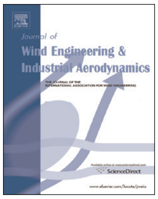
J. Wind Eng. Ind. Aerodyn. 142 (2015) 65–81

Contents lists available at ScienceDirect

Journal of Wind Engineering and Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia



The platform pitching motion of floating offshore wind turbine: A preliminary unsteady aerodynamic analysis

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ARTICLE INFO

Article history:
Received 19 May 2014
Received in revised form
6 February 2015
Accepted 17 March 2015

Keywords:
Floating offshore wind turbine
CFD
Dynamic mesh
Unsteady blade element momentum
Direct local relative velocity approach
Blade-tip vortices
Blade–wake interaction

ABSTRACT

The flow-field around the rotor blades of an FOWT may be significantly influenced by the six rigid-body motions of the floating platform via the blade–wake interaction. Therefore, the accurate prediction of unsteady aerodynamic load which is calculated by many conventional numerical approaches is still questionable for an FOWT. In this study, the periodic pitching motion of the rotating turbine blades due to the floating platform motion is considered to investigate the effects of vortex–wake–blade interaction for the aerodynamic performance of an FOWT. The unsteady computational fluid dynamics (CFD) simulations based on the dynamic mesh technique were applied for analyzing the pitching motion of wind turbine due to the platform motion. The in-house unsteady blade element momentum code using the direct local relative velocity approach was also applied to simulate the unsteady aerodynamic performance. The equivalent average velocity approach which simplifies the relative velocity contribution due to the platform motion was proposed and incorporated to the in-house code. It is shown that the unsteady aerodynamic loads of the floating offshore wind turbine become sensitively changed due to the variation of frequency and amplitude of the platform motion. Additionally, there are strong flow interaction phenomena between the rotating blades with oscillating motions and generated blade-tip vortices.

1. Introduction

Various Multi-MW turbine systems have been installed in the offshore area since the year 2000 (EWEA, 2013a, 2013b). Until the end of June 2013, total amount installed offshore wind turbine (OWT) rose up to 1939 units, with a combined capacity of 6040 MW fully grid connected in European waters in 58 wind farms across 10 countries (EWEA, 2013a, 2013b). The reason may be explained that a wind speed is typically stronger and much more sustained in the offshore wind farm (OWF). That is one of the reasons for the attraction of OWT system. The developments of bottom-fixed offshore wind turbines, which are based on the experiences of the onshore wind turbines, have been succeeded for the installation of the OWF in the shallow water. On the other hand, the floating offshore wind turbines (FOWTs) can be installed even in the deep sea area based on the existing technology, the construction experience of offshore petroleum and natural gas industries for the design and installation of the supporting platform. In the view point of engineering design, the FOWT has several difficulties such as more advanced blade control due to the floating motion, the large inertia loading on the tower and nacelle caused by induced accelerations due to floater motions, and more expensive and complicated installation processes, etc. (Luo et al., 2012; Transportation Research Board, 2011). If above issues can be effectively solved, the FOWT farms are expected to generate a large amount of clean energy with a competitive price compared to other energy resources. Thus, the FOWT still has many challenges to design, manufacture, install, control, and maintain (Butterfield et al., 2005). It has been attracted by many researchers, engineers as well as the universities, institutes, and governments.

Physically, the flow-field around a rotating wind turbine blade is inherently complex because of the existence of wind shear, turbulence, gust, and yaw motion of the nacelle. For a floating offshore, horizontal axis wind turbine (HAWT), flow characteristics become more complex than those of a fixed offshore wind turbine. Because of the motion of floating platform, which includes three translational components (heave in the vertical, sway in the lateral, and surge in the axial) and three rotational components (yaw about the vertical axis, pitch about the lateral, and roll about the axial) motion as shown in Fig. 1, the additional effect of the wind contribution which is basically transmitted to the rotor due to the platform motion needs to be considered. In those motions, platform pitch and yaw degrees of freedoms significantly lead to the unsteady aerodynamic effects on the rotating blades combining the effect of wind shear, gradient across the rotor disk, dynamic stall, rotor blade–wake interaction, and skewed flow, etc. (Sebastian and Lackner, 2012a, 2012b, 2012c;

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http://dx.doi.org/10.1016/j.jweia.2015.03.009

Sebastian, 2012). As an example, a typical floating offshore HAWT (Fig. 2 (Sebastian and Lackner, 2012c), from left to right) shows a flow-field around a rotor blade during the pitching motion of the spar-buoy FOWT type. As the rotor blade begins to pitch back, it interacts with its own wake which leads to the development of turbulence region. In Fig. 2, the toroidal recirculations can be seen and this transitional aerodynamic phenomenon is called the vortex ring state, or settling with power (Peters and Chen, 1982). The pitching motion intermediately causes a transient flow condition which is one of potential operating and simulating problems for a floating wind turbine. Particularly, it is believed that pitching and yawing motions lead to large variation of the aerodynamic performance of a floating offshore HAWT system because of the above issues (Sebastian and Lackner, 2012a, 2012b, 2012c).

One of the common challenges to all support structure designs is the ability to predict the dynamic load responses of the coupled wind turbine and platform system which usually combines stochastic wave and wind loading. Because of the load prediction challenges for design requirements, various experiments with floating substructures have been performed. At present, several experimental floating substructures of floating offshore horizontal axis wind turbine seem to be in test phases: Statoil Hywind (Spar), SWAY (Spar), Blue H (TLP), Gusto Trifloater (Semisubmersible) and Poseidon (Semisubmersible) in Europe, Fukushima (Semisubmersible), Kabashima Island (Spar) and WindLens Floater (Semisubmersible) in Japan and DeepCwind (Semisubmersible) and Principle Power WindFloat (Semisubmersible) floating turbine in the US (EWEA, 2013a, 2013b; Main(e) International Consulting LLC Report, 2013). However, to effectively design an FOWT system, the designer, researcher, and engineer need to produce an analysis tool that is able to accurately predict loads and resulting dynamic responses of the coupled wind turbine and platform system caused by combined stochastic wave and wind loading. The fully coupled aero–hydro–servo–elastic dynamic approaches (Jonkman and Buhl, 2007a, 2007b; Jonkman, 2009a, 2009b; Shim and Kim, 2008; Roddier et al., 2010; Cermelli et al., 2009; Marshall et al., 2009; Crozier, 2011; Cordle, 2010; Bossanyi, 2003), or a simplified aero-hydro-dynamic method (Karimirad and Moan, 2012) have been considered to calculate the dynamic responses of a floating offshore wind turbine. FAST code (Jonkman and Buhl, 2007a, 2007b; Jonkman, 2009a, 2009b) for the aeroelastic analysis of a horizontal axis wind turbine (HAWT) has been developed by NREL's National Wind Technology Center (NWTC). Now, it is extended with a HydroDyn model to have additional capability of the fully coupled time-domain aero–hydro–servo–elastic simulations considering floating platform motions. FAST has been coupled with several sub-modules in order to model FOWT such as Charm3D (Shim and Kim, 2008), TimeFloat (Roddier et al., 2010; Cermelli et al., 2009), ADAM (Marshall et al., 2009), etc. Additionally, the other time-domain programs for the modeling and simulation of an offshore structure have been developed such as SIMO, HAWC2, 3Dfloat, DeepC, Bladed, etc. (Crozier, 2011; Cordle, 2010; Bossanyi, 2003). However, almost all design codes currently capable of performing integrated modeling of floating wind turbines are based on the commonly-used sufficient aerodynamic analysis method, blade element momentum (BEM) theory to calculate aerodynamic forces on the wind turbine rotor. The conventional blade element momentum (BEM) method is applied based on empirical

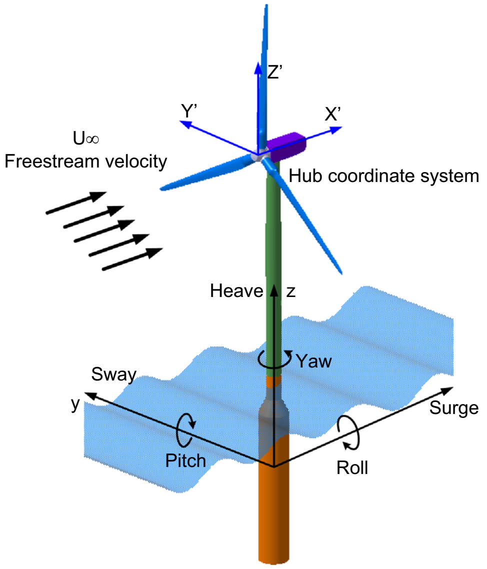

Fig. 1. The degrees of freedom of an offshore floating wind turbine platform.

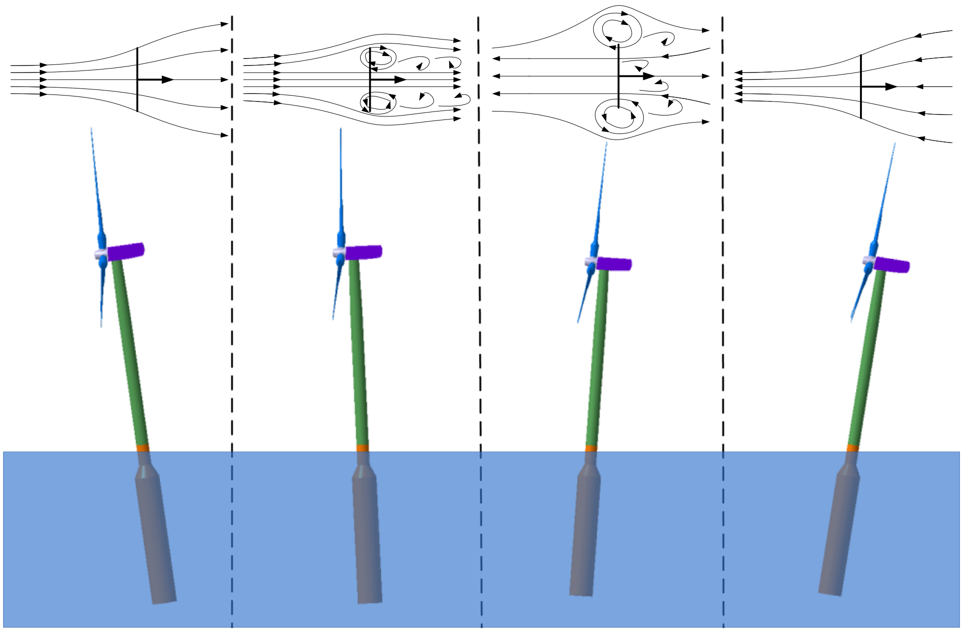

Fig. 2. Platform pitching motion and its effects on surrounding flow-field.