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Detecting wake performance of floating offshore wind turbine

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ABSTRACT

Floating offshore wind turbine (FOWT) is always in a more complex environmental condition than onshore horizontal axis wind turbine (HAWT). The platform motions, especially pitch and surge motions, increase aerodynamic unsteadiness, wake interactions and other complex flow phenomena. These conditions influence the velocities and accelerations at the rotor sections along the blade. In the recent material, most reaches are studying aerodynamic performance of FOWT in a simple motion, for example, pitch or surge motion. However, in this paper, the aerodynamic characteristics are presented in a system pitch and surge motions. Moreover, the applying and validation of CFD method will be outlined in this paper. It can be shown from the results that the aerodynamics of floating offshore wind turbines is sufficiently distinct from conventional offshore and onshore wind turbines. It is obvious that the platform motions will have a profound effect on unsteady aerodynamic performance of the wind turbine rotor. Due to the motions, the wake will be asymmetric and more complicated. The wake appears to generate an over-predicted power and thrust. This paper will study and explain the rules and reasons of this phenomenon in detail.

1. Introduction

In the Early, wind energy development was concentrated in land. However, as wind power technology gradually extended from land to sea, offshore wind energy development has become the important direction of the global wind power industry. Floating offshore wind turbine is always in a more complex environmental condition than onshore HAWT. The unsteady aerodynamic performance of floating offshore wind turbine is associated with platform motions: surge, sway, heave, roll, pitch and yaw (illustrated in Fig. 1). Seen in Fig. 1, the origin of the coordinate x-y-z is at CG of the FOWT and moving with the floater. Meanwhile, the origin of the coordinate x'-y'-z' is at the hub center and rotating with the hub. In addition to significant yaw and pitch motions, large lower-frequency translational surge motions are also predicted. These rotational and translational motions primarily cause larger oblique flow conditions on a rotor turbine, rotor-wake interactions and influence the unsteady aerodynamics of the rotor. Unsteady aerodynamics effects can be split into mainly two parts, unsteady profile aerodynamics and dynamic inflow effects. Second, an effective wind shear or gradient across the rotor disk will be occurred due to angular motions. What's more, as a result of unsteady flows arising from a platform derived effective wind component, rapid local velocity changes. The platform motion produced an effective velocity contribution with respect to the rotor as shown in Equation (1). Here, $\hat{\mathrm{i}}, \hat{\mathrm{j}}, \hat{\mathrm{k}}$, are the coordinates of a point in the flow field in the rotor reference frame which means the same direction of *x, y, z* in Fig. 1.

$$U_{platform} = \left(U_{surge} + \dot{\theta}_{pitch} z - \dot{\theta}_{yaw} y\right)\hat{\mathrm{i}} + \left(U_{sway} + \dot{\theta}_{yaw} x - \dot{\theta}_{roll} z\right)\hat{\mathrm{j}} + \left(U_{heave} + \dot{\theta}_{roll} y - \dot{\theta}_{yaw} y\right) \quad (1)$$

Moreover, motions of FOWT will result in significant cyclical loads on all major turbine components. In order to reduce this influence, the control system, like generator torque or independent blade pitch, maybe used to reduce the peak cyclical loads. However, tuning these systems needs an accurate aerodynamic simulation capability. Most design and dynamics study of floating offshore wind turbine is to assume that the aerodynamic analysis methods used in the onshore or conventional offshore wind turbine are also suitable for floating offshore wind turbine. But this hypothesis may be not accurate. They may be in violation of the original formula assumes. For example, using Blade Element Momentum (BEM) theory and generalized dynamic wake (GDW) method, it supposed potential energy conservation of blades. Due to the limitation of this method, this may not be valid for FOWT. So the rationality of the results

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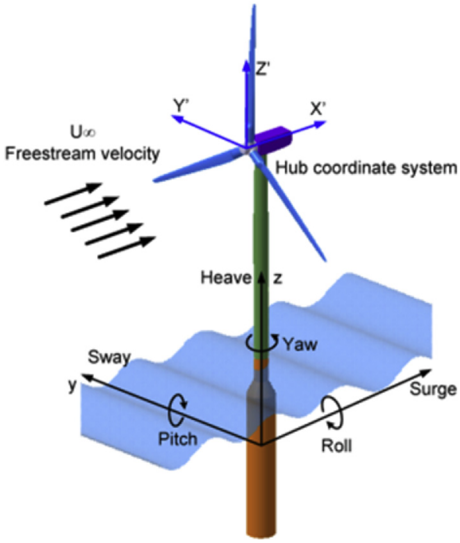

Fig. 1. Platform motion of floating offshore wind turbine (GOOGLE, Left).

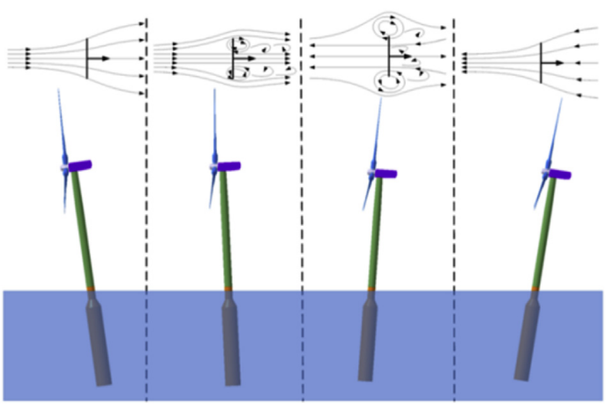

Fig. 2. Platform pitching motion flow-field (Thanhtoan et al., 2014, Right).

Table 1
Wind and sea state definitions for FAST simulations.

	U_∞(m/s)	Ω (rpm)	H_s (m)	T_p (s)
Below-rated	8.00	9.16	1.83	12.72
Severe sea condition	8.00	9.16	5.00	8.00
Rated	11.40	12.10	2.54	13.35

Table 2
Output from FAST of Spar platform.

Condition	Platform Pitching Amplitude (deg)	Platform Mean Pitch Angle (deg)	Platform Surge Amplitude (m)
Below-rated	0.34	2.50	0.70
Severe sea condition	0.36	5.00	0.65
Rated	0.49	5.00	1.14

obtained from these assumptions is doubtful.

Additionally, modern large blades are of increased flexibility allowing for larger tip deflections. The platform motions make the rotor blades precipitous drop in wind speed which leads tip speed ratios increasing. As the rotor blade begins to pitch back, it interacts with its own wake which develops the turbulent region. These contain the normal working state (NWS), the turbulent wake state (TWS), the vortex ring state (VBS) and the windmill braking state (WBS). Fig. 2 illustrates how various flow states occur when the floating platform undergoes pitching motion (Minu et al., 2014).

The different aerodynamic performance between fixed and floating wind turbine lead to researching into FOWT, see for example Musial et al. (2004). Several prototype concepts have been deployed. For example Hywind, a spar design floating wind turbine. In this study, Phase IV of the IEA Annex XXIII offshore Code Comparison Collaboration (Jonkman, 2010), which considered the spar buoy concept, is chosen to show the critical effects of unsteady aerodynamic loads because of platform motion. Due to the increasing of tower height, the slight motion of the

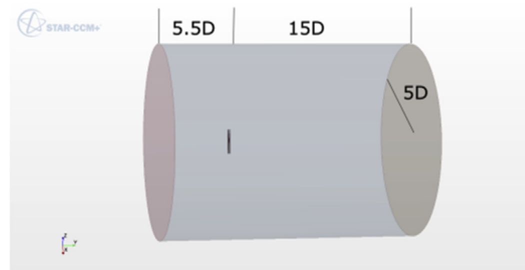

Fig. 3. Calculation domain.

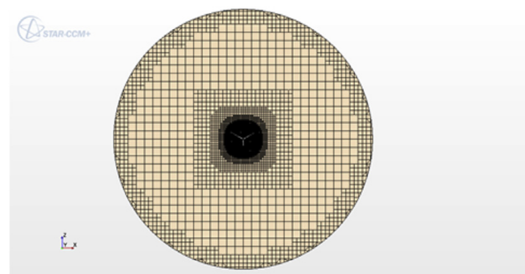

Fig. 4. vol mesh.

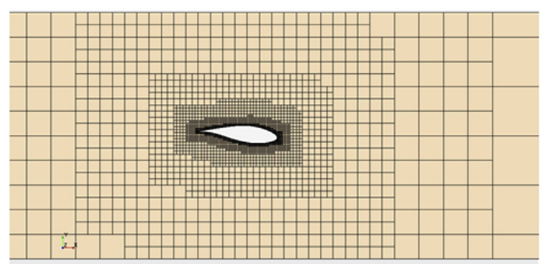

Fig. 5. vol mesh.

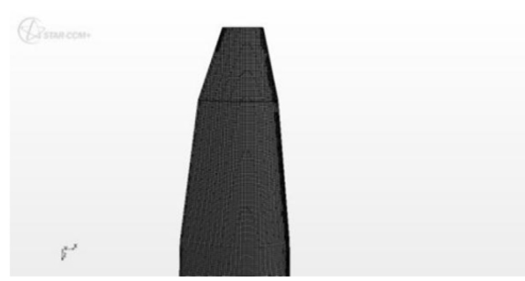

Fig. 6. Blade surface grids in the tip region.