ATLANTIS PRESS
Advances in Computer Science Research, volume 74
2nd International Conference on Computer Engineering, Information Science & Application Technology (ICCIA 2017)

Dynamic response sensitivity of an offshore wind turbine for multiple load condition

Youliang Cheng, Zhanpu Xue[a,*], Yuekun Wang and Ning Zhang
School of Energy Power and Mechanical Engineering, North China Electric Power University, Baoding 071003, China
[a]shenghuo166@163.com

Keywords: Response, Multiple load, offshore wind turbine, Dynamics.

Abstract. In this paper, a comprehensive study is performed on the dynamic response of an offshore wind turbine for multiple load condition. The aim is to evaluate to what extent the multiple loading affects the wind turbine for running. Based on consistent flexible multi-body models calibrated to multiple loading functions of a monopole embedded in a linear viscoelastic soil layer, fully coupled aero-hydro-elastic simulations are conducted in the nonlinear multi-body code. Correlation of wind speeds and waves is derived on basis of wind–wave scatter diagrams from China south sea. Changes of the multiple loading, the response of an offshore wind turbine are shown to be critical for the fatigue damage equivalent moment that may change with more than 20% for parked wind turbine conditions.

1. Introduction

Under the excitations of offshore loads, such as wind, wave and current, random vibration and displacement of offshore wind turbine would occur. Both wind speed, wave frequencies and misalignment between wind and waves have on the floating wind turbine system dynamics [1].Furthermore, the wake of a single vertical axis wind turbines placed in the atmospheric boundary layer using large-eddy simulation for the first time [2].In the design, pole-placement is used as a time-domain performance specification while optimization is used to improve the closed-loop system robustness to exogenous disturbances or modelling uncertainty [3].It improves on previous efforts by incorporating a cross-coupling stiffness thereby modelling the foundation using three springs, it also derives the natural frequency using Timoshenko beam model by including rotary inertia and shear deformation [4]. A 5-MW offshore wind turbine on a monopile structure is modelled and the load effects in the drivetrain are calculated through a de-coupled analysis approach [5]. A preliminary assessment of the dynamic behavior of a 5-MW braceless semisubmersible offshore wind turbine with three columns and two fully submerged pontoons is presented for selected environmental operational conditions that correspond to a deep water offshore site with depth 200 m[6]. To simulate the pitching motion of floating platform, it used onshore wind turbine model with inflow with oscillating wind speed that simulates relative wind speed change from wind turbine's fore-aft pitching motion [7]. Particulars of this research are to examine the unique dynamic response characteristics of the thrust-matched blade system, which includes a better performance-matched rotor relative to the geometry-matched blade system [8]. The aim was to design a suitable substructure, such as a jacket or multipile, to support a 5 MW wind turbine in 33 m deep water for the Korean Southwest Offshore Wind Farm. It also aimed to compare the dynamic responses of different substructures including the monopile, jacket and multipile and evaluate their feasibility [9].

In this study, taking account the aeroelastic coupling, the present studies introduce the airfoil vibrational velocity and the torsional deflection of a flexible blade in the wind response of an offshore wind turbine, the intention of this study is to simulate the dynamic response of an offshore wind turbine for multiple load condition, such as wind, wave and current coupling. To investigate the unsteady load characteristics, an analysis on the time domain multiple loads aeroelastic coupling responses of an offshore wind turbine is completed. The effects of wind turbine tower torsional deflection and kinetic parameters change on the multiple dynamic loads are quantifiably analyzed.

The comparison and analysis on the simulation results clearly indicate the significance and necessity of considering multiple loads aeroelastic coupling characteristics in an offshore wind turbine aerodynamic load calculation during the offshore wind turbine design stage.

2. Modeling of an Offshore Wind Turbine on Multiple Load

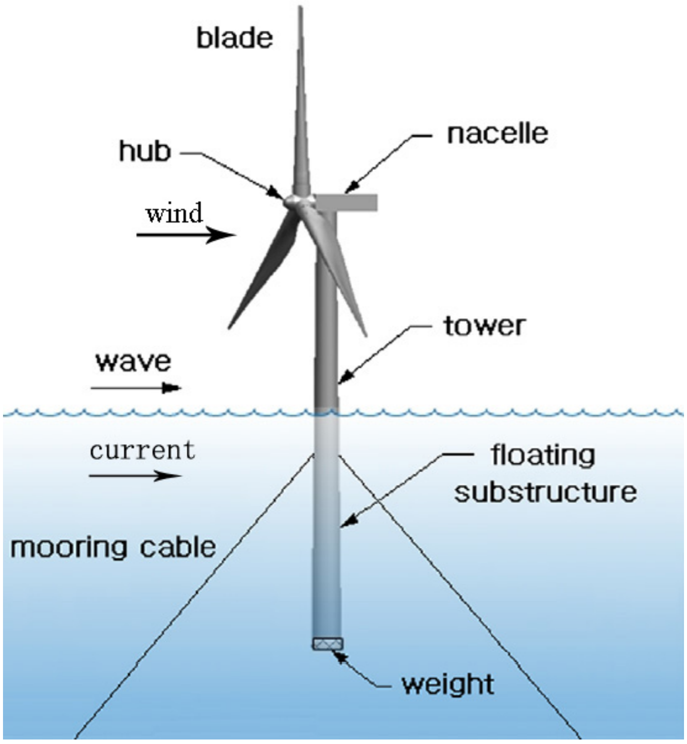


Fig. 1 An offshore wind turbine model

An offshore wind turbine model is represented in Fig.1, where the whole wind turbine is supported by the buoyancy force and the amplitude of rotational oscillations could be reduced by the bottom weight, tuned liquid damper and hydraulic control. Regarding the dynamic displacement of wind turbine which is caused by wind, wave and current loads, only surge and sway displacements are counteracted by the mooring lines when a catenary mooring system is adopted while the displacements in all DOFs are counteracted by tension lines if a TLP system is adopted. Wind force acting on the wind turbine can be divided into two parts. The first part is a concentrated force called thrust which is applied at the top of the tower. The second part contains a distributed force which is applied along the height of the tower.

3. Equations of Motion

$$\frac{\partial \rho}{\partial t} + \nabla \times (\rho u) = 0 \tag{1}$$

Where ρ is density, t is time and u is refers to fluid velocity vector.

$$\frac{\partial (\rho u)}{\partial t} + \nabla \times (\rho u u) = -\nabla p + \rho g + \nabla \times (\mu \nabla u) - \nabla \times \tau_t \tag{2}$$

Where p is the pressure, g is vector of gravitational acceleration, μ is molecular dynamic viscosity and τ_t is the divergence of the turbulence stresses which accounts for auxiliary stresses due to velocity fluctuations.

$$\frac{\partial (\rho e)}{\partial t} + \nabla \times (\rho e u) = \nabla \times (k_{eff} \nabla T) - \nabla \times \left(\sum_i h_i j_i \right) \tag{3}$$

Where e is the specific internal energy, k_{eff} is the effective heat conductivity, T is the air temperature, h_i is the specific enthalpy of fluid and j_i is the mass flux.

$$\frac{\partial(\rho k)}{\partial t}+\nabla\times(\rho k u)=\nabla\times\left[\alpha_k\mu_{eff}\nabla k\right]+G_k+G_b-\rho_\varepsilon \tag{4}$$

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\nabla\times(\rho\varepsilon u)=\nabla\times\left[\alpha_k\mu_{eff}\nabla\varepsilon\right]+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \tag{5}$$

Where G_k stands for source of turbulent kinetic energy due to average velocity gradient, G_b is source of turbulent kinetic energy due to buoyancy force, α_k and α_ε are turbulent Prandtls numbers, $C_{1\varepsilon}$, $C_{2\varepsilon}$ and $C_{3\varepsilon}$ are empirical model constants.

4. Results and Discussion

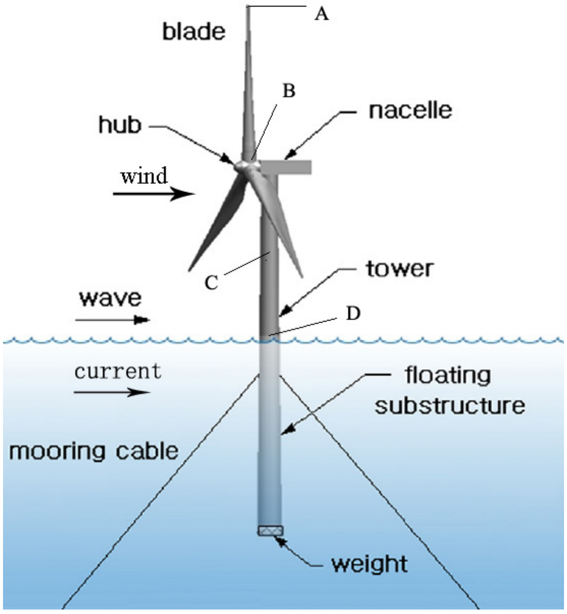
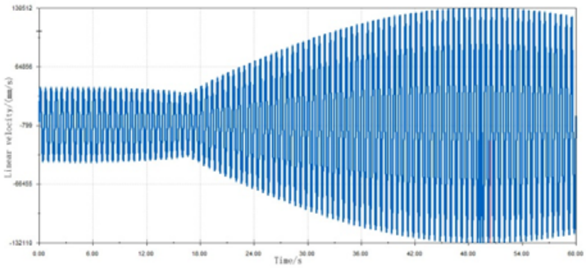


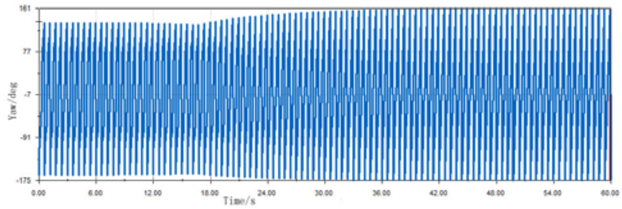
Fig.2 The point position of the offshore wind turbine

In this section, the response of the 5-MW offshore wind turbine is subjected to the dynamic parameter is evaluated using Solidworks software, wind turbine tower must be discretized to the finite number of elements. As seen in Fig.2, The point(A,B,C,D) show the position of the offshore wind turbine.Fig.3 (a) and (b) represent the time and velocity responses of the point A in offshore wind turbine(OWT), and considering wind and wave coupling. In 60S, the tip of the blade maximum linear speed is 136512 mm/s in Fig.3(a) ,the yaw angle change -175 °to 161°in Fig.3(b).

Fig. 3 shows the time domain response of the offshore wind turbine under the wind, wave and current coupling. Dynamic charting of the coupling response is very useful because the response can be examined independently of the wind speed and the kinetic energy factor. In the figure, the horizonta axis represents the time of the energy consumption to the movement energy and the horizontal axis indicates the ratio of the average kinetic energy which takes 10 rpm in the case study. By examining the below diagram, it can be realized that the ratio of the dynamic amplitude to the static amplitude is reduced by increasing the average kinetic energy. This finding suggests that dynamic part of the response reduces the maximum torque. Moreover, it can be realized that the tip of the blade resonance frequency equals to half of the natural frequencies.



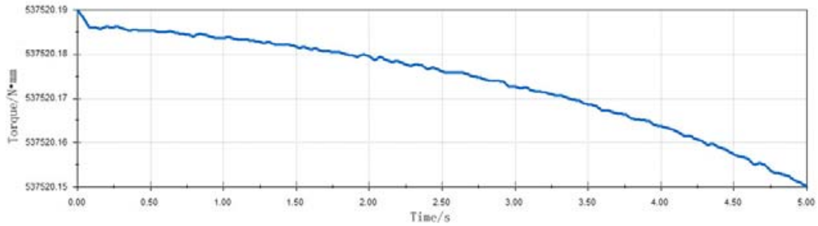
(a)



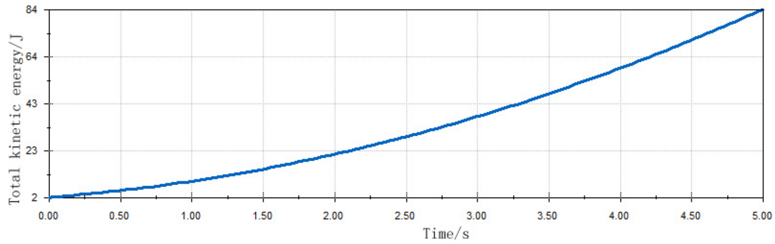
(b)

Fig.3 The dynamic response of the point A in offshore wind turbine

Fig. 4 represents the time and frequency responses of wind and wave coupled motions in point B of an offshore wind turbine. The torque such a fraction does not have any influence on the the total kinetic energy because its change is counteracted by the reaction. The point B of the torque maximum is 537.52N • m in Fig.4(a), the total kinetic energy maximum is 84 J and the minimum value is 2 J in Fig.4(b).The point B motion at the offshore wind turbine shows the torque time history with the peak amplitude. Meanwhile, the total kinetic energy shows a small pitch motion with the peak amplitude near at the beginning and then it exhibits a beating-like pitch motion with the peak amplitude, implying that the rotational inertia of point B is remarkable.



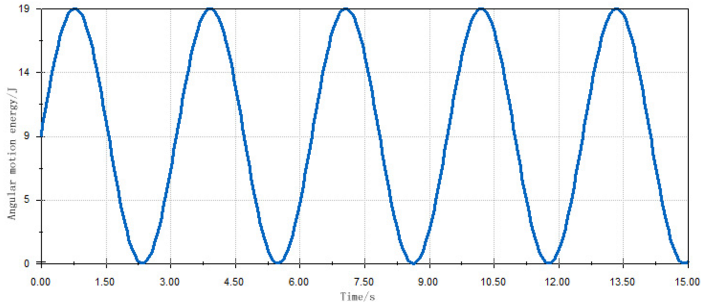
(a)



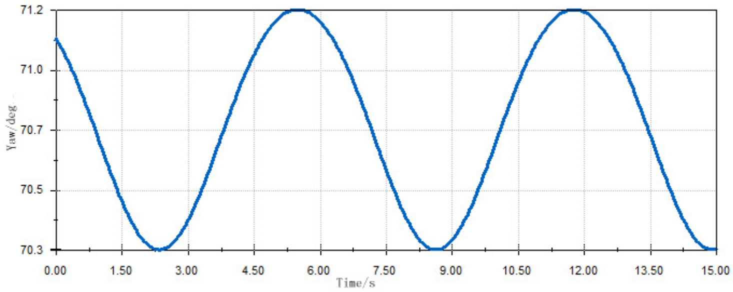
(b)

Fig..4 The dynamic response of the point B in offshore wind turbine

Fig. 5 shows that the motion parameters variation amplitude of the point C in offshore wind turbine can be computed by t the finite element model, considering wind, wave and current coupling. The point C of the angular motion energy of the maximum value is 19 J and the minimum value is 0 J in Fig.5(a), the yaw of the maximum value is 71.2°and the minimum value is 70.3°in Fig.5(b).As the mean wind speed increases, the Brandt angle of the means obtained by applying the multple load changes little, but the sine-wave-like time history with the peak amplitude and the amplitude of Brandt variances increases dramatically. When the wind speed is low, the point C mainly work in the linear region, therefore, there is little difference between the calculation results of the steady and unsteady models. Nevertheless, when the mean wind speed approaches to 20 m/s, the point C in stall conditions, so the dynamic stall makes the values of the lift and drag coefficients fluctuate more violently.



(a)

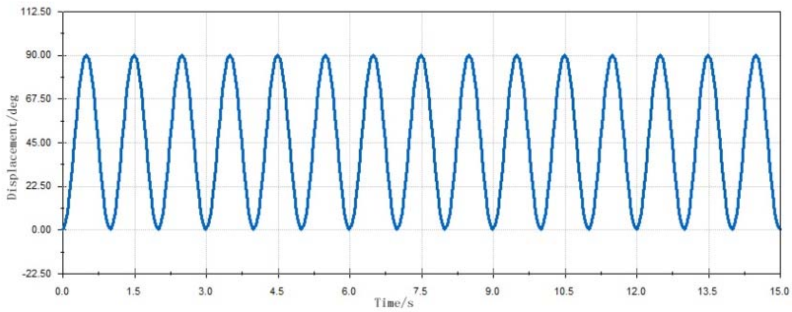


(b)

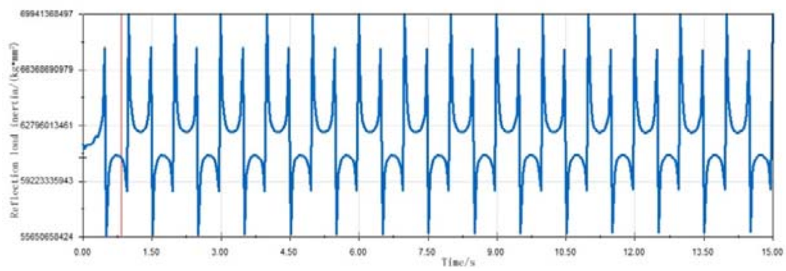
Fig. 5 The dynamic response of the point C in offshore wind turbine

Fig. 6 represents the dependence of the peak amplitude in the response of motion on the offshore wind turbine point D which considering wind, wave and current coupling. The point D of the displacement maximum value is 90° and minimum value is 0° in Fig.6(a).The reflection load inertia maximum value is 69941kg • m2 and the minimum value is 55650kg • m2 in Fig.6(b).

The reflection load inertia becomes more sensitive to the dynamic system of the offshore wind turbine in wind, wave and current coupling excitation, because the total kinetic energy increases when the reflection load inertia becomes tigh tened. But, it is observed that the peak amplitudes in coupled motions approach certain values, implying that an appropriate approach which can be sensitive to dynamic responses of the offshore wind turbine.



(a)



(b)

Fig.6 The dynamic response of the point D in offshore wind turbine

5. Conclusion

In this paper, the dynamic responses of an offshore wind turbine in multiple load, such as wind, wave and current coupled. Kinetic parameters changes have been investigated by the Finite Element Analysis. The upper part of offshore wind turbine is simplified both the blade and nacelle. The incompressible potential wave flow in domain was generated by the Pierson–Moskowitz spectrum, and the wave-floating substructure and wave-mooring cable interactions were simulated by the coupled iterative methods. The time and frequency responses of the rigid floating substructure and the cable tension were parametrically investigated with respect to the total length and connection position of the points in the offshore wind turbine system.

According to the parametric numerical results the following main observations are drawn, It can be concluded that,

1).The Brandt angle and Reflection load inertia motions of the offshore wind turbine system become more sensitive to the external load excitation such that the wind, wave and current coupled. Meanwhile, the energy consumption is important sensitive to the response. Changes of the multiple loading, the response of an offshore wind turbine are shown to be critical for the fatigue damage equivalent moment that may change with more than 20% for parked wind turbine conditions.

2).To the connection position of the offshore wind turbine system, the peak amplitude in wave motion slightly decreases until the connection position reaches the center of buoyancy, but it dramatically increases as the connection position becomes lower than such a critical position. Meanwhile,

The linear displacement amplitude in blade motion monotonically increases as the connection position goes down.

6. Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgements

This work is generously supported by The Fundamental Research Funds for the Central Universities of China (NO.2016XS107)

References

[1]. Søren Christiansen, Thomas Bak, Torben Knudsen. Damping Wind and Wave Loads on a Floating Wind Turbine. Energies,6(2013):4097-4116.
[2]. Sina Shamsoddin, Fernando Porté-Agel. A Large-Eddy Simulation Study of Vertical Axis Wind Turbine Wakes in the Atmospheric Boundary Layer. Energies, 9(2016):1-23.
[3]. Fengming Shi, Ron Patton. An Active Fault Tolerant Control Approach to an Offshore Wind Turbine Model. Renewable Energy, 75(2015): 788-798.
[4]. L. Arany, S. Bhattacharya, S. Adhikari, S.J. Hogan, J.H.G. Macdonald. An Analytical Model to Predict the Natural Frequency of Offshore Wind Turbines on Three-spring Flexible Foundations Using two Different Beam Models. Soil Dynamics and Earthquake Engineering 74(2015): 40–45.
[5]. Amir Rasekhi Nejad, Erin E. Bachynski, Lin Li, Torgeir Moan. Correlation between Acceleration and Drivetrain Load Effects for Monopile Offshore Wind Turbines. Energy Procedia, 94(2016): 487 – 496.
[6]. Madjid Karimirad, Constantine Michailides. Dynamic Analysis of a Braceless Semisubmersible Offshore Wind Turbine in Operational Conditions. Energy Procedia, 80 (2015):21 – 29.
[7]. Mitsumasa Iino, Toshiki Chujo, Makoto Iida, Chuichi Arakawa. Effect of Forced Excitation on Wind Turbine with Dynamic Analysis in Deep Offshore Wind in Addition to Japanese Status of Offshore Projects. Energy Procedia, 24(2012):11 – 17.

[8]. Fei Duan, Zhiqiang Hu, Geliang Liu, Jin Wang. Experimental Comparisons of Dynamic Properties of Floating Wind Turbine Systems Based on two Different Rotor Concepts. Applied Ocean Research, 58(2016):266–280.

[9]. Wei Shi, Jonghoon Han, Changwan Kim, Daeyong Lee, Hyunkyoung Shin, Hyunchul Park. Feasibility Study of offshore Wind Turbine Substructures for Southwest Offshore Wind Farm Project in Korea. Renewable Energy, 74(2015):406-413.