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Floating offshore wind turbine system simulation

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Abstract : Offshore wind energy is gaining more and more attention during this decade. For the countries with coast sites, the water depth is significantly large. This causes attention to the floating wind turbine. Offshore wind turbines are designed and analyzed using comprehensive simulation codes that account for the coupled dynamics of the wind inflow, aerodynamics, elasticity and controls of the wind turbine, along with the incident waves, sea current, hydrodynamics, and foundation dynamics of the support structures. In this work, a three-bladed 5MW upwind wind turbine installed on a floating spar buoy in 320m of water is studied by using of fully coupled aero-hydro-servo-elastic simulation tool. Specifications of the structures are chosen from the OC3 (Offshore Code Comparison Collaboration) under "IEA Wind Annex XXIII-subtask2". The primary external conditions due to wind and waves are simulated. Certain design load case is investigated.

Key words : offshore wind energy(해상풍력), turbulence(난류), floating foundation(부유식 기초), hydrodynamic load (수력부하)

Nomenclature

V_{hub} : wind speed, m/s
V_r: rated wind speed, m/s
I_{ref}: reference turbulence intensity
H_s: significant wave height, m
T_p: peak spectral period, s

subscrip

IEA: International Energy Agency
NREL: National Renewable Energy Laboratory
OC3: Offshore Code Comparison Collaboration
DLC: Design Load Case
OWT: Offshore Wind Turbine
FAST:(Fatigue, Aerodynamics, Structures and Turbulence)
SWL:Still Water Level
NTM: Normal Turbulence Model
NSS: Normal Sea State

1. Introduction

Due to the high oil price and climate change the emerging need for renewable and environment-friendly sources of energy has led to a dramatic development of the wind energy technologies. Especially because of good wind condition, less turbulence and no area limitation, the offshore wind energy drives so much attention these years. The vast offshore wind resource represents a potential to use wind turbines installed offshore to power much of the world. Although it is still in very early stage (only 1.2% of the total wind energy installed capacity in 2008)[1], estimated annual growth rate of offshore wind energy is 31% and the global installed capacity will be likely to reach at least 38GW in 2020.

So far, a lot of focus has been on offshore turbines mounted on a fix foundation. By the end of 2008, all the offshore foundation types, which are used in the commercial wind farms, are monopile or gravity. Current fixed-bottom technology has seen limited deployment to water depth up to 50m. However, for a lot of coast sites, especially in Norway, Spain and the eastern coast of USA, water depths are much larger so that floating type platform may be the most economical means for deploying offshore wind turbines.

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Numerous floating platform concepts are possible for offshore wind turbines, including spar-buoys, tension leg platforms, barges and hybrid concepts and so on. The spar-buoys concept called "Hywind"[3], developed by StatoilHydro of Norway, was chosen for the modeling activities of OC3 (Offshore Code Comparison Collaboration) under "IEA Wind Annex XXIII-subtask2"[2]. It is referred as "OC3-Hywind" with slightly difference from the original Hywind concept.

In this work, a three-bladed 5MW upwind wind turbine installed on a floating spar buoy in 320m water is studied by using of fully coupled aero-hydro-servo-elastic simulation tool. Specifications of the structures and platform are chosen from the OC3. The steady state power curve and power production loads are evaluated.

2. Description of the work

2.1 Wind turbine model

Based on the fictitious and real models, which include WindPACT, DOWEC, RECOFF, Multibrid M5000 and RePower5M, the NREL offshore 5MW model is proposed by National Renewable Energy Laboratory[4]. The NREL 5MW model is a representative of utility-scale multimegawatt turbine which also has been used to establish the reference specification model for several other research projects[5)6)7)].

In our work, the NREL offshore 5MW wind turbine is used as baseline model. The description of the main characteristics of the model is presented in Table 1.

Table 1 Specifications of NREL offshore 5MW wind turbine

Rated power	5MW
Wind Regime	IEC61400-3 Class 1B
Rotor Orientation	Upwind
Control	Variable Speed, Collective Pitch
Drivetrain	High Speed, Multiple Stage Gearbox
Rotor Diameter	126 m
Hub Height	90 m
Cut-In, Rated, Cut-Out Wind Speed	3 m/s, 11.4 m/s, 25 m/s
Cut-In, Rated Rotor Speed	6.9rpm, 12.1 rpm
Rated Tip Speed	80 m/s
Overhang, Shaft Tilt, Precone	5 m, 5°, 2.5°
Rotor Mass	110,000 kg
Nacelle Mass	240,000 kg
Tower Mass	347460 kg
Overall Center of Mass	(-0.2m, 0.0m, 64.0m)

2.2 Platform model

The OC3-Hywind platform is a slender draft hull with ballast in the lower part, which is supported by three mooring lines consisting of steel wires and clump weights (Fig. 1). A floating structure had the typical DOFs, namely surge, sway, heave, roll, pitch, yaw (Fig.2). The OC3-Hywind platform is designed for water depth between 200 and 700m. But in OC3, 320m of water is assumed. The key parameters of this model are given in Table 2.

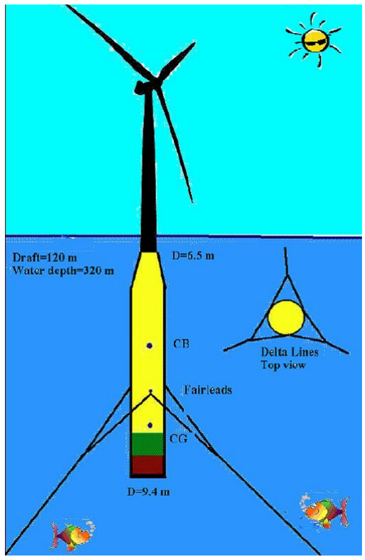

Fig.1 Illustration of platform model

Table 2 Properties of OC3-Hywind platform

Depth to platform base below SWL (Total draft)	120m
Elevation to platform top (Tower base) above SWL	10m
Depth to top of taper below SWL	4m
Depth to bottom of taper below SWL	12m
Platform diameter above taper	6.5m
Platform diameter below taper	9.4m
Platform mass, including ballast	7,466,330kg
CM below SWL along platform centerline	89.9155m
Platform roll inertia about CM	4,229,230,000 kg m^2
Platform pitch inertia about CM	4,226,230,000 kg m^2
Platform yaw inertia about platform centerline	164,230,000kg m^2

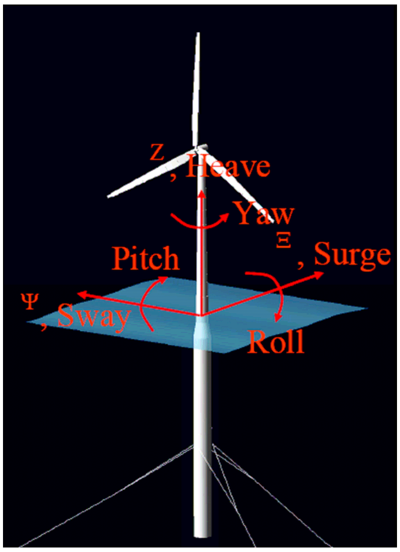

Fig. 2 Coordinate system of the platform

2.3 Definition of the design load case

The key issue in the deployment of the offshore floating turbine has been to well predict the coupled aero-hydro-servo-elastic behavior of the whole system. The fully coupled, flexible offshore wind turbine is considered in our load case. The load case and environmental conditions are summarized in Table 3 in detail. Here, stochastic wind and wave conditions are applied. The Mann turbulence model and irregular Airy wave model —Pierson-Moskowitz spectrum used in simulation are shown in Fig. 3 and Fig.4.

Table 3 Load case and environmental conditions for our simulation

DLC	wind	wave
	NTM: $V_{hub}=V_r$(11.4 m/s). I_{ref}=0.14(B), turbulence model=Mann	NSS: Irregular Airy, H_s=6m. T_p=10s

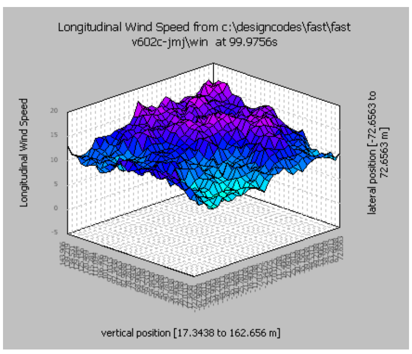

Fig. 3 Mann turbulence model

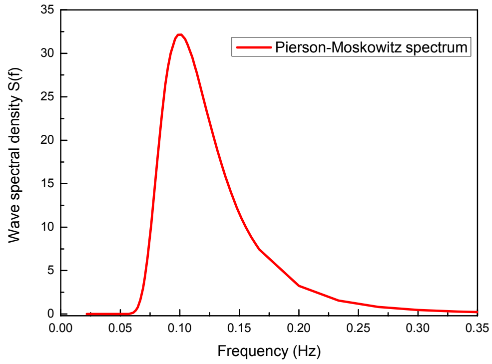

Fig. 4 Pierson-Moskowitz spectral

2.4 Simulation process

In our simulation, the fully coupled aero-hydro-servo-elastic simulation tool is used. Firstly, the time series wind data is generated by a stochastic, full field, turbulent wind simulator for modeling different wind conditions. By using those wind data, the aerodynamic loads along the blades are calculated by AeroDyn. The aerodynamic model in AeroDyn, used to transform the wind flow field to loads on the blades, is a blade element momentum model or generalized dynamic wake model. Then hydrodynamic effects and the forces which arise from motions of the floating type OWT are calculated in HydroDyn on basis of the potential flow theory. The structural-dynamic & control-system responses, as part of the aero-hydro-servo-elastic solution, are simulated by FAST, which is an open source code developed in NREL.

An external dynamic link library (DLL) in the style of Garrad Hassan's Bladed wind turbine software package is implemented directly as the control system. By integrating AeroDyn, HydroDyn and external controller into FAST, we can get the aero-hydro-servo-elastic response of the whole system. The simulation process is given in Fig.5.

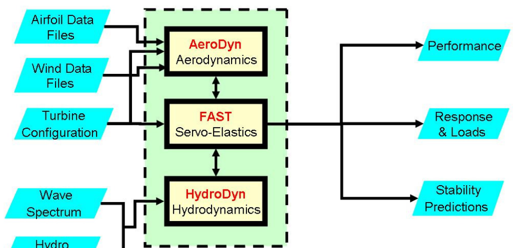

Fig.5 Simulation process

3. Results and Discussion

In the simulation, there are totally 57 output parameters (Fig.6), which involve loads and deflection of the blade, driven, generator, tower, platform and mooring system. Time series with the statistic results of some outputs are given in the following.

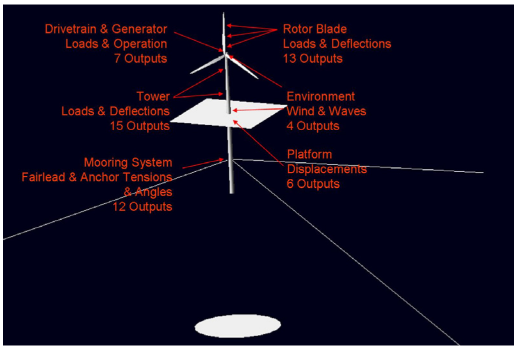

Fig.6 Output parameters

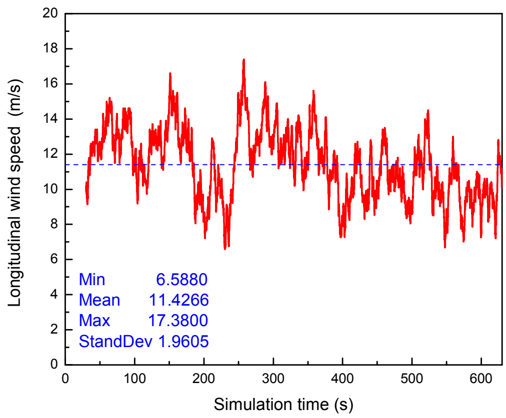

Fig.7 Longitudinal wind speed

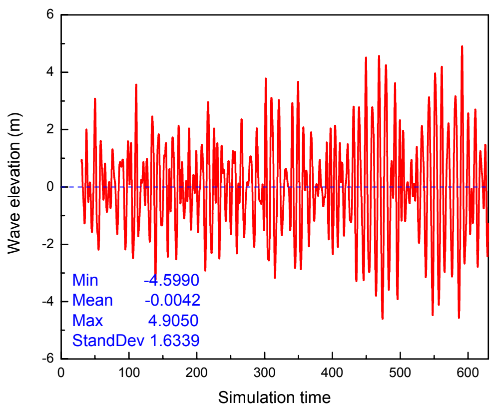

Fig. 8 Wave elevation

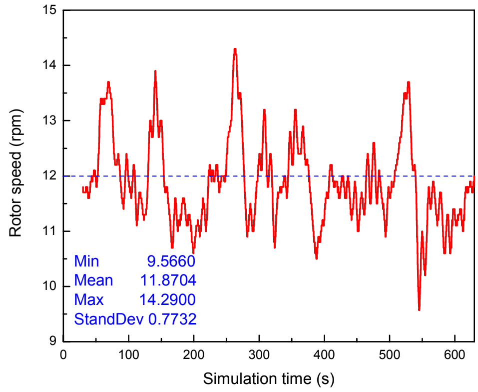

Fig. 9 Rotor speed

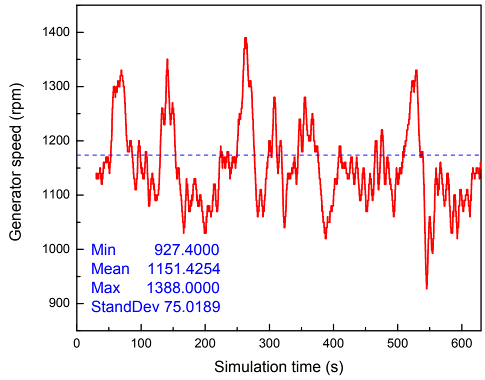

Fig.10 Generator speed

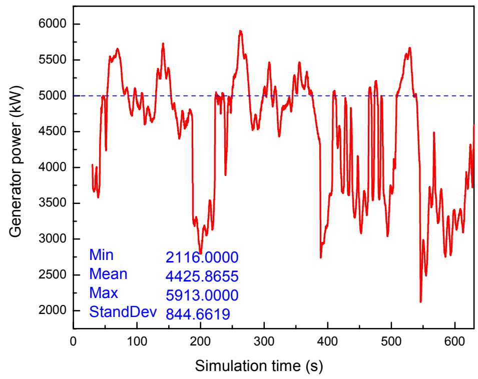

Fig.11 Generator electrical power

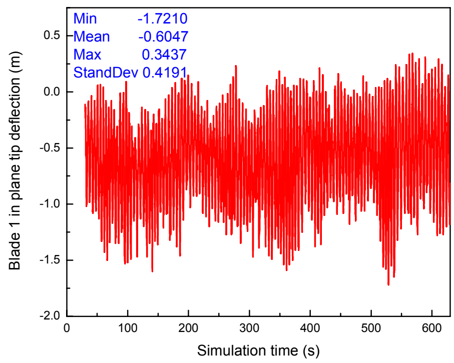

Fig.12 Blade 1 in-plane tip deflection

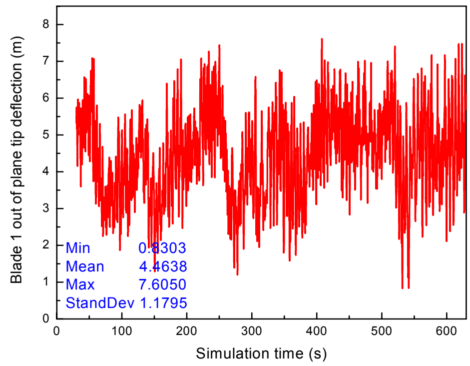

Fig.13 Blade 1 out of plane tip deflection

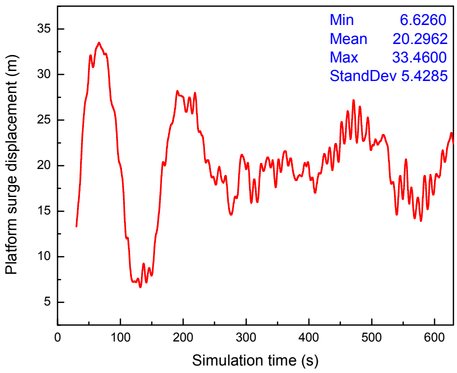

Fig.14 Platform surge displacement

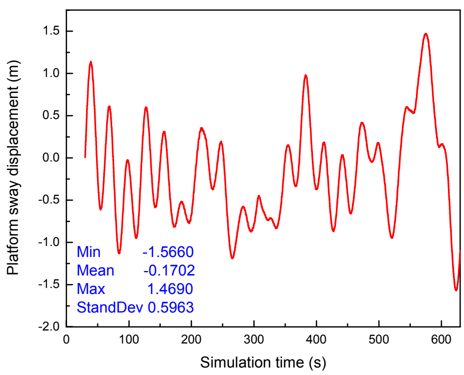

Fig.15 Platform sway displacement

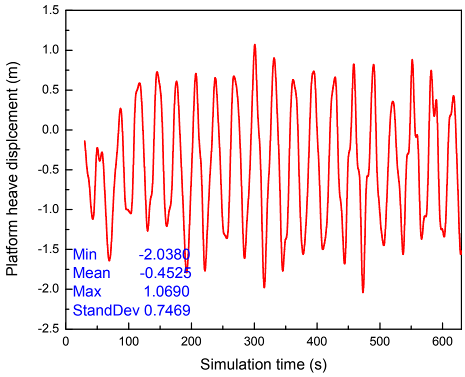

Fig.16 Platform heave displacement

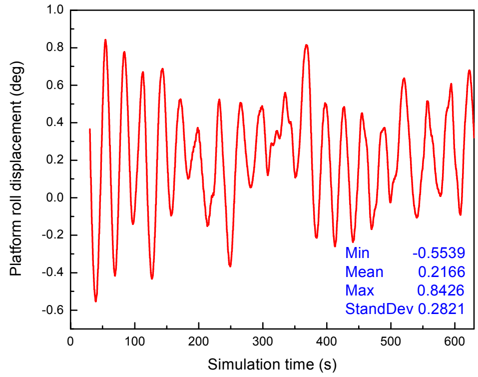

Fig.17 Platform roll displacement

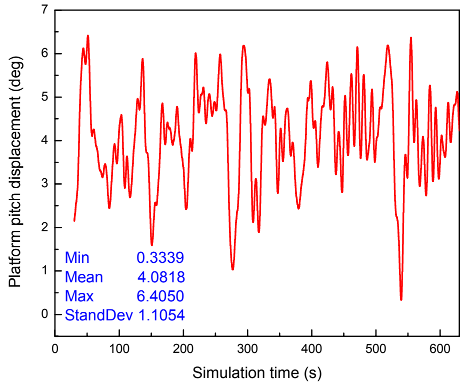

Fig.18 Platform pitch displacement

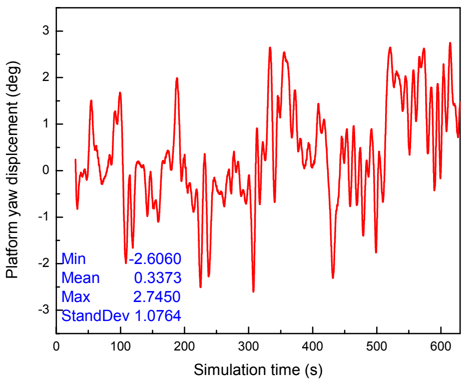

Fig.19 Platform yaw displacement

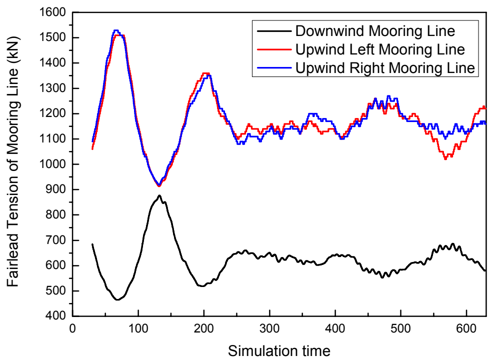

Fig.20 Fairlead tension of mooring lines

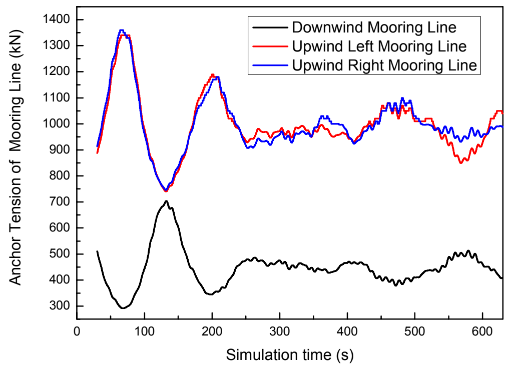

Fig.21 Anchor tension of mooring lines

From the simulation results, we see that the longitudinal wind speed deviates from the rated speed at hub (11.4m/s) with the turbulence intensity of 0.14% (Fig.7). Different from the regular wave, the stochastic wave profile, in the case of irregular wave condition, could be seen instead of oscillative one (Fig.8). From Fig. 9 and Fig.10, we see the rotor speed varies with respect to rated rotor speed 12rpm while the speed of generator varies with respect to rated 1173.7rpm. The data profiles from these two results are so similar because 100% generator efficiency is assumed in our simulation. Considering the generated electrical power, the mean value of 4.42MW is presented, which is a little bit lower than the rated one (5MW).

For the blade, the out of plane deflection is much lager than in plane deflection(Fig. 12 and Fig. 13). The displacements of platform in its every DOF (surge, sway, heave, roll, pitch and yaw) are shown in Fig. 14 through Fig. 19. Among the translational displacements, the surge, which is in the direction of wind inflow, is much larger than others. Fig. 20 and Fig. 21 present the fairlead and anchor tension of different mooring lines, respectively. The upwind mooring lines receive almost two times tension load of that in downwind mooring line.

4. Conclusion

The three-bladed NREL 5MW offshore upwind variable speed, pitch collective control wind turbine is investigated. The design load case with normal turbulence and normal sea state is simulated by the coupled aero-hydro-servo-elastic tool.

With given wind and wave condition, the aerodynamic loads, hydrodynamic loads and some other results are presented in this work.

Our work results in more understanding of the behavior of offshore floating wind turbines and modeling techniques. The further research of the frequency domain investigation and stability analysis is needed.

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