Research on foundation response of a tri-floater offshore wind turbine

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Abstract. Platform structure is the basic guarantee for safety operation of offshore wind turbines. Based on the boundary element method and combined with multi-body dynamics, we analyzed motion response and wave force mechanism to the platform structure, and obtained the dynamic response and the wave force change of the platform structures in time domain. We also analyzed the motion response and wave force change of semi-submerged platform in surge, sway and heave also roll, pitch and yaw direction. The results show that in translational direction, the motion response is periodic variation under three different incident direction; in the translational direction response appear a periodic attenuation change, and in the direction of rotation, motion response mainly concentrated in the 0s to 50s; in time domain, 90° of incidence, platform force is largest, wave force are mainly concentrated in the 0s to 50s. The result is high reference value on offshore tension leg platform structural design and optimization.

1. Introduction

From land to offshore has become a main trend in the development of wind power, and offshore wind turbine research gradually become a key and hot research field in wind power[1-2]. Compared with onshore wind, offshore wind has the advantage of large wind energy resources, developing high efficiency and little environmental pollution etc. Offshore wind do not take up land, little conditioned by the environment, and average wind speed is high, offshore from the 10 Km , wind speed is higher than onshore about 25%[3]. In addition, our country has a long coastline, and rich offshore wind resources .Also power load mostly concentrated in eastern coastal areas, so offshore wind power has a broad development prospects[4].

Overseas study on floating wind turbine have obtained certain achievement, for example, in 1991, Britain conducted a floating wind turbine project and developed a Spar floating wind turbine FLOAT[5]. In 1998, the University College London of Halfpenny [6] began to focus on the point of hydrodynamics to study floating wind turbine, referring to the methods of frequency domain analysis of ocean engineering ,focus on shallow sea and floating wind turbine hydrodynamics characteristics . Withee [7], first of all, based on the algorithm of hydrodynamics and aerodynamics for calculating the dynamic responses of the structures, and calculated three different sea state conditions platform RAO of six degrees of freedom. Jonkman and Buhl(2007) [8]summarized the couple method of dynamic analysis of marine floating foundation wind power system, and proposed fully-coupled simulation method .Respective limitation of time domain was overcome ,and all possible load can affect the
system are considered with this method, and model test proved the reliability of the method. 2006. Zambrano [9] obtained dynamic response of platform by the Runge-Kutta method on the spectrums of six degrees of freedom, concluded the mooring tension of the mooring system in different wind load Tomoaki et al. (2009) [10] examined a 1/22.5 scale SPAR-type floating offshore wind turbine model subjected to regular and irregular wave loadings. The experimental results are compared with the numerical simulation results for validation of the simulation method. The RAOs are basically in good agreement between the experiment and the numerical simulations.

At present, most analysis model of floating turbine are in traditional semi-submersible type, and this paper focuses on the design of offshore wind turbines in 200m water depth, it is still in adequate to study work in this field. Considering the coupled effects between floating foundation and mooring lines, the paper focuses on the key factors, such as aerodynamic thrust of blade, wind, wave and current loads and couple effects.

2. Computational theory

In this paper, according to the API-RP2A to calculate wind speed and wind load, the average wind speed generally take one hour average wind speed, return period of 100 years, the reference height is 10 meters above sea level. Average wind speed in other height is obtained by fixed reference point calculation formula as follows:

\[ U_a(lh, z) = U_a(lh, z_R) \left( \frac{z}{z_R} \right)^{0.125} \]  

(1)

Where: \( z \) for static vertical height above the water (m); \( z_R \) for the average wind speed reference point (10 m); \( U_a(lh, z_R) \) as the reference point of the average wind speed (m/s); \( U_a(lh, z) \) force for static surface height of \( z \) at the average wind speed (m/s). Floating platform movement consist of first order slightly amplitude and the second order low-frequency, that is movement of floating platform can be caused by superposition of wave frequency and low frequency motion. As a result, the time domain solution of the motion equation process can be seen as solving wave respectively frequency and low frequency. Equation (2) express the coupling movement under the action of external force of floating platform in wind flow, etc.

\[ [M_s + M_d] \ddot{x}(t) = F_{sw}(t) + F_c(t) + F_u(t) + F_f(t) + F_d(t) + F_h(t) + F_{wf}(t) \]  

(2)

Where, \( \ddot{x} \) for the acceleration, \( M_s \) as structure quality, \( M_d \) for drift frequency added mass, \( F_{sw} \) as slow wave drift force, \( F_c \) as the flow force, \( F_u \) as the wind force, \( F_f \) as mooring force, \( F_h \) as the hydrostatic force, \( F_d \) as the damping force, \( F_{wf} \) for platform first-order wave frequency force.

3. Structure and environmental parameters

Platform response analysis choose the Marine environment parameters for the waters of the south China sea in one hundred above years sea state conditions, this paper is different from traditional semi-submersible platform structure, platform was positively symmetrical distributed triangular structure, main parameters are shown in table 1. Including environmental parameters, wave and wind parameters such as table 2, current parameter such as table 3.

TLP platform RAOs for 6 degrees of freedom in each direction, its essence is an inspired by wave to the floating body movement of the transfer function, defined as \( RAO = \eta_i / \xi \). Where, \( \eta_i \) is the \( i \)th degree of freedom of platform movement; \( \xi \) for a particular frequency amplitude of wave height. Wind, wave current incidence angle is at the same, the structure motion response and wave forces is the largest, so this paper direction is at the same. Incident direction 0° as forward along the X axis, 90° as along the X anticlockwise 90°, -90° as along the X clockwise 90°.
Table 1. Properties of TLP Platform

| Main Dimension       | Value | Main Dimension       | Value |
|----------------------|-------|----------------------|-------|
| Mid Floating Diameter (m) | 8     | Mean Draught (m)     | 20    |
| Mid Floating Height (m)    | 30    | Roll inertia (kg.m²) | 9.139E9 |
| Side Floating Diameter (m) | 10    | Pitch inertia (kg.m²) | 9.139E9 |
| Side Floating Height (m)   | 30    | Yaw inertia (kg.m²)  | 1.617E10 |
| Brace Diameter (m)       | 2     | Water Depth (m)      | 200   |

Table 2. Parameters of wave and wind

| Wave                  | P-M   | Wind         | API |
|-----------------------|-------|--------------|-----|
| Circular Frequency (rad/s) | 0.1-0.35 | Speed of Wind (m/s) | 11.4 |
| Amplitude (m)         | 7.7   |              |     |
| Zero-cross Period (s) | 9.5   |              |     |

Table 3. Current parameters

| Depth of Water (m) | Current Speed (m/s) | Depth of Water (m) | Current Speed (m/s) |
|--------------------|---------------------|--------------------|---------------------|
| 0                  | 1.85                | -120               | 1.63                |
| -60                | 1.76                | -200               | 0                   |

Figure 1. Floating semi-submersible type wind turbine model.

4. Hydrodynamic model

Hydrodynamic computing total computational grid is about 7779, figure can be seen that in 0° Angle of incidence, the semi-submersible platform, as well as the whole wave model, and the platform structure near the pressure change and the wave motion.

5. Results analysis

5.1. Actual motion response of platform

As can be seen from the figure 2, with the different of wave incident direction, semi-submersible platform motion response is not the same. In surge direction, wind, wave, current angle of incidence of
0° and 90°, the platform motion response is periodic change, and when the incidence of angle is 0°, the platform motion response is more significant. In sway direction, motion response presents periodic change in three different wave incident angles, under the direction of 90°, the platform motion response is significant, next to is -90°, minimum motion response for the incident angle is 0°. In heave direction, motion response is maximum in 0°, 90° at the minimum, and motion response gradually decay over time. On the direction of rotation, the platform motion response is not periodic, generally 90° incident, the motion response is the largest, next to is -90° incident, minimum motion response is 0°. In roll direction of 90° incident, the motion response is mainly concentrated in the 0 s to 50 s, in the pitch direction of 90°, the motion response is mainly concentrated in the 20 s to 40 s, and -90° incident, motion response mainly 40 s to 60 s. In yaw direction of 90° motion response is very great, and all in between the maximum and minimum values.

![Figure 2. Actual motion response of platform.](image)

5.2. Time domain response of the platform structure force
As can be seen from the figure 3, with the different of wave incident direction, semi-submersible platform force is not the same. In surge direction, wind, wave, current angle of incidence of 90° and 90°, the platform structure force appears plus or minus with time, and force is gradually decay. In sway direction, structure force appears plus or minus with time, in the 90°, the structure force mainly concentrated in the 20 s and 40 s, and -90° incident, the force gradually diminish over time. In heave direction, generally 90° incident, the motion response is the largest value, next to is -90° incident, minimum motion response is 0°, and the force appears periodic damping. Platform in the direction of rotation, force decreases over time, generally 90° incidence, the largest platform force, next to is 90°, and the minimum force is 0°. In the roll direction of 90°, the platform force mainly concentrated in the 0 s to 20 s, in the pitch direction of 90°, the platform forces are mainly concentrated in 10 s to 30 s. In yaw direction of 90°, platform forces concentrated in the 20 s to 30 s.

Figure 3. Time domain response of the platform structure force.
6. Conclusion
This work analyses the motion responses and wave force semi-submerged platform of floating wind turbine using radiation/diffraction theory together with Boundary Element Methods. Through the analysis above we gain several conclusions:

1. In translational direction, the motion response is periodic variation under three different incident direction, and in the direction of rotation, 90° of incidence, the platform motion response is the largest, next to is -90°, minimum is 0° incident.

2. In the translational direction response appear a periodic attenuation change, and in the direction of rotation, motion response mainly concentrated in the 0 s to 50 s, but in the yaw direction, motion response greatly changed in 90° incident.

3. In time domain, 90° of incidence, platform force is largest, next to is -90°, 0° is minimum force of platform.

4. In time domain, wave force are mainly concentrated in the 0 s to 50 s, in the direction of rotation, the wave force is significant.

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References
[1] Gao K 2010 The Conceptual Design And simulation of the Floating Offshore Wind Turbine (Shanghai: University of Shanghai for Science and technology)
[2] Li C, Ye Z, Gao W, et al. 2012 Modern land and offshore wind turbine calculation and simulation (Shanghai: Shanghai Science and Technology Press)
[3] BWEA 2000 Prospects for offshore wind energy, a report written for the EU Proceedings of OWEMES (Rome, Italy, 13-15 April 2000)
[4] Lin Y F, Li J Y, Shen D, et al. 2007 Shanghai Electric Power 2 153-7
[5] Tong K C, Quarton D C and Standing R 1993 FLOAT-a floating offshore wind turbine system wind energy conversion Proceeding of the BWEA Wind Energy Conference (York, England, 6-8 Oct 1993) pp 407-13
[6] Halfpenny A 1998 Dynamic analysis of both on- and off-shore wind turbines in the frequency domain (London: University College London)
[7] Withee J E 2002 Fully Coupled Dynamic Analysis of a Floating Wind Turbine System (USA: Massachusetts Institute of Technology, Cambridge)
[8] Jonkman J M and Buhl Jr M L 2007 Development and verification of a fully coupled simulator for offshore wind turbines Proceedings of the 45th AIAA Aerospace Sciences Meeting and Exhibit, Wind Energy Symposium (Reno, Nevada, USA 8-11 Jan 2007)
[9] Zambrano T, MacCready T, Kiceniuk Jr T, et al. 2006 Dynamic modeling of deep water offshore wind turbine structures in Gulf of Mexico storm conditions Proceedings of OMAE2006 25th International Conference on Offshore Mechanics and Arctic Engineering (Hamburg, Germany 4–9 June 2006)
[10] Tomoaki, Utsunomiya, Tomoki, Sato H, Matsukuma et al, 2009 Experimental validation for motion of a Spar-type floating offshore wind turbine using 1/22.5 scale model Proceedings of the ASME 28th International Conference on Ocean, Offshore and Arctic Engineering (Honolulu, Hawaii, 31 May-5 June 2009)