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Motion response analysis of floating foundation of offshore wind turbines

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Abstract: Offshore wind turbines are mainly installed on the offshore floating Foundation, the stability of floating foundation greatly affects the operation effect of wind turbines and the safe operation of power generation equipment. This paper combines the characteristics of large ships and third-generation Spar platforms, conceptually designed a type II Spar-type offshore wind turbine floating foundation. Based on the theory of potential flow and the linear micro-amplitude wave theory of wave force in large scale component, the dynamic response of the floating wind power generation system under the coupling of wind and waves is analyzed by using the finite element software to analyze and simulate the wave excitation force on the floating Foundation. The results show that the floating foundation has good stability under the coupling of wind and waves.

1. Introduction

The early development of wind power was mainly concentrated on land. With the saturation of wind power on land, the destruction of the surrounding ecological environment and the impact of noise and radiation on local residents, the wind turbines on land were gradually developed to the sea. As the world's energy demand has grown, more and more stationary wind turbine foundations have been installed in shallow waters. At the same time, there are a large number of conceptual designs for floating foundations for deep seas and offshore. The floating foundation of offshore wind turbines is roughly divided into three types: Spar type, tension leg type, half dive type, and other novel floating infrastructure.

In 1996, Garrad Hassan and others in the United States conducted preliminary research and evaluation on the Spar platform carrying a single turbine. The research scope involved the selection of wind turbines and the mooring force method\textsuperscript{[1];} In 2007, MIT experts in the United States studied the hydrodynamics-aerodynamics coupling analysis in depth\textsuperscript{[2];} Since 2017, some research institutes in China have carried out in-depth study on the offshore Floating Foundation, based on the design of a 600 MW submersible floating foundation, considering the coupling action of fan and mooring system, this paper analyzes the floating foundation of the target working environment in 60 m depth, and considers the fluctuating wind and the function of constant flow and random wave; Tang Yougang et al.\textsuperscript{[3]} proposed a semi-submersible floating foundation suitable for 5 MW offshore wind turbines, and analyzed the stability, motion and mooring tension of the floating foundation.

Experts and scholars from all over the world have made a deep analysis and research on floating
foundation including fan in different aspects, which has made great contribution to the development and progress of offshore wind power generation. However, they did not consider the aerodynamic load of blade elasticity and column elasticity calculation\cite{4}, nor did the wind-wave coupled motion response analysis of the floating Foundation.

This paper uses Ansys finite element software to simulate the motion response of the floating foundation, analyzes the motion response of the floating foundation under the action of wind waves, and provides suggestions for the stability of the floating foundation.

2. Storm load
Due to the particularity of the marine environment in which the floating foundation is located, the load on the floating foundation of offshore wind turbines will be more complicated. In this paper, the motion response of the floating foundation is studied. The blades, struts, mechanical switching devices and towers in the wind turbine system are taken as the whole. The wind load and wave load are calculated and numerically simulated under the blade stop state.

2.1. Wind load
Since the Spar floating foundation floats in the sea, it often encounters pulsating winds, which are short-lived parts of the wind. The cycle is often only a few seconds to tens of seconds, which is close to the period of the building structure. Its force is a dynamic property and belongs to a random dynamic load\cite{5}. By analyzing the force of the Spar floating foundation under the pulsating wind, the structural stability of the Spar floating foundation can be better grasped.

| Height (m) | 10  | 20  | 30  | 40  | 50  | 60  | 70  | 80  | 90  | 98.25 |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-------|
| Level 5 wind speed (m/s) | 9.35 | 10.16 | 10.67 | 11.04 | 11.34 | 11.59 | 11.80 | 12.00 | 12.17 | 12.30 |

In this paper, the Spar floating foundation is divided into ten parts, and the wind speed corresponding to the different heights of the Spar floating foundation at the 5th level under typical sea conditions is obtained. According to the calculation formula of the wind pressure, the wind speed of each section can be obtained, as shown in Table 1. Select the pulsating wind pressure time history curve at \(10m, 50m, 98.25m\) of the first section, the middle section and the tail end to obtain the wind load as shown in Figure 1.

![Figure 1. The time curve of fluctuating wind pressure.](image)

2.2. Wave load
It is feasible to calculate the structure by the equivalent regular wave, that is, the concept that the wave height is equal to the design wave height. Since the offshore wind turbine Spar type floating foundation platform is composed of a cylinder, the wave excitation force is calculated for the Spar platform cylinder. The axial integration of the floating foundation, from the bottom of the floating foundation (ballast tank) to the sea level, obtains the pendulum excitation force acting on all floating foundation towers as Figure 2.

From the bottom of the platform to the static surface of the main axis integral to obtain the role of the platform at the center of gravity excitation moment, the longitudinal moment can be expressed as Figure 3.

The vertical diffraction force acting on the vertically truncated cylinder can be obtained by multiplying a diffraction coefficient with the Froude-krylov force, so the wave excitation force acting on the Spar Floating foundation body can be expressed as\cite{6} Figure 4.
3. **Finite element model**

This paper combines the characteristics of large ships and third-generation Spar platforms, conceptually designed a type II Spar-type offshore wind turbine floating foundation platform. The Spar-type floating foundation consists of a pontoon, a heave plate, a column, and a soft The cabin is composed of four parts, as shown in Figure 5.

![Figure 5. 5MW Offshore wind power Spar platform.](image)

Because the Spar floating foundation is only an ideal conceptual design, the structure of the floating infrastructure platform has not been specifically designed. The floating foundation platform uses ordinary steel as the main raw material. In order to lower the center of gravity of the entire platform model, the upper pontoon and the lower soft cabin are filled with concrete. The specific parameters of the floating base platform are shown in Table 2a and Table 2b.

| Project                              | Numerical value | Project                              | Numerical value |
|--------------------------------------|-----------------|--------------------------------------|-----------------|
| Buoyancy chamber diameter/ $m$       | 17.5            | Height of center of gravity/ $m$     | 43.08           |
| Mechanical cabin diameter/ $m$       | 28              | Floating height/ $m$                 | 56.3            |
| Side length of the hanging plate/ $m$| 12              | Platform weight/ kg                  | $7.343 \times 10^7$ |
| Height of hanging plate/ $m$         | 0.4             | Moment of inertia of a longitudinal wave/ $kg \cdot m^2$ | $3.356 \times 10^{10}$ |
| Ballast tank length/ $m$             | 12              | Moment of inertia of rolling/ $kg \cdot m^2$ | $3.356 \times 10^{10}$ |

| Project                              | Numerical value | Project                              | Numerical |
|--------------------------------------|-----------------|--------------------------------------|-----------|
| Mechanical Cabin Height/ $m$         | 10              | Power/ $MW$                          | 5         |
| Truss height/ $m$                    | 6.7             | Rated speed/ $r \cdot \text{min}^{-1}$| 12        |
The structure of the new floating foundation has the advantages of reducing the potential of wave force, having constant stability and low construction difficulty, and provides a new type of structure for the floating foundation design of offshore wind power spar.

4. Simulation Analysis of Floating Foundation

Offshore wind power II type Spar platform based on the classic Spar floating platform, through the improved blade, swing plate and buoyancy cabin. The II type Spar Floating foundation positioning device adopts the catenary mooring line, the anchor chain is connected to the bottom of the upper mechanical cabin, the lower part of the anchor chain is fixed with the seabed, the anchor chain adopts three symmetrical array distribution connection, and the horizontal angle between the adjacent chain chains is 120°.

Under the mooring action, the floating Foundation can be well fixed, the floating foundation can automatically adjust to the initial state with the change of wind and wave load, the floating foundation in the transverse direction does not need longer work to block the wave, thus increasing the lateral stability of the floating foundation, and due to the decrease of the force area, The wave force of the floating Foundation is greatly reduced, and the mooring forces of the anchor chain are effectively buffered, which is helpful to increase the service life of mooring.

4.1. Response of dynamic characteristics under the coupling excitation of disturbance

According to the relevant literature[8] and combined with the floating foundation of this paper, in order to facilitate the time domain analysis of floating foundation, the floating foundation structure is divided into 10 sections, taking 10 segments of floating foundation, according to the structural characteristics of floating foundation, the mesh is divided, and the finite element model is shown in Figure 6. In this paper, we will analyze the situation of rolling, vertical, longitudinal response, wind pressure and vertical force under the influence of wave force on the floating foundation of 5 class wind-4 wave typical sea state, and analyze the motion response, and get the force load and constraint model of Figure 7.

| Ballast tank height/m | 4 | Rated wind speed/m·s⁻¹ | 15 |
|-----------------------|---|------------------------|----|
| Tower column Diameter/m | 5 | Blade string length/m | 3.5 |
| Inner diameter of tower column/m | 4 | Leaf blade airfoil | NCA0018 |
| Strut diameter/m | 1 | Blade length/m | 78.75 |
| Inside diameter of strut/m | 0.6 |

The structure of the new floating foundation has the advantages of reducing the potential of wave force, having constant stability and low construction difficulty, and provides a new type of structure for the floating foundation design of offshore wind power spar.

![Figure 6. Ansys simulation model.](image1)

According to the parameters of typical sea conditions, the paper analyses the maximum and maximum offset of the 5-stage wind-4 wave. After solving, the offset cloud image of the floating base, the offset cloud of the mechanical cabin at the horizontal plane, the migration time curve, the offset curve, and the mechanical cabin offset curves at the horizontal plane are extracted, as shown in Figures 8 and 9.
In Level 5 wind-4 waves, the maximum offset at the top of the floating Foundation is 8.388m, the maximum deviation from the equilibrium position is 5.458°, and the floating Foundation is offset to 4.127m at the top and bottom of the wind-wave coupling, and the maximum offset displacement of the floating Foundation is 8.0912m in the mechanical cabin on the sea level.

5. Conclusion

In this paper, the concept design and basic parameters of floating foundation of offshore wind turbines are described, and the dynamic response characteristics of the floating foundation of offshore wind turbines with a depth of 300 meters are analyzed by means of time domain coupling analysis method, which provides some reference value for the design of floating Foundation. Draw the following conclusions:

1) Floating Foundation in the 5-stage wind-4 wave coupled sea conditions, the top off the equilibrium position maximum displacement (Peaks in the x-direction are basically around 30s.)

2) Floating Foundation in the wind-wave coupling of the top in (z-direction) amplitude offset is 4.127m, the top away from the equilibrium position maximum deflection 5.458°, at the same time sea level at the mechanical cabin offset maximum of 8.0912m, peak in the vicinity of 28s, with good convergence;

3) For the floating foundation in the operating sea, the combination of wind and waves, the vertical-longitudinal motion response is very significant to meet the requirements of the response criterion;

In short, the offshore wind turbine floating foundation is one of the most important forms of deep-sea energy development, but also for the main carrier of new energy wind turbines, reasonable
floating foundation design, can effectively increase the stability of the platform, as well as the service life.

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