preliminary design, the detailed design of the tower. Detailed design should include the node design of the tower, connection mode, anti-corrosion treatment, foundation design and so on. The detailed design should consider the special requirements of the manufacturing process, transportation and installation process.

Fifth, use finite element analysis software to conduct detailed structural analysis of the tower to verify the reasonableness and reliability of the design. Analyze the possible problems of stress concentration, vibration mode, fatigue life, etc., and propose improvement measures.

Sixth, according to the finite element analysis results, the tower design is optimized to improve its performance and economy. The optimized design may involve a number of aspects such as material selection, cross-section size, and connection methods.

Seventh, a detailed manufacturing and installation plan is developed to ensure that the manufacturing and installation process of the tower meets the design requirements. The quality of the manufacturing and installation process is strictly controlled to ensure the quality and performance of the final product.

Eighth, conduct rigorous testing and acceptance of the completed manufacturing tower to ensure that its performance meets the design requirements. Testing and acceptance may include static load test, dynamic load test, fatigue test and many other aspects.

Ninth, formulate a detailed maintenance and monitoring program to ensure the safety and stability of the tower during operation. Conduct regular inspections and monitoring of the tower to identify and address potential problems in a timely manner.

Until 2019, the world's largest single offshore wind turbine capacity has reached a staggering 12MW, and its impeller diameter has even reached 220 meters. It is predicted that by 2030, the single capacity of offshore wind turbines will reach 15MW, and their impeller diameter will further increase to 230-250 meters. It can be seen that the future of offshore wind turbines will continue to develop in the direction of a larger scale.

3. Exploration

In order to effectively draw energy from the wind, wind turbines must be able to withstand strong wind loads. Since atmospheric turbulence structures have dimensions comparable to or even smaller than the rotor plane of a large wind turbine, their effects cannot be ignored. Kelley et al. noted that when turbulence structures are smaller than the rotor, they can cause more severe damage than when turbulence structures are larger than the rotor plane. This may be due to the fact that a smaller turbulent structure can cause different blades of a large turbine to be subjected to different wind conditions, which can lead to severe fatigue and extreme loading problems, further exacerbating the damage to the turbine structure. Currently, many turbine accidents show that the blade root and tower foundation joints are the high incidence areas of damage. However, relatively few studies have been conducted on wind load-induced fatigue damage to turbine structures. In addition, the non-Gaussian nature of wind speed can significantly affect large wind turbines. Shuang Miao and Song Bo analyzed the fatigue of wind tur-

bines under different probabilistic characteristics of wind fields (e.g., Gaussian, non-Gaussian hardening and softening), and found that the crack expansion is more sensitive to the non-Gaussian nature of wind loads.

Compared with onshore wind power, offshore wind power is in a more severe marine environment, facing multiple challenges such as strong winds, huge waves and storm surges, so its technical requirements are also more complex. The steel structure of offshore wind turbines is prone to corrosion under the erosion of the ocean, and key components such as bearings and yawing systems are also more susceptible to damage. At the same time, due to the instability of the offshore environment, wind turbines need to withstand greater external loads than onshore wind turbines. This external load will not only increase the vibration of the wind turbine, but may also exacerbate the fatigue damage of the weak links of its structure, such as corrosion and connection parts, which in turn reduces the reliability of the whole structure.

In recent years, the research on offshore wind turbine towers has achieved remarkable results among scholars at home and abroad. In this field, both the selection of materials and the optimization of structural design have made great progress. The application of high-strength steel and composite materials makes the bearing capacity of the tower significantly improved, and at the same time, its durability is also well guaranteed. In terms of structural design, the overall performance of the tower has been effectively improved through the optimization of the cross-section shape, the increase of reinforcement and many other ways.

The application of numerical simulation and simulation analysis in tower design provides strong technical support for the optimization of tower design. However, compared with onshore wind power, offshore wind power faces more severe challenges. Due to the special characteristics of the marine environment, offshore wind turbines need to cope with multiple challenges such as strong winds, huge waves and storm surges, which makes their technical requirements more complex. Under the erosion of the marine environment, the steel structure of offshore wind turbines is prone to corrosion, and its bearings, yawing systems and other key components are also more likely to be damaged. At the same time, due to the instability of the offshore environment, wind turbines need to withstand greater external loads than onshore turbines. On the one hand, through the optimization of material and structural design, the corrosion resistance and bearing capacity of the tower are improved; on the other hand, using computer technology, numerical simulation and simulation analysis provide technical support for the optimal design of the tower. In addition, for the external load problem of offshore wind power, researchers are also exploring new coping strategies to reduce the impact of external load on the wind turbine structure. In China, offshore wind power is rich in resources, but its development and utilization face many technical difficulties. It is believed that in the near future, with the progress of science and technology, China's offshore wind power technology will certainly make greater breakthroughs, and make greater contributions to the transformation of China's energy structure and green low-carbon development.

4. Summary

With the growing global demand for renewable energy, offshore wind power generation has become a high-profile field. As the core part of offshore wind power generation system, the structural design of tower is directly related to the stability and economy of the whole wind power system. The purpose of this paper is to conduct an in-depth study on the structural design of offshore wind turbine towers, summarize the existing technology, and look forward to the future development trend.

At present, offshore wind turbine towers mainly adopt steel tube tower or truss structure. Steel pipe towers are widely used in large-scale offshore wind power projects due to their excellent bending resistance and high load carrying capacity. The truss structure, on the other hand, has a lighter deadweight and good wind resistance, and is suitable for some special environmental conditions.

In the future, the structural design of offshore wind turbine towers will pay more attention to environmental protection, economy and sustainability. On the one hand, with the continuous emergence of new materials and new technologies, the material and structural design of the tower will be more diversified and efficient. On the other hand, as the scale of offshore wind farms continues to expand and offshore wind power technology advances, the design of the tower will pay more attention to the harmonization with the surrounding environment and aesthetics. At the same time, with the increasingly serious global climate change and environmental problems, the design of offshore wind turbine towers also needs to consider more environmental factors and ecological impacts in order to realize the sustainable development of the wind power industry.

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About the author: Guorong Yan(1988.01-), Male, Han nationality, Shaoxing, Zhejiang, Bachelor degree, Intermediate engineer, Research direction: Wind Power Generation, Tower Room, Mainly responsible for the tower part of offshore wind power generation, the current research direction is floating fan tower