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The typhoon effect on the aerodynamic performance of a floating offshore wind turbine

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Abstract

The wind energy resource is considerably rich in the deep water of China South Sea, where wind farms have to face the challenge of extreme typhoon events. In this work, the typhoon effect on the aerodynamic performance of the 5MW OC3-Hywind floating offshore wind turbine (FOWT) system has been investigated, based on the Aero-Hydro-Servo-Elastic FAST code. First, considering the full field observation data of typhoon "Damrey" is a long duration process with significant turbulence and high wind speed, so one 3-h representative truncated typhoon wind speed time history has been selected. Second, the effects of both the (variable-speed and collective-pitch) control system of NREL 5 MW wind turbine and the motion of the floating platform on the blade aerodynamic performance of the FOWT system during the representative typhoon time history has been investigated, based on blade element momentum (BEM) theory (coupled with potential theory for the calculation of the hydrodynamic loads of the Spar platform). Finally, the effects of different wind turbine control strategies, control parameter (KP–KI) combinations, wave heights and parked modes on the rotor aerodynamic responses of the FOWT system have been clarified. The extreme typhoon event can result in considerably large extreme responses of the rotor thrust and the generated power due to the possible blade pitch angle error phenomenon. One active-parked strategy has been proposed for reducing the maximum aerodynamic responses of the FOWT system during extreme typhoon events.

Keywords: Typhoon; Floating offshore wind turbine; Aerodynamic performance; Control system; FAST.

1. Introduction

The offshore wind energy resource is very rich in China South Sea, where the wind farms have to face the challenge of extreme typhoon events. Comparing with normal wind condition, typhoons are usually of higher wind speed, larger turbulence intensity, and fiercer direction variation, which tend to result in the failure of the wind turbine blades, and even the failure of the supporting tower. Wang and Chen [1] pointed out that the reason for the failure of wind turbine blades and towers during typhoon "Dujuan" was the aerodynamic overload of blades. The present wind turbine operational control systems have been designed with very limited considerations of extreme typhoon events [2], so that is the main reason for the high accident rate of wind turbines during typhoon events.

As offshore wind farms are moving into deep water for more and better wind energy resource, the foundations of offshore wind turbines have been changed from the traditional fixed-bottom type to innovative floating types, which may be more suitable and more economical for deep water. The most representative one is the "Hywind" built in 2009, which is the first floating offshore wind turbine (FOWT) project in the world. Nielsen et al. [3] used both numerical method and 1/47 scale experiment tests to study the dynamic responses of

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the deep draft spar FOWT system, "Hywind", the feasibility of which was well proven. Utsunomiya et al. [4] used 1/22.5 scale test model to focus his study on wave loads of the "Hywind" FOWT system, and the related numerical method was further verified. In addition, Jonkman [5–7] made great contributions to the development and verification of a fully coupled simulator for the analysis of wind turbine systems. He upgraded FAST as a fully coupled Aero-Hydro-Servo-Elastic code and applied it to test different typical FOWT concepts. Ren et al. [8,9] proposed an innovational floating wind turbine with combined tension leg-mooring line system, and the good performance of the new FOWT systems was effectively verified by both coupled aerodynamic and hydrodynamic analysis and scale model tests.

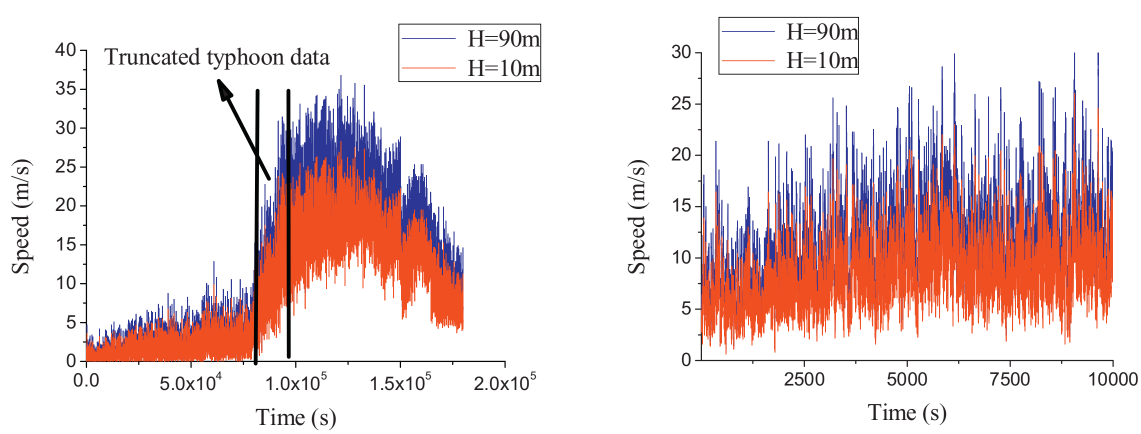
The aerodynamic analysis methods for wind turbine blades range from one-dimensional momentum balance models to full three-dimensional Navier–Stokes solutions [10]. In practice, the blade element momentum (BEM) theory is the most widely used due to its high computational efficiency and fairly accuracy, especially for the coupled wind-wave time-domain analysis of the FOWT system. Many researchers [11–13] made important and meaningful corrections for improving the accuracy of the BEM theory. Boukhezzar et al. [14] used BEM theory to investigate effect of the variable speed-collective pitch control strategy on the aerodynamic performance of wind turbine blades, and obtained a series of useful conclusions. Based on PI-regulation of rotor speed and power through the collective blade pitch angle and generator moment, three different controller designs have been investigated [15], which indicated that numerical optimization can be used to tune controller parameters, especially when the optimization is used as a qualified refinement initial guess. Larsen and Hanson [16] and Jonkman et al. [17] have proposed modifications to conventional wind turbine control system for eliminating the possible negative damping effect of the platform-pitch mode of FOWT systems. In addition, based on Navier–Stokes equation and RNG k–ε turbulence model, Ren et al. [18] investigated the typical aeroelastic performance of the offshore wind turbine airfoil during one typhoon event. So far, the study on the aerodynamic performance of the offshore wind turbine system during typhoon events is very limited, especially for the FOWT systems.

In this work, the aerodynamic characteristics of 5MW OC3-Hywind FOWT system during the typhoon "Damrey" event have been investigated based on the FAST code. The effect of the (variable-speed and collective-pitch) control system and the motion of the floating platform on aerodynamic performance of NREL 5 MW wind turbine have been studied based on BEM theory coupled with potential theory for the calculation of the hydrodynamic loads. In addition, the effects of different operational control strategies, control parameter (KP–KI) combinations, wave heights and parked modes on rotor aerodynamic responses of the FOWT system during the representative typhoon time history have been also clarified.

2. Theoretical basis and numerical model

2.1. The typhoon observation data

The field observation typhoon data was obtained from the typhoon "Damrey" (2005 No. 0518, in Xuwen, China) by YOUNG05106L anemometer with the sampling frequency of 1 Hz. The detailed wind speed time histories were shown in Fig. 1. Considering the whole typhoon time history was more than 30 h and the wind turbine would be parked when the wind speed was over the cut-off value (25 m/s), so one 3-h representative truncated typhoon data has been selected for the time domain analysis with the variable-speed and collective-pitch control strategy in operational mode (in Fig. 1b). It (11.4 m/s < wind speed < 25 m/s) could be the most dangerous moment for wind turbines due to extremely high turbulence intensity and large aerodynamic loads (just before changing the operational mode into the parked mode with the function of the control system). When the wind speed is larger than 25 m/s, the wind turbine will be parked and the aerodynamic loads will be significantly reduced [17]. In addition, the wind speed at 10-m height was transformed into the wind speed



a) Full typhoon history b) Truncated typhoon history

Fig. 1. Field observation wind speed of the typhoon "Damrey".

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