Design and analysis of the mooring system for the box-type inverter-transformer floating platform

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Abstract. In the floating photovoltaic industry, the array layout, geographical location, and topographical conditions can greatly increase the difficulty to arrange the inverter-transformer in the design of a floating photovoltaic power station. Therefore, it is sometimes necessary to arrange the box-type inverter-transformer on the floating platform so that the inverter-transformer can float above the water surface. Thus the cable layout can be optimized and the economic efficiency of the project can be improved in this way. In order to ensure the stability of the inverter-transformer floating system, a specific mooring system should be designed for the floating platform. By now, the design and analysis with respect to the mooring system for inverter-transformer floating platform can rarely be conducted in the industry. In this paper, the design and analysis of the mooring system for the inverter-transformer floating platform is presented, and the related hydrodynamic calculation is performed accordingly. The design and analysis are based on the AQWA software. It can be concluded that the mooring system design presented in this paper can guarantee the stability and anti-overturning ability of the inverter-transformer floating platform. An actual engineering application of this mooring system design is finally introduced.

1. Introduction

On the basis of the development indicators proposed by the National Energy Administration of China, the installed capacity of photovoltaic power generation is expected to reach 160 million kilowatts by the end of 2020, demonstrating that the photovoltaic power has a bright prospect of development. However, due to the insufficient consumptive ability of the power system, there is a growing tendency to limit the photovoltaic power generation in Northwest China. For this reason, the construction of photovoltaic power stations has gradually transferred to the central and eastern regions in China, where has greater power demands. But there are few mountain areas to arrange the photovoltaic power stations in central and eastern regions, so that the contradiction between the increasing photovoltaic power construction demand and the reducing approval of land occupation facilitates the photovoltaic industry to put interest in the utilization of vast water space. According to the statistics, the lake area in China reaches 80 thousand square kilometres, the reservoir quantity is up to 86 thousand, and the coal mining subsidence areas is still continuously increasing. It is explicitly encouraged in the “13th Five-Year Plan for Solar Energy Development” [1,2] to construct photovoltaic power plants in coal mining subsidence areas and pit ponds. Since the launch of the “Photovoltaic Project Leading Program” in 2015 [3], three to five leading Photovoltaic Development Bases has been approved by the government annually, and a large number of floating photovoltaic projects are developed in those bases. Currently, a capacity of 3.2 million kilowatts has been planned to be installed in the coal mining subsidence area in Huainan and Huaibei areas during the years of 2016 and 2018. With the growing extensive application of the floating photovoltaic power technology, the potential market foreground in the future must be extremely huge.

In order to optimize the cable layout and to improve economic efficiency, the inverter-transformer system is generally placed above the water in the floating photovoltaic systems design. According to different supporting forms, the supporting structure can be divided into two types: the piling type and the floating type. The application of piling type is limited to shallow water and geologically stable areas. However, the floating type does not have this restriction. In this paper, the floating type will be designed and analyzed. The floating buoy material can also be grouped into many types such as galvanized steel, HDPE, concrete, etc. The inverter-transformer system is the key part of the entire floating photovoltaic power generation system, and the stability of the inverter-transformer floating platform directly affects the safety of the entire system. Besides, the design, calculation and analysis of the box-type inverter-transformer floating system are yet to be found in existing literatures.

This paper presents the detailed design with respect to the mooring system for the box-type inverter-transformer floating platform according to specific engineering requirements. Then it establishes the numerical model based on this design in AQWA software [4-7]. Further, the dynamic responses of the floating system have been analyzed in both frequency and time domain, respectively. Finally, a case of actual engineering application based on this design has been presented.

2. System design

The floating platform for inverter-transformer is usually designed as a cuboid. Though directions of wind, wave and current are complex and diverse, all loads can be finally decomposed into two directions. Therefore, considering the shape of the floating platform and the load-bearing characteristic, six mooring points have been set on the floating platform in a symmetric way, as shown in Figure 1. The angle between the platform edge and the mooring line that extended from the platform corner is set as 45 degree. And the mooring line extended from the middle point of platform edge is arranged vertical to the platform length side.

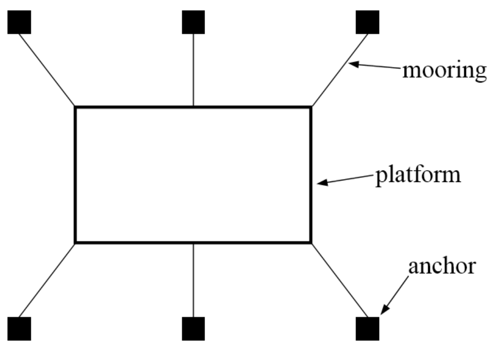

Figure 1. The mooring system layout of the inverter-transformer floating platform.

Taking 10 meters water depth for instance, the angle between the mooring line and the still water level is 45 degrees, so that the straight line distance between the fairlead and the anchor point is 10 m. if the redundant length of mooring line is set as 1 meter, the mooring system has the ability of responding to ±1.5 meters water level variation. The mooring line material is selected as a stainless steel wire rope with a diameter of 10 millimeters, and the minimum breaking tension of this rope is 63 kN. The double-strand design is adopted for the mooring line, and the safety is ensured by this redundancy design. It is preferable to set the fairleads on the deck, so as to provide greater restoring forces and moments, to reduce the six-degree-freedom motions of the floating platform under strong wind and wave, which can improve the stability and anti-overturning performance of the moored floating system.

3. Numerical model set-up

The three-dimension (3D) numerical model of the inverter-transformer supporting platform is established in CATIA software as shown in Figure 2, with the prototype parameters. The model of box-type inverter-transformer has been necessarily simplified.

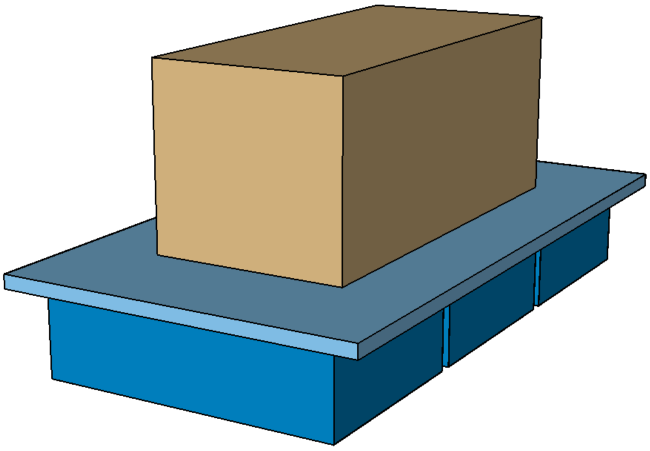

Figure 2. 3D model of the floating platform for the all-in-one box-type inverter.

The 3D model in Figure 2 has been imported into the AQWA software, and the mooring system has been modelled afterward, as shown in Figure 3. The finite element model was finally established after meshing.

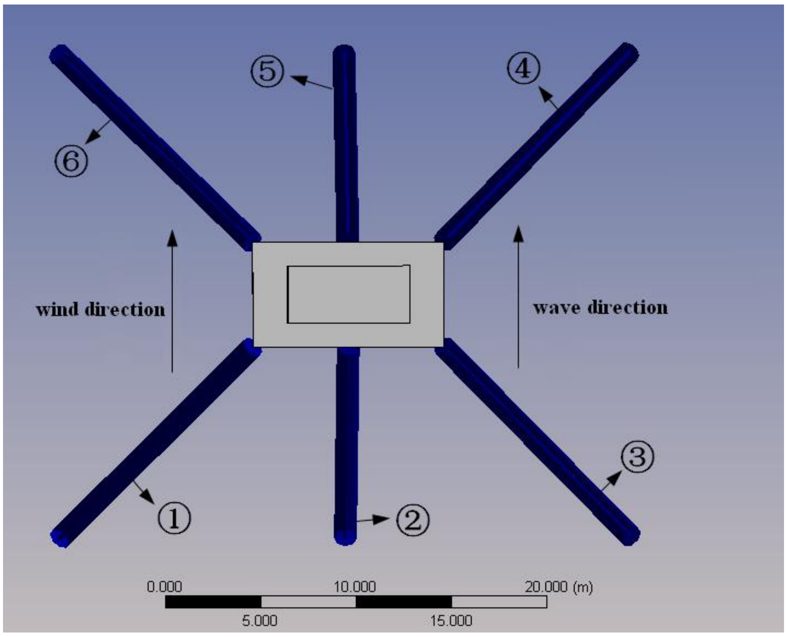

Figure 3. Moored floating platform system layout in AQWA.

4. Analysis based on simulation results

Based on the specific environmental load condition for a given engineering project in inland and corresponding standards, the load case of combined wind with wave is defined in Table 1.

Table 1. Load case definition.

Parameters	Values
Wind speed	30 m/s
Wave height	0.1 m

The harshest loading direction has been taken into consider for simulation, namely the directions of wind and wave both are perpendicular to the length side of the platform. Under this load condition, the mooring line tensions and motions are simulated and analysed.

4.1. Simulation results in frequency domain

Seven wave directions have been selected during simulation in frequency domain, including -135 deg, -90 deg, -45 deg, 0 deg, 45 deg, 90 deg and 135 deg, respectively. The wave force results in frequency domain have been calculated based on various incoming direction.

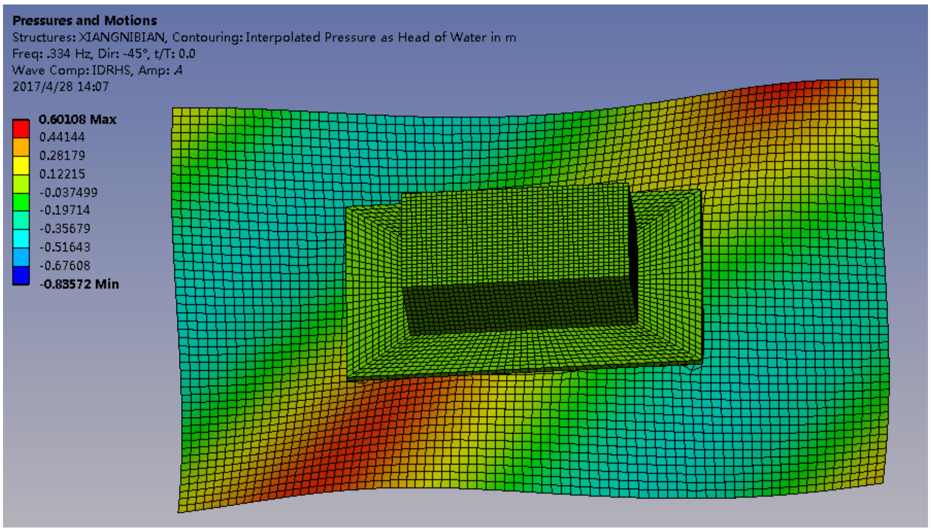

Figure 4. Wave pressure acting on the front side of the platform.

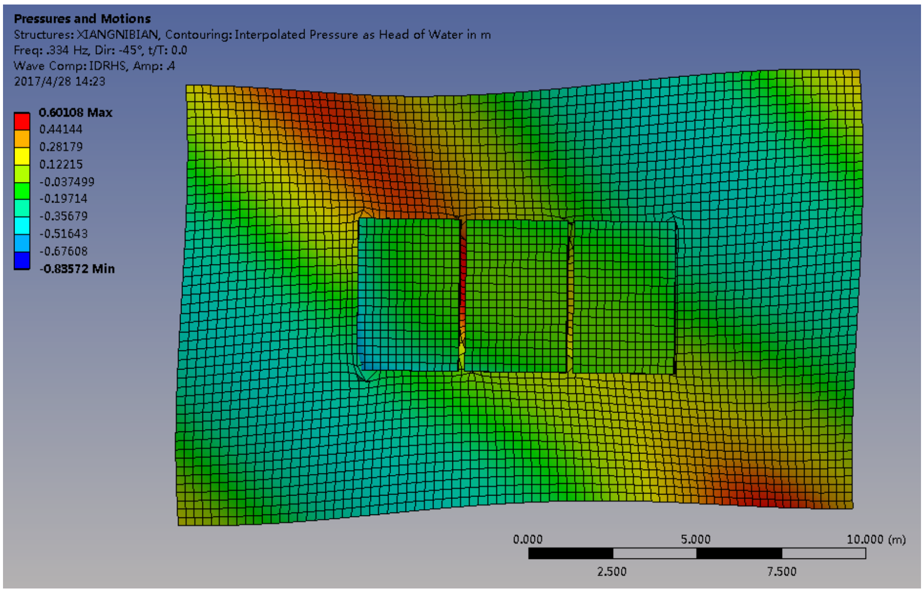

Figure 5. Wave pressure acting on the front side of the platform.

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Take the 45 degree wave direction for instance, the wave pressure on the front side of the platform is shown in Figure 4, and the wave pressure on the bottom side of the platform is shown in Figure 5, from which the load-bearing condition of the platform under the combined wind and wave excitation can be clearly identified.

4.2. Simulation results in time domain

The dynamic responses of the floating platform system under combined wind and wave load condition will be simulated and analysed in the following content. The entire simulation time is set as 300 s and the time step is set as 0.02 s.

In consideration of the wind direction, mooring line #1, #2, #3 and #6 have been selected, and time histories of these mooring tensions have been plotted in Figure 6.

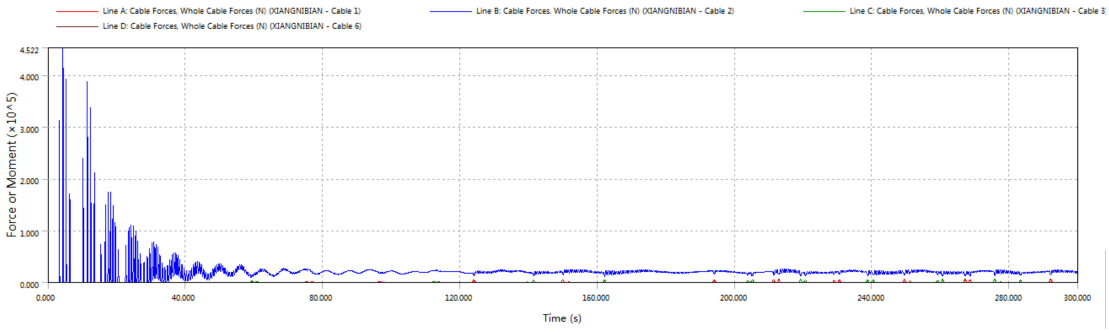

Figure 6. Time-history of mooring tensions.

It can be seen from Figure 6, all the mooring tensions arrive the stable state around eightieth seconds. The mooring line # 2 is the predominant load-bearing line with a max tension of 20 kN when it comes to the stable state. While other mooring tensions can only arrived at 10 kN after stable. The tensions of all the mooring lines are far away from the breaking-tension limitation, which means the design meets the safe requirement.

The anti-overturning analysis of the floating system has been conducted based on the roll and pitch responses under the combined wind and wave load condition, as shown in Figure 7. As can be seen from Figure 7, when reaching the stable state, the max value of roll turns out to be 5 degree and the max pitch is only 0.5 degree, demonstrating the overturning will not happen.

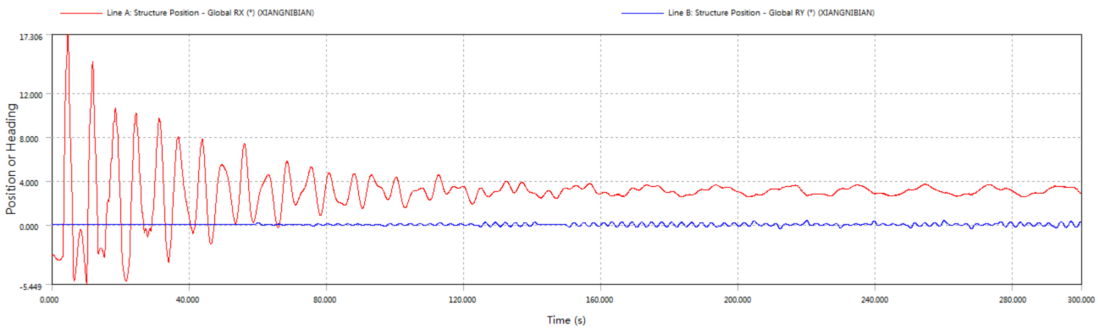

Figure 7. Responses of roll and pitch under combined wind and wave load case.

For further investigation of the motion behaviour, the yaw response is presented in Figure 8. It can be seen from Figure 8 that the yaw motion has been in a state of unstable vibration with a max value of 6.2 degree, which is acceptable.

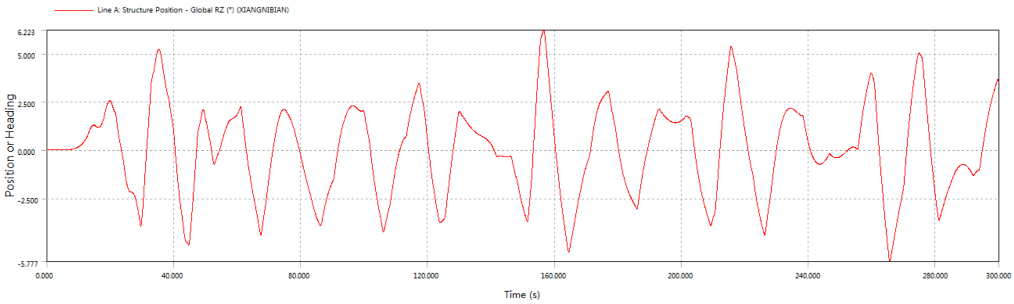

Figure 8. Response of yaw under combined wind and wave load case.

5. Engineering application

The mooring system design presented in this paper has been successfully applied to the largest floating photovoltaic power plant project in the world (Sanxia Huainan 150 MW floating photovoltaic power plant project), as shown in Figure 9. The long-term safe and normal operation has verified the reasonability and reliability of the design and analysis method proposed in this paper.

Figure 9. Actual engineering application in Huainan project.

6. Conclusions

The design and analysis of the mooring system for the box-type inverter-transformer floating platform has been performed by AQWA software, based on the parameters of an actual project. And the application of a practical engineering project has been introduced. It can be concluded that responses of the mooring tensions, roll, pitch and yaw motions all meet the safe requirement under the given extreme load condition. The design of mooring system in this article can ensure the stability and overturning resistance of the moored floating system under the given extreme load condition.

References

[1] National Energy Administration 2016 “13th Five-Year” plan of solar energy *Sol. Energy.* 5-14
[2] Ding G L 2017 800 Million square meter of solar energy in "13th Five-Year" plan-- business opportunity decryption *Sol. Energy Ind. Inform. China* **3** 14-14

[3] He P Y 2016 A brief analysis of the "PV leader program" in China *Big Sci. Tech.* **24** 290-291
[4] Xiao Y W and Sun S M 2012 A study of light tension leg platform types based on AQWA *Sci. Tech. Engin.* **33** 8987-8993
[5] Chen P, Ma J, Huang J H, *et al* 2013 Hydrodynamic analysis and mooring performance analysis of semi-submersible platform based on AQWA *Ship & Ocean Engineering* **42** 44-7
[6] Yan G 2009 Dynamic response analysis of TLP based on AQWA *J. Southeast Univ.* **47 (S1)** S130-S137
[7] Gao J K, Liang Y H, Liu H, *et al* 2017 On Application of AQWA and HARP in Global Performance Analysis of TLP *Ship Ocean Engineering* **4** 156-160