

Dynamic Response Analysis of a Floating Wind Turbine Tri-Floater Type with Heave-Plate and Mooring System

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ABSTRACT

In this paper, the dynamic behaviors are studied for the semi-submersible floating foundation of a tri-pod and spar wind turbine. It is a 5 MW wind turbine in 320 m deep water considering the coupled load effects of waves, wind, and sea current on floating foundation and mooring lines and ocean environment. The paper focuses on the key issues of floating foundation design, such as coupling dynamic analysis model and calculating methods. The motion performance and line tension are investigated by using an aero-hydrodynamic software Ansys-AQWA. The results show that the tri-pod wind turbine with mooring system may work in the ocean environment without heave-plates.

KEY WORDS: *Floating Wind Turbine, Dynamic Response, Heave Plate*

1.0 INTRODUCTION

Wind energy is one of the most renowned source of renewable energy, with steep hikes in fuel prices, wind energy poses to be an attractive and environment friendly source of power generation. Most of world's metropolises are near shore and offshore wind energy offers the obvious advantage of no land usage and probably more reliable wind resource [1].

In the recent decades, the floating offshore wind turbine with different floater configurations is being built and installed in deep waters for production of electricity. The wind power resource is on average 50% higher offshore than onshore, however, the cost to install and run offshore winds power units is around double. This has raised the challenge of optimizing the economical perspectives of offshore wind power. The generation of wind power is mainly located in areas within a distance of 5–50 km from the coastline, where the water depth is generally greater than 20 m. Studies have shown that the traditional fixed foundations will not be economically viable for offshore wind turbines in waters deeper than 30 m. So the assessment for the performance of the offshore floating wind turbine is very important for proper design of the floater. In order to have reference values to use as design targets, it is necessary to predict the most probable maximum values of motion parameters [2].

It is essential to employ floating offshore technology, which needs to be borrowed from existing oil and gas (O&G) industry. The O&G systems design is always safety driven and is thus conservative. The structures are very large and heavy with rigid components, due to small response hydrodynamic and aerodynamic damping has small contribution and the mooring system is in linear range. Floating offshore wind turbine systems can be divided into two groups, single turbine system and multi-turbine system.

Due to small size such floaters are subjected to large wave induced response, which leads to nonlinear behavior of restoring force and mooring system. It is therefore, essential to investigate means such as heave plates and Tension Legged mooring systems to reduce floater response [3].

Recently, a few time domain simulations, including the coupling effect between the aerodynamics of the wind turbine and platform motion, have been studied (Kim et al., [4]; Andersen et al., [5]; Huijs et al., [6]). Also, Abtahi and Ghassemi carried out six degrees of freedom numerical analysis of an offshore wind turbine floating on a spar buoy [7].

In this study, a nonlinear boundary element model is used to investigate dynamic response of a floating offshore wind turbine with Tri-Floater systems considering coupling between wind turbine, floater and mooring system. And it has been used Ansys-Aqwa software to aim this purpose.

One of the important parameters due to its high influence on hydrodynamic impact is the geometry. The dominating wave force regimes on cylindrical structures depend on the ratios of wave height to column diameter (H/D) and of column diameter to wavelength (D/L).

2.0 SPAR AND TRI-FLOATER WITH WIND TURBINE

The WindFloat Tri-Floater design considered in this paper is dimensioned to support the 5MW NREL reference wind turbine. The design is based on a fictive offshore site at 320 m water depth. The main particulars of the design are summarized in this section. **Figure 1** shows the Tri-Floater.



Figure 1: Tri-Floater type wind turbine [3]

Table 1: Wind turbines properties

Parameters	Tri-Floater	Spar
Hub Height	90 m	90 m
Center of Mass Location (From Sea Level)	43.4 m	43.4 m
Rotor Diameter	126 m	126 m
Number of Blades	3	3
Initial Rotational Speed	12.1 rpm	12.1 rpm
Blades Mass	53,220 kg	53,220 kg
Nacelle Mass	240,000 kg	240,000 kg
Hub Mass	56,780 kg	56,780 kg
Tower Mass	249,000 kg	249,000 kg
Power Output	5 MW	5 MW
Cut-In, Rated, Cut-Out Wind Speed	3 m/s, 11.4 m/s, 25 m/s	3 m/s, 11.4 m/s, 25 m/s

Table 2: Platforms properties

Parameters	Tri-Floater	Spar
Operating Draft / Total Draft	17 m	-
Length of Entrapment Plate Edge	15 m	-
Length of Column to Center	46 m	-
Main Beam Diameter	2.1 m	-
Bracing Diameter	1.5 m	-
Column Diameter	10 m	-
Total Draft	-	120 m
Depth to top of taper below sea water level	-	4 m
Depth to below of taper below sea water level	-	12 m
Platform diameter above taper	-	6.5 m
Platform diameter below taper	-	9.4 m
Center of Mass Location below Sea Water Level along platform centerline	-	89.9155
Mass, Including Ballast	4,640,000 kg	7,466,330 kg
Center of Mass Location Above Sea Water Level	3.728 m	-
Platform Roll Inertia (Ixx)	5,720,000,000 kg.m ²	4,229,230,000 kg.m ²
Platform Pitch Inertia (Iyy)	5,650,000,000 kg.m ²	4,229,230,000 kg.m ²
Platform Yaw Inertia (Izz)	3,260,000,000 kg.m ²	164,230,000 kg.m ²

Table 3: Mooring systems properties

Parameters	Tri-Floater	Spar
Number of Mooring Lines	3	3
Angle Between Lines	120°	120°
Depth of Anchors From Sea Level	320 m	320 m
Depth to Fairleads Below Sea Level	70.0 m	70.0 m
Radius to Anchors from Platform Centerline	853.87 m	853.87 m
Radius to Fairleads from Platform Centerline	5.2 m	5.2 m
Un-stretched Mooring Line Length	902.2 m	902.2 m
Mooring Line Diameter	0.09 m	0.09 m
Equivalent Mooring Line Mass Density	77.7066 kg/m	77.7066 kg/m
Equivalent Mooring Line Weight in Water	698.094 N/m	698.094 N/m
Equivalent Mooring Line Extensional Stiffness	384,243,000 N	384,243,000 N
Additional Yaw Spring Stiffness	98,340,000 Nm/rad	98,340,000 Nm/rad

Windfloat wind turbine properties, the main dimensions of the considered Tri-Floater design and properties of mooring system are provided in Tables 1 to 3. The hull shape of the semisubmersible is designed for optimal motion response in waves, wind and currents. The wind turbine is positioned at the center of the unit. The chains of mooring system are connected at main deck level. The wind turbine supported by the Tri-Floater is the NREL 5 MW Reference Wind Turbine. For the operational wind turbine, the following limitations to the global motions are

assumed that combined roll and pitch inclination should not exceed 10 deg [8].

The environmental conditions which are assessed in the coupled simulations are listed below:
JONSWAP wave spectra with a peak enhancement factor $\gamma=3$ and $H_s=4$ m is applied.

The incident current with 30° angle is assumed constant over the draft of the Tri-Floater. Because of Ansys-AQWA disability to rotate the wind turbine blades, API wind spectra with a wind

velocity of 25 m/s are assumed. Why so the turbine will park if the wind velocity increase to 25 m /s. In all cases, wind and waves are assumed to act collinear.

3.0 NUMERICAL MODEL AND VERIFICATION

Ansys AQWA is a commercial suite of hydrodynamic programs, which is widely used in the offshore industry. First order hydrodynamics and wave loading are calculated in the frequency domain (FD) using a potential flow linear diffraction model. Applying retardation functions, these results can then be used to perform time domain simulations. Morison type elements can be added to simulate viscous damping and wave excitation. Second order wave loading can be included in AQWA, using the full quadratic transfer function (QTF). The software includes a methodology to account for wave drift damping and the effect of current on second order wave drift loads. This methodology is based on a heuristic approach described by Clark et al, and is considered to be a reasonable approach for structures consisting of one or several vertical cylinders, such as the Tri-Floater. Wind and current loads on the floater can be included using load coefficients. AQWA allows modeling the full mooring system of the floater. The mooring line reaction forces can be either calculated using quasi-static or a dynamic model. The software has been successfully verified by running simulations where the response can be calculated analytically. A visualization of the numerical model in Ansys-AQWA of the spar and tri-floater types is shown in Figures 2 and 3. The far-field method has been used to calculate the QTF for the simulations reported in this paper.

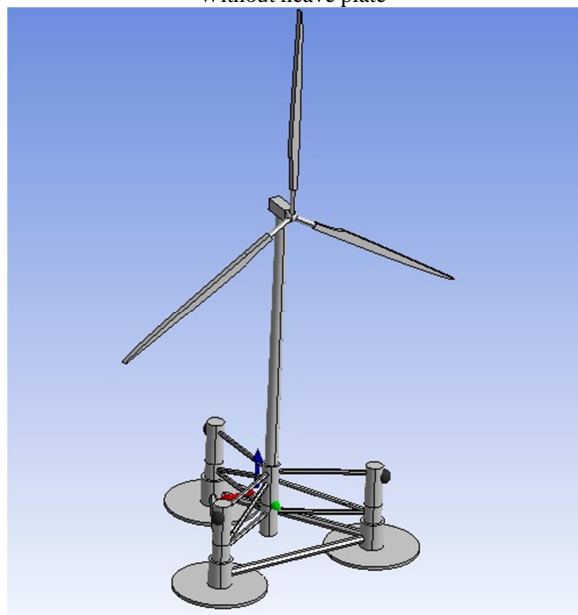
Current loads on the hull are incorporated in the model using current coefficients. The current load is calculated at each time step using the instantaneous relative velocity. This implies that the horizontal damping due to current is incorporated. Wind loads and damping acting on the hull and the tower of the turbine are included in a similar manner.

For validate the results first Spar platform analyzed with catenary mooring system. The results of six degree of freedom are presented in Figure 4. In these figures the dashed-blue line is related to the FAST software and the red line is related to the AQWA software.

As it shows in Figure 4 the amplitude of all of six-DOF are in same range. sway, heave, roll, pitch and yaw motion is below are close together and surge motion is going to be same after 200 s. Tri-Floater semi-submersible platform analyzed with catenary mooring with and without heave plates. The results of six degree of freedom are presented in Figure 5. In these figures the dashed-blue line is related to the platform without heave-plate and the red line is related to the platform with heave plates.



Without heave plate



With heave plate

Figure 2: Tri-Floater type wind turbine with and without heave plates

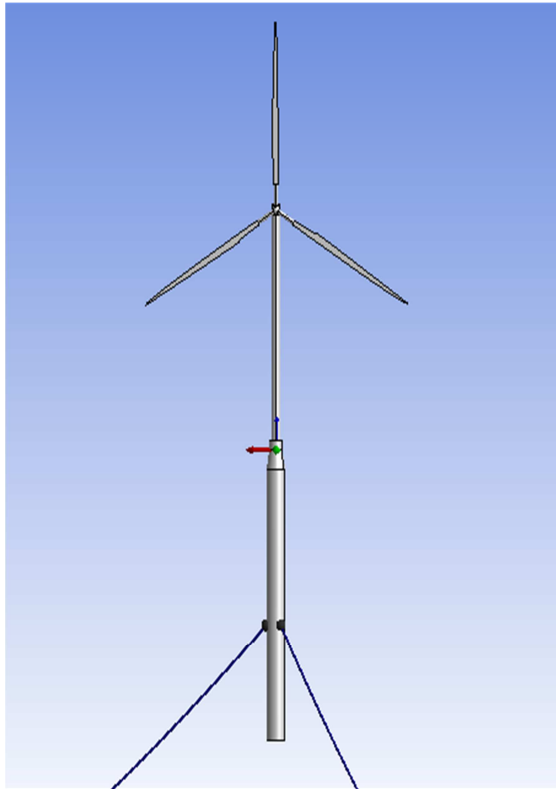


Figure 3: Spar type wind turbine

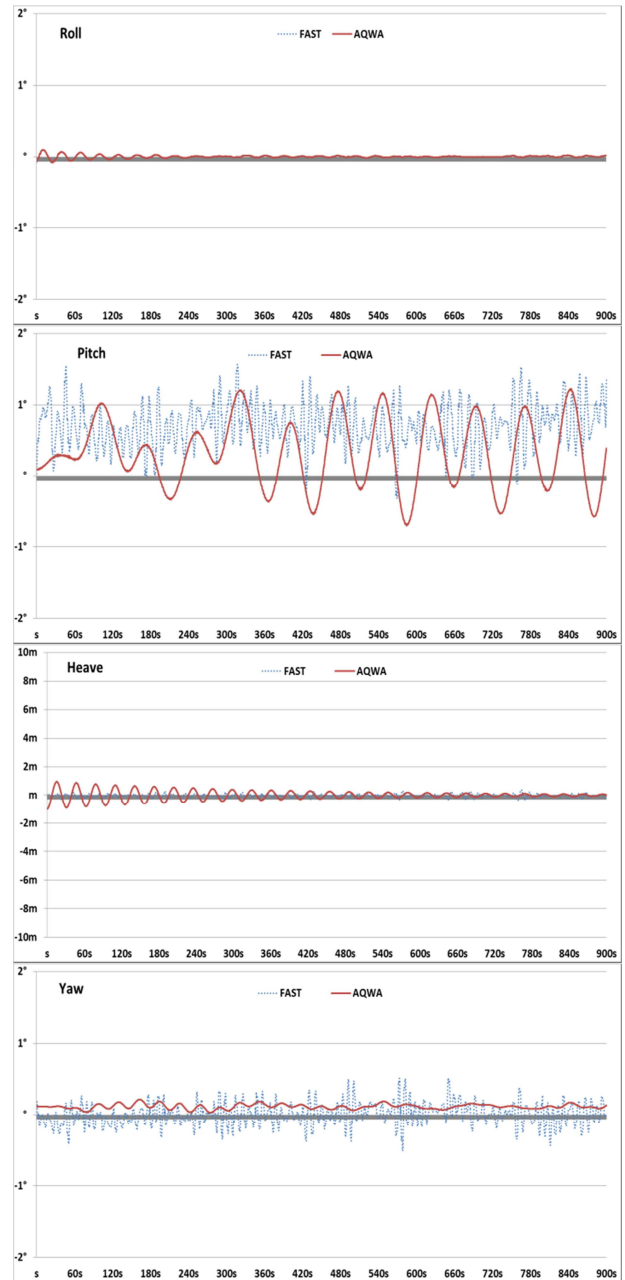
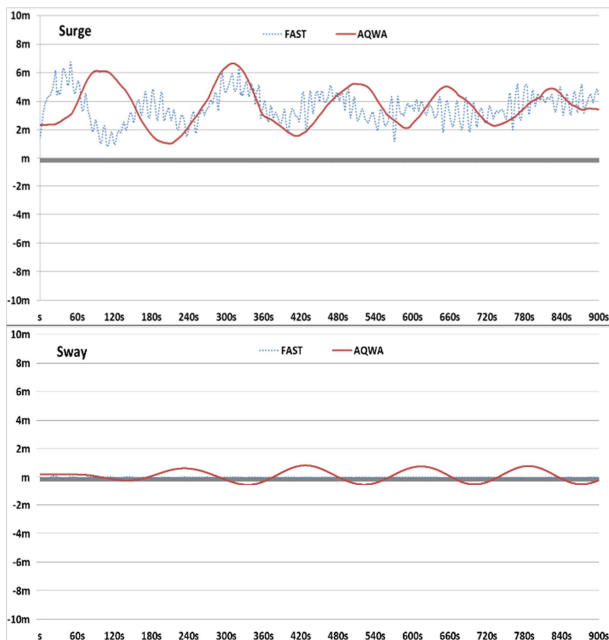


Figure 4: Six-DOF Time responses analyses of Spar type wind turbine with catenary mooring system

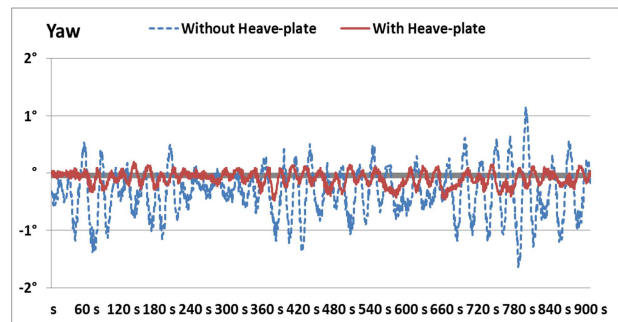
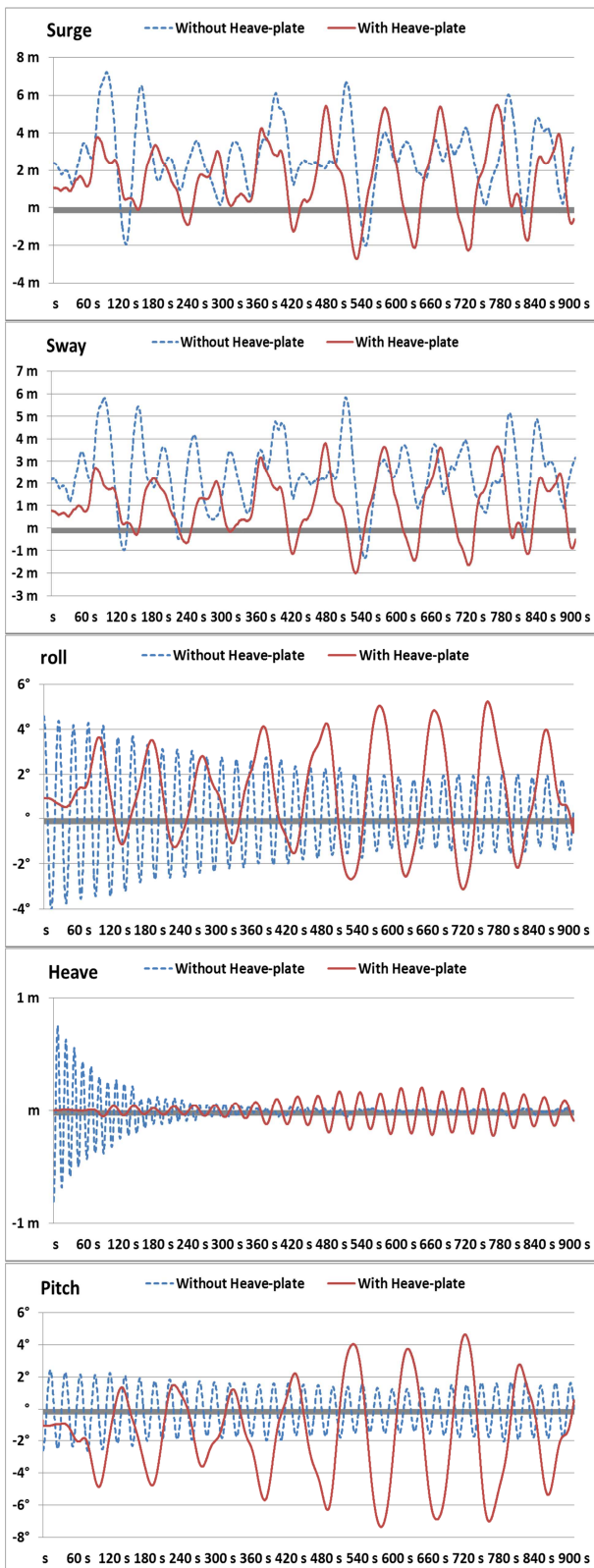


Figure 5: Six-DOF Time responses analyses of Tri-Floater type wind turbine with and without heave-plate and catenary mooring system

As it shows in Figure 5 that amplitude of surge and sway motion is reduced by adding heave plates.

Adding heave-plates cause increase in the amplitude of pitch and roll and according to section 2 the result is reducing the power generating. Also adding heave-plates cause reducing in heave motion amplitude but it cause some motion increasing between 420s to 900s. by the way in these two condition heave motion is not a condition to worry about. Also it causes reducing in yaw angle; by the way, yaw angle in first condition was not an inappropriate motion.

4.0 CONCLUSIONS

A concept design for the Tri-Floater semi-submersible equipped with the NREL 5MW reference wind turbine has been verified by aero-hydro-servo-elastic simulations. These simulations have been performed using Ansys-AQWA. Based on the evaluation of the simulation results, it is concluded that the Tri-Floater concept design meets the design requirements regarding global motions, accelerations and mooring loads. In this study we try to optimize the motion of platform with adds heave-plate to the keel of platform. The simulation results shows that this is not in our goal way and add heave-plate despite of good effect on surge, sway, heave and yaw had undesirable effort on pitch and roll angle.

REFERENCES

1. Waris, Muhammad Bilal, and Takeshi Ishihara. (2012) "Dynamic response analysis of floating offshore wind turbine with different types of heave plates and mooring systems by using a fully nonlinear model." *Coupled Systems Mechanics* 1(3): 247-268.
2. Bagbanci, Hasan, D. Karmakar, and C. Guedes Soares. (2015) "Comparison of Spar and Semisubmersible Floater Concepts of Offshore Wind Turbines Using Long-Term Analysis." *Journal of Offshore Mechanics and Arctic Engineering* 137(6): 061601.
3. Karimirad, Madjid, and Torgeir Moan. (2011) *Extreme dynamic structural response analysis of catenary moored spar wind turbine in harsh environmental*

- conditions*. Journal of offshore mechanics and Arctic engineering 133(4): 041103.
4. Kim, Jin Ha, Sa Young Hong, and Hyun Joe Kim. (2013)*The shape design and analysis of floating offshore wind turbine structures with damper structure and shallow draft*. The Twenty-third International Offshore and Polar Engineering Conference. International Society of Offshore and Polar Engineers,.
 5. Andersen, Morten Thøtt, Dennis Hindhede, and Jimmy Lauridsen. (2015)*Influence of Model Simplifications Excitation Force in Surge for a Floating Foundation for Offshore Wind Turbines*. Energies 8(4): 3212-3224.
 6. Huijs, Fons, Rogier de Bruijn, and Feike Savenije (2014) *Concept design verification of a semi-submersible floating wind turbine using coupled simulations*. Energy Procedia 53: 2-12.
 7. Abtahi Shahryar, Ghassemi Hassan, (2016) *Six Degrees of Freedom Numerical Analysis of an Offshore Wind Turbine Floating on a Spar Buoys*, Journal of Subsea and Offshore - Science and engineering, 8(4).
 8. Bagbanci, Hasan (2011). *Dynamic analysis of offshore floating wind turbines*. Naval Architecture and Marine Engineering, Technical University of Lisbon.