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Research Article

# Preliminary Design of Offshore Wind Turbine Tension Leg Platform In the South China Sea

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***Abstract***

China has the richest offshore wind resource in the world. Much of undeveloped resource should consider floating tension leg platform (TLP) wind turbine because of its advantage and potential in cost and safety for deep sea, but the related research is short in China. In this thesis we assess a preliminary design for a type of TLP structure in the South China Sea (SCS-TLP) closed to Guangdong province basing on NREL 5MW wind turbine. By coupled analysis in the time domain, the platform displacement and tower base force are obtained and analyzed. As a result, SCS-TLP has good features in the dynamic response except yaw motion, it needs to improve the yaw direction damping to induce motion in this direction.

*Keywords:* Floating Foundation; Tension Leg Platform; Dynamic Response; Yaw Response

## 1. Introduction

China potential ranks first in the world for the offshore wind resource, following figures present the wind energy distribution in China. In the East Sea and the South Sea closed to Guangdong deposit large wind energy [1], [2], [3]. In South China Sea, most of the water depth comes to 50m. The traditional fixed foundation is too expensive in this water field. In order to deal with the challenge, floating foundation concept should be applied [3], [7].

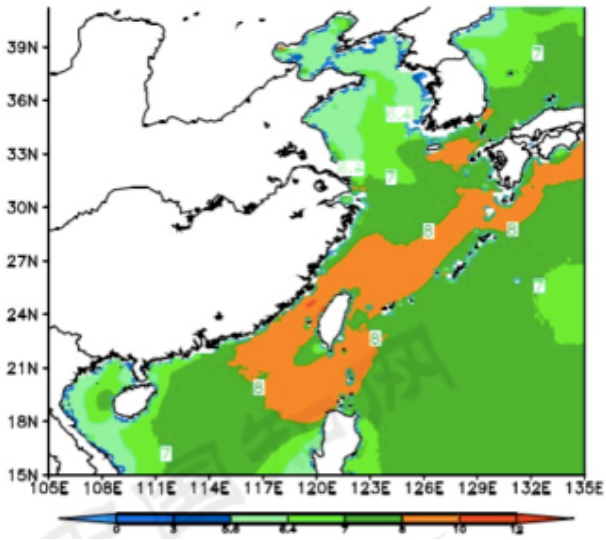


**Fig. 1.** China wind speed distribution [1]

Three types of floating foundations have been used at this moment including spar, tension leg platform and semi-submersible structure. The tension leg platform supporting structure concept for wind turbine is regards as the first choice because the structural loading on the wind turbine and tower can be reduced better when comparing with other floating concepts [4], [5], [6].At this moment, tension leg platform concept for wind turbine is an active research recently. The first work in developing a TLP wind turbine supporting structure was performed by Withee [8] in 2004 at MIT. The dependencies between the design parameters and performance and important effects were examined by Alina [9]. Withee [10] researched fully coupled time-domain simulations for whole system combined a tension leg platform supporting structure in wave and wind. That tension Leg platform floating type is soft in surge and sway is found by Lee [11].Suzuki [12] verified a TLP floating structure which is designed in Japan in earthquakes conditions. Bae [13] researched dynamic response of a mini TLP-type offshore floating wind turbine. Nihei [14] investigated the motion characteristics in waves and wind for TLP wind turbine. Bachynski [15] analyzed a wide range of parametric single-column TLP design. He finally pointed that bigger spoke radius maybe show best overall behavior in the special environment conditions, but he did not show other proof to verify it. In China the research for TLP floating structure for wind turbine is scant. Ren [1], [26] introduced a floating structure consider tension leg and mooring lines, also did a experiment to test it. Zhao [16] proposed a new tension leg platform foundation (Wind-Star TLP) to the NREL 5000KW offshore wind turbine and studied motion characteristics under extreme conditions. At present, though some results are got, detail researches on

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TLP floating supporting structure coupled with wind turbine are in the research stage no matter China or other country.

## 2. Concept Design

### 2.1 Wind Turbine& Environmental Condition

In this paper, 5MW offshore wind turbine which is design by NREL (*the National Renewable Energy Laboratory, U.S.*) is considered to be arranged on the TLP floating structure.

The purpose for this concept is to do the initial design and research for the offshore floating supporting structure. Many papers adopted this wind turbine as the base. More information about this NREL 5MW wind turbine can be found in [16], [17].

The wind turbine installation place is in the Guangdong coast. Environmental conditions which are got from previous research [18], [19] are shown in Table 1. Because the depth is variable, the installation site average depth 200m is considered in there. The energy density of wave is defines by [24] in the Pierson-Moskowitz spectrum,

$$S(\omega) = \pi^3 (\frac{2H_S}{T_z^2})^2 \frac{1}{\omega^5} \exp[-\pi^3 (\frac{2}{T_z \omega})^4]$$

$\omega$ is the wave frequency, Hs the significant wave height and $T_z$ is the zero-crossing period. It has an equivalent equation basing on peak wave period definition between peak wave period $T_p$ and zero crossing period [25]:

$$T_p = (\frac{5\pi}{4})^{0.25} T_z$$

**Table 1.** Environmental condition

| Condition | Operation | Survival |
|---|---|---|
| Significant wave height-$H_s$ | 3 | 13.3 |
| Peak wave period-$T_p$(s) | 6 | 15.5 |
| Zero-cross period-$T_z$(s) | 4.25 | 10.99 |
| Mean wind speed(m/s) | 8.7 | 50 |

### 2.2 Initial Design Requirement

The conceptual design for wind turbine TLP structure is an active research field. Bachynski [15], Zambrano [20], Wayman [21], Zhao [16] and Bulder [22] presented their understanding for conceptual design requirement, but they are lack of the whole consideration from installation situation to extreme situation. Summarizing above ideas for the initial design, the TLP initial design should satisfy following requirements in our research:

(1) Wind turbine TLP design should consider whole life process from installation, transportation and operation to extreme condition because of cost and safety.

(2) Significant restoring is enough in any situation.

(3) In transportation and installation process, the wind force use the minimize operation wind speed. The mean surge force considering waves coming from the pressure integration and viscous force for regular waves. All the force can be explained in following equation [23]:

$$F_{thrust} = \frac{\rho g \delta_a^2 D_1}{3} + \frac{2}{3\pi} \rho C_D \omega^2 \delta_a^3 + \frac{1}{2} C_T \rho_a A_b V_{rb}^2$$

where $F_{thrust}$ is the total force adding on the wind turbine and TLP whole structure. $\delta_a$ is the significant amplitude. $D_1$ is the column diameter. $C_D$ is the drag coefficient and $C_T$ is the thrust coefficient. $A_b$ is the rotor sweep area.

(4) Pitch angle less than 10 degree during transportation and installation, in operation situation it less than 5 degree.

(5) The natural periods should be limited in a range because of the resonance effect. For NREL 5MW, the coupled pitch value is between 2.7s and 3.5s.

(6) Horizontal displacement is less than 10m in operation situation and translation.

(7) During operation, the tethers tension is not exceed the maximum allowable tension and also not have slack. And the safety factor should no less than 2 in extreme condition for tension.

### 2.3 CSC-TLP Concept Design Result

For the new TLP supporting structure we called it is SCS-TLP (*South China Sea tension leg platform*) for NREL wind turbine in order to distinguish with MIT/NREL TLP and other types. Considering above condition partly, SCS-TLP has the following features:

(1) It includes single-column with four spokes; four tendons groups are arranged in of the end of spoke, and a anchor is to fix motion in the seabed.

(2) The four horizontal spokes are designed to connect the column, and the spokes cross-section is round shape, in the connection between column and spoke is strengthened.

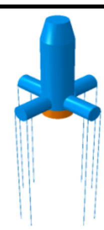
(3) Adequate distance between the bottom of the tower (top of the CSC-TLP) and water line to prevent potential wave impact damage, the height is constant 10m (free board height).

(4) Top of the freeboard is bevel shape to avoid floating impurities. The upper diameter is constant 10m, which is bigger than first section of the tower.

(5) The reason for considering concrete as ballast is in China concrete price is cheaper than other countries during rich offshore wind res. The concrete ballast added to the center column bottom in order to improve the performance and allow better stability during installation and transportation in lowest cost. The position for the concrete ballast which is different as other types is lower than the plane of the bottom of the column. The diameter is same as hull column in this research.

Table 2 presents initial design result and we will calculate and decide whether it satisfies the initial requirement that we have proposed from installation to extreme situation in given environmental condition. The diameter of the column is 15m and the depth is 40m. In the south China coast, the harbor is easy to satisfy and assemble. We use the big spoke diameter in our model , because this type of design perhaps can get better performance in the motion basing on the Bachynski paper[15]. Of course it need to verify in detail, in this paper we consider this idea. The concrete ballast in the bottom of the column is 2m. And the total displacement is 9080m^3, concrete displacement is 353m^3.In the future we will consider large concrete displacement to show the cost advantage.

**Table 2.** SCS-TLP dimension

| `Parameters | |  |
|---|---|---|
| Column | Diamter (m) | 15 |
| | Length (m) | 40 |
| Spokes | Diamter (m) | 5.5 |
| | Length (m) | 25 |
| Concrete ballast | Height (m) | 2 |
| Gravity point | | 0,0,-32.988 |
| Total mass | T | 1468.632 |
| Displacement | M^3 | 9080.49 |
| Concrete displacement | M^3 | 353.25 |

## 3. Dynamic Calculation and Analysis

Computer codes are used to simulate CSC-TLP supporting structure: CATIA is used to create geometric model and HyberMesh is used to mesh model; ANSYS AQWA is used to calculate hydro-dynamic characteristic parameters. An aero-hydro-servo-elastic coupled analysis is carried out in the time domain with the numerical tools FAST. The matrices for the wind turbines and the platform are passed to the dynamic analysis module, where they are combined to the represent the coupled system, and motions of the combined system are calculated.

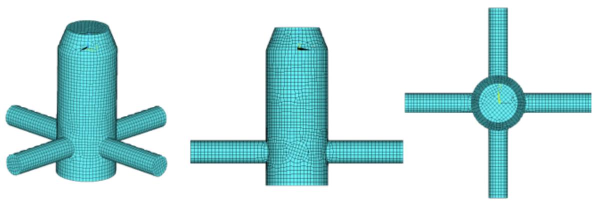


**Fig. 2.** Mesh grid in different direction

The response of SCS-TLP design to bear wind and wave excitation during 800s simulation is calculated and presented the displacement and tower base force, the overall displacements in 6-DOFs are calculated and analyzed. The different load cases are considered in this part. In Fig.3 we find the displacement and angle in load case 1, the max surge displacement is limited to 2.5m, which is less than the limited value in the initial requirements; heave and sway displacements are small because of the stiffness in these directions. For the yaw response, the max angle is bigger than 2 degree which is limited in 5 degree. In Fig.4, the moment in Y direction is bigger than any other result. The method we think improving the spoke length is better in near future. The longer spoke can get a good rotation leg that make the damping become bigger .Because the extreme environmental situation in the China South Sea is different as other sea such as North sea , Fig.4 and Fig.5 show displacement and force and moment in load case 2. Generally, the max value in load case 2 is much bigger than load case 1 result. For the platform displacements and angles, surge displacement comes to 20m and sway comes to 2m, heave result is smaller than 1m, which verifies tension leg is good at restricting vertical motion. The roll angle in the initial stage is small and as the time increasing the value is bigger; in the pitch part, angle limited value is 2 degree .For the yaw response, angle is smaller than 10 degree. In the real situation, when extreme load case occurs, wind turbine stops and the last time is not longer, so the initial time need to make sure the response value is small. Water depth in this thesis is 200m, and the restricted value in displacement is 10m in operational situation, it can be satisfied. And in extreme situation the value is 10% of the water depth, in there the value is 20m, so it satisfies the requirement .In order to be safe, we also suggest improving some parameters to get better performance.

In figure 7 and figure 9 we consider low-speed and high-speed shaft in different loads. In figure 8 and 10 we consider the wind velocity and wave elevation. In fact, in load case 2, because of the high wind speed the wind turbine stops to run so the high speed shat is a line.

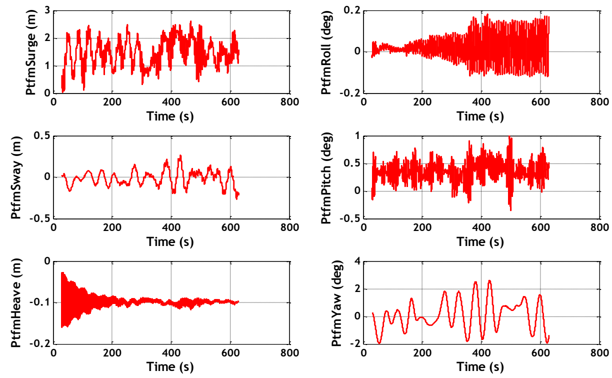



**Fig. 3.** The displacement and angle in load case 1

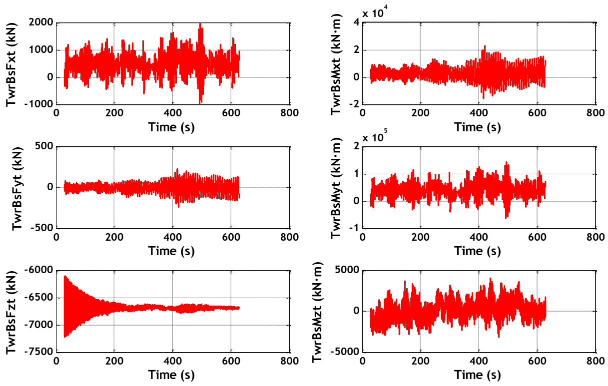



**Fig. 4.** The tower base force and moment in six directions in load case 1

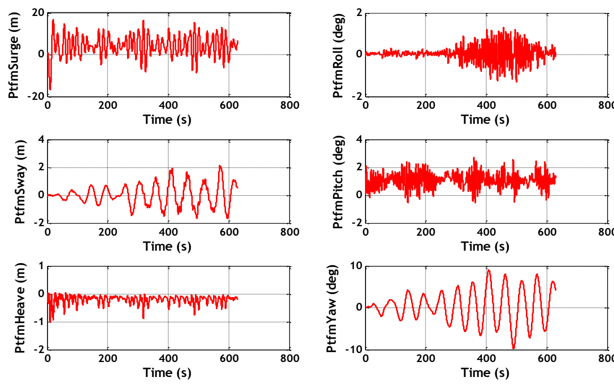


**Fig. 5.** The displacement and angle in load case 2

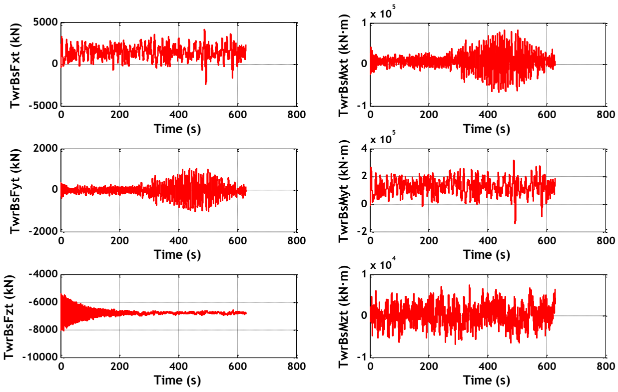



**Fig. 6.** The displacement and angle in load case 2

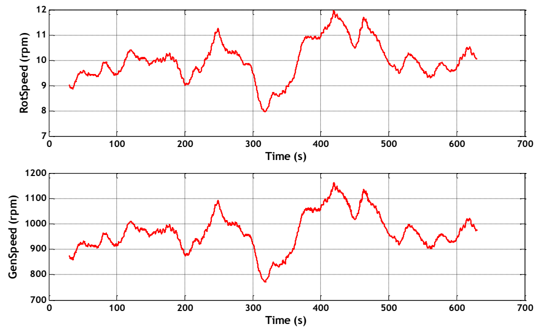



**Fig. 7.** Time Series Plots of Low-speed shaft and high-speed shaft speeds in load case1

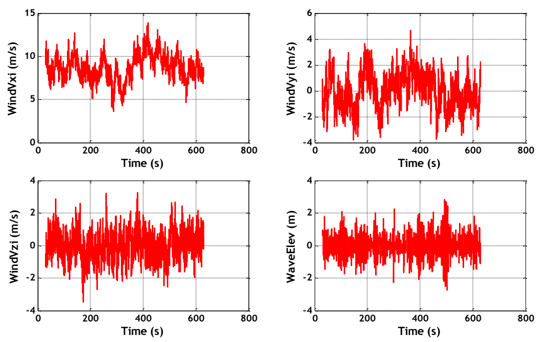



**Fig. 8.** Time Series Plots of Wind velocity and wave elevation in load case1

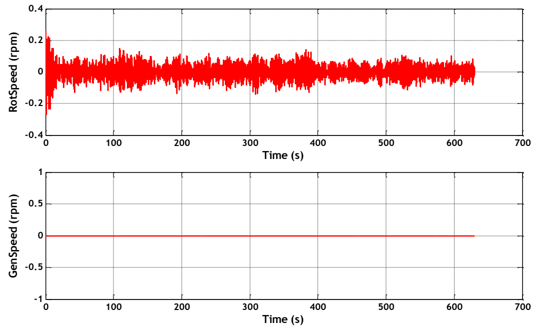



**Fig. 9.** Time Series Plots of Low-speed shaft and high-speed shaft speeds in load case2

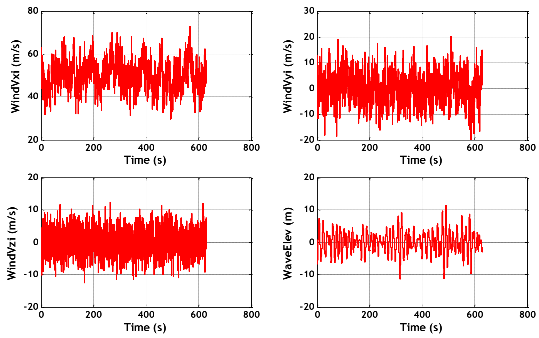



**Fig. 10.** Time Series Plots of Wind velocity and wave elevation in load case2

## 4. Conclusion

In this thesis, the TLP for 5MW offshore wind turbine in Guangdong is proposed and the dimension is decided initially basing on the requirements, we get following results need to be noticed:

(1) All the results including displacement and angle in load case 1 (operational situation) and load case 2 (extreme situation) satisfies initial requirements though dynamic analysis.

(2) The yaw response in two load cases, it needs to improve. We propose to improve the length of the spoke to make damping increase. But the increasing extent for spoke dimension need to research in detail.

(3) This show a potential understanding that increasing total displacement of TLP can be done by increasing concrete ballast volume which is arranged in a plane of spoke bottom where concrete price is cheaper, especially in China.

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