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Dynamic analysis of spar-type floating offshore wind turbine

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Abstract:
In the present study, a coupled dynamic analysis of NREL 5MW Spar-type floating wind turbine is presented. The turbine design variables used in the analysis are the hub height of 90 m above the mean sea level, rotor diameter of 126 m and maximum rotor speed of 12.1 rpm. Hydrodynamic added mass, damping and exiting force are obtained in frequency domain using WAMIT and are validated with the result obtained for OC3 Hywind. The hydrodynamic study of the floater is combined with the FAST code to obtain a coupled aero-servo-hydro-elastic model. The spar-type floating wind turbine is considered to be connected with delta connection three mooring lines, and the mooring lines are fixed at bottom. The tower base motions and platform motions are obtained for wind speed 3.7 m/s with 4m wave height and 0º wave heading angle.
Keywords:
Ocean renewable energy – Floating wind turbine – Spar-buoy – WAMIT – FAST code

1. Introduction

In the recent decades, the offshore wind energy emerged as a promising technology for the utilization of offshore wind resources for the large scale generation of electricity. Most of the offshore wind power projects that are proposed recently are in deep water where the winds are of sufficient intensity. Some of the floaters concepts have been proposed for the wind turbines in deep water, among which there is the spar-type floating wind turbine. The spar wind turbine comprises the floating foundation which is referred as the floater, the tower and the rotor-nacelle assembly (RNA). The floater may be towed in the horizontal position in calm waters near the deployment site. It is then upended, stabilised, and the tower and the RNA mounted by a derrick crane barge before finally being towed by escort tugs in the vertical position to the deployment site for connection to the mooring system. The first full scale size spar floating turbine has been deployed off the south-west coast of Karmoy Island, Norway, by Statoil in the Hywind demonstration project.

TONG (1998) analyzed the technical and economic aspects of wind farms. The conceptual design for FLOAT which is a spar-buoy type floating wind turbine was presented. NIELSON *et al.* (2006) discussed the integrated dynamic analysis of spar-buoy type floating wind turbines. They developed simulation models for Hywind and

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compared their numerical results with model scale test results. SUZUKI & SATO (2007) investigated the loads on turbine blades induced by the motions of a floating platform. The effect of stabilization of the fin attached to the base of the floating foundation to reduce the pitch motion of the floating spar-type wind turbine was analyzed.

MATSUKUMA & UTSUNOMIYA (2008) performed a motion analysis of a spar-buoy type floating wind turbine under steady wind considering rotor rotation. The wind loads acting on the rotor blades are calculated using the blade element momentum theory. As a result, the motion of yaw, sway and roll are generated due to the effect of the gyro moment for the rotor-rotation. UTSUNOMIYA *et al*. (2009) continued the experimental validation for motion of a spar-buoy type floating offshore wind turbine. In this case, the motion of a prototype spar wind turbine was determined under regular and irregular waves, and a steady horizontal force that simulates the steady wind condition was analyzed. A detailed review on offshore floating wind turbines and the effect of environment on design loads on monopole offshore wind turbine is studied by BAGBANCI *et al*. (2011a; 2011b).

In the present study, a dynamic analysis of 5MW Spar-type floating wind turbine is presented. The hydrodynamic study of the floater is done using WAMIT. The added mass and damping coefficients, exciting forces from diffraction potential and the hydrostatic data obtained using WAMIT are combined with the FAST code to obtain an aero-servo-hydro-elastic model. The hydrodynamic added mass and damping are compared with the OC3-Hywind (JONKMAN, 2010) and the tower base motions and platform motions are obtained for wind speed 3.7 m/s with 4 meter wave height and 0º wave heading angle.

2. NREL 5MW Spar-type floating turbine

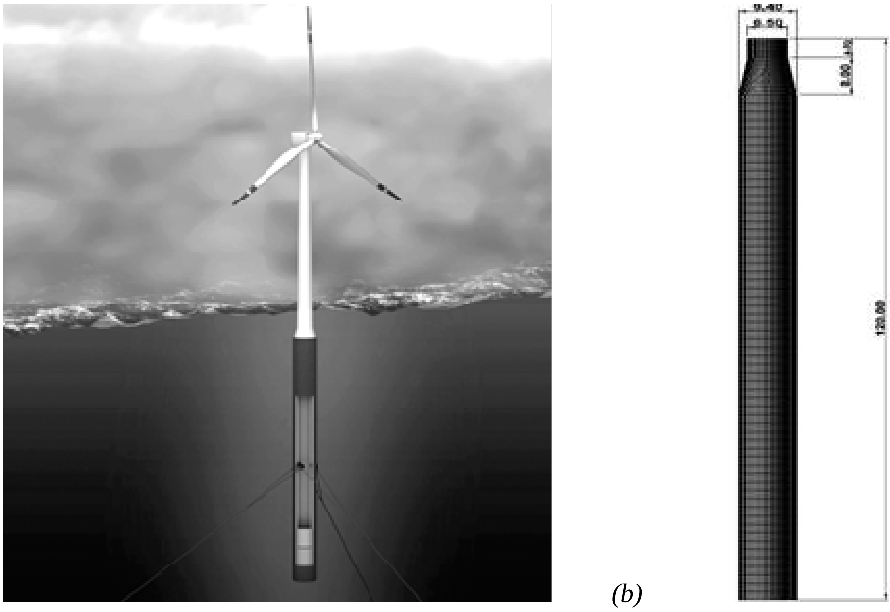
In the present study, the NREL 5MW Spar-type floating wind turbine is considered for the analysis. The hydrodynamic analysis of the spar-type floating wind turbine is also carried out, and the detailed descriptions for the study are as follows. The wind turbine properties, platform properties and mooring system properties are kept the same as described in OC3 Hywind (see JONKMAN, 2010).

2.1 Geometry of Spar-type floating wind turbine

The Spar-type floater is modeled with two geometric planes of symmetry with 1,900 rectangular panels within a quarter of the body for WAMIT. The Spar-type floating wind turbine and the geometry of the Spar-type floater is shown in figure 1(a,b).

2.2 Hydrodynamic added mass and damping

The mesh size of 1900 panels for a quarter body is simulated in frequency domain from 0.05 rad/s to 3 rad/s. Added mass, damping coefficient, hydrostatic matrices and exciting force are generated using WAMIT, which depends on the shape of the floater. In figure 2(a), the added mass for translation forces are obtained and in figure 2(b), the added mass for the rotational moments are obtained using the geometry of the Spar-type floating wind turbine. It is observed that the surge-surge element of the frequency dependent added mass for translation force is identical to the sway-sway element. On the other hand, the roll-roll element for the rotational force is identical to the pitch-pitch element. This is due to the symmetry in the spar's body.



(a) *(b)*

Figure 1. (a) Spar-type floting wind turbine (b) WAMIT geometry for spar-type floater

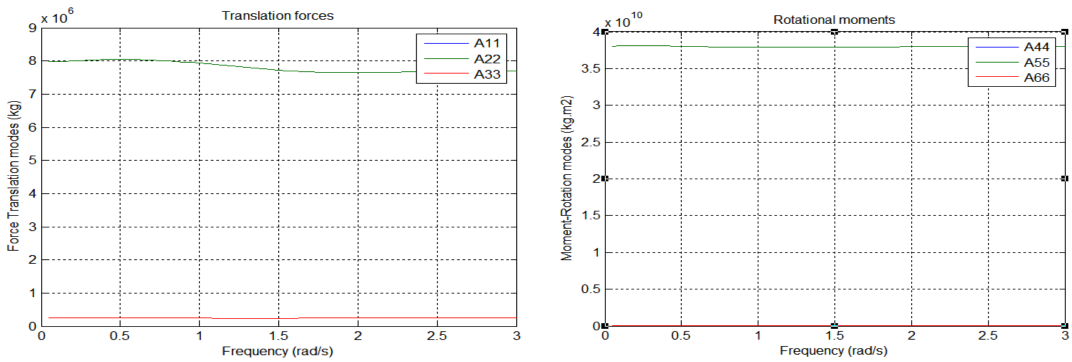


Figure 2. Hydrodynamic added mass for (a)translation forces, (b)rotational moments.

In figure 3(a), the damping coefficient for the translation forces are plotted, whereas, in figure 3(b), the damping for the rotational moments are plotted. In this case also the surge-surge element for translation force is identical to the sway-sway element and the roll-roll element for the rotational force is identical to the pitch-pitch element. The comparison of the present result with OC3-Hywind results shows that both the translation force and the rotational moments are almost same.

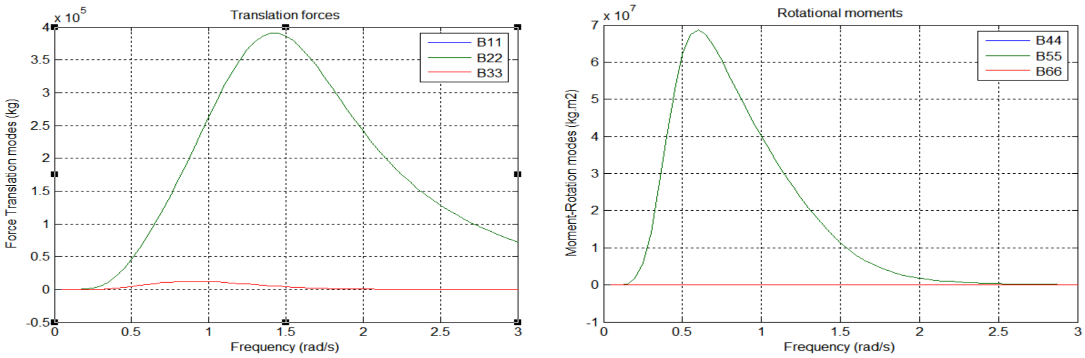


Figure 3. (a) Hydrodynamic damping for (a)translation forces, (b)rotational moments.

2.3 <u>Fully coupled Aero-Hydro-Servo-Elastic simulation</u>

The coupled aero-hydro-servo-elastic simulations are performed using the FAST code. The mean wave height is fixed at 4 m and 0º wave heading angle for wind speed 3.7 m/s. The simulation is performed for 15 min time series of tower base: surge, heave, sway and platform rotations; pitch, roll, yaw motions simulations. Tower base motions and platform rotations results are shown for 3.7 m/s wind speed.

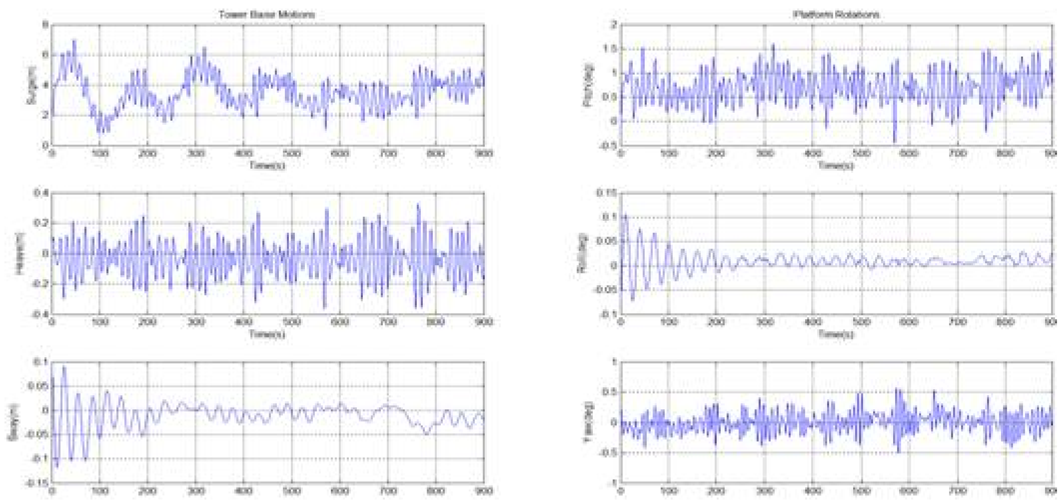


Figure 4. Tower base motions and platform motions for 4m wave height, 0º wave heading angle and 3.7 m/s wind speed.

Stability is an important case of wind generation for floating wind turbines. In figure 4, fully coupled sample time series for tower base motions: surge, heave, sway and platform rotations; pitch, roll yaw for fifteen minutes are obtained. It is observed that within first 400 s, the surge motion is between 1 m-7 m but after 700 s, the surge motion decreases to 3 m-5 m. Heave motion is in between approximately ±0.1 m. Sway motion is observed to be decreasing after 200 s, and is in between approximately ±0.01 m. Pitch oscillation is approximately within 1º-0.5º. The roll motion approaches to zero after 200 s, and yaw oscillation is very close to 0º.

In figure 5(a), the sway motion is plotted versus wind speed for various values of mean time range with 4m wave height. It is observed that, the sway motion increases as the wind speed increases. This may be due to fact that, as the wind speed increases, the blades of the turbine starts rotating faster and the horizontal component of the force induces sway motion. In figure 5(b), the pitch motion is observed to be increasing with the increase in wind speed but for higher values of wind speed the pitch motion decreases. This is due to the change in the pitch angle of the blades which results in the decrease in pitch motion after certain values of wind speed.
In figure 6(a), the sway motion is plotted versus wave height for various values of mean time range with 3.7m/s wind speed. It is observed that, the sway motion increases with the increase in wave height for 200s-400s and 600s-800s but for other values sway remains constant. The constant value in sway motion for certain mean time range suggests that at that time range the effect of wave height is minimal. In figure 6(b), the pitch motion is observed to be constant for all values of mean time range. This is due to fact that, the rotations of the blade suppress the pitch motion with the increase in wave height, and as a result the pitch motion is not affected with the increase in wave height.

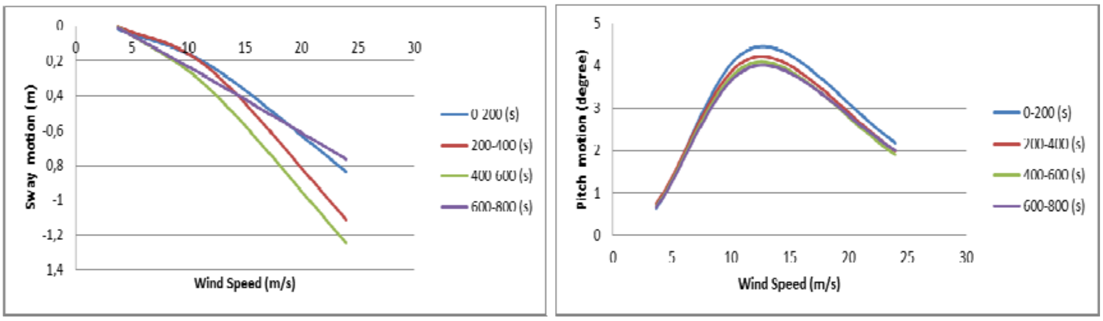


Figure 5. Variation in sway and pitch motion versus wind speed for wave height 4 m.

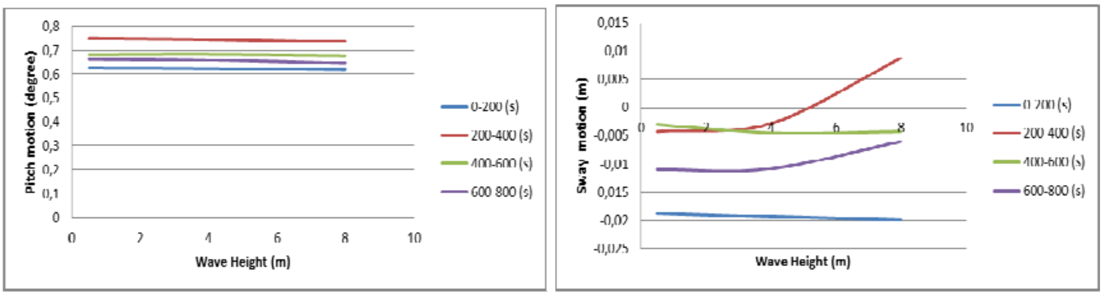


Figure 6. Variation in sway and pitch motion versus wave height for wind speed 3.7m/s.

3. Conclusions

A dynamic analysis of 5MW Spar-type floating wind turbine is performed using the FAST code. The hydrodynamic behaviour of the Spar-type floater concept is studied using WAMIT. The hydrodynamic added mass for the force translation and moment rotation is observed to be the same as compared to OC3-Hywind (JONKMAN, 2010). The hydrodynamic damping for force translation is low as compared to OC3-Hywind, whereas the moment rotation is observed to be the same. The aero-servo-hydro-elastic model for FAST is obtained by combining hydrodynamic characteristics of the floater obtained using WAMIT with aero-servo-elastic model of FAST. The results for tower base motions and platform motions are obtained for wind speed 3.7 m/s with 4 m wave height and 0º wave heading angle.

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