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The Study of the Effect of Floating Platform Rotational Disturbance on the Aerodynamic Performance of Offshore Wind Turbine in the Presence of Pitch Control System

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ABSTRACT: The aerodynamic performance of an offshore floating wind turbine is more complicated than onshore wind turbines because of the motions of the floating platform. In this paper, the effects of a floating platform rotational motion on the performance of an offshore wind turbine are investigated. For this sake, the unsteady blade element momentum method is used as the aerodynamic modeling tool. The proposed model has been validated based on data available for the reference turbine in the ground or fixed platform. To estimate the pitch angle as the control parameter in the power adjusting system, the proportional integral controller has been utilized. This control system is utilized to maintain the rated power of the wind turbine and also to approach a closer model of the wind turbine. The rotation of floating platform including three main angular motion as pitch, roll, and yaw have been studied which are approximated by a sinusoidal function. Results showed that among rotational motions, the effect of pitch motion is more considerable than roll and yaw motions. In the case of pitching motion input, reduction of mean power coefficient for tip speed ratios less than 7 is expected. For high tip speed ratios more than a critical ratio, the trend is reversed with respect to the fixed-platform case. The magnitude of change in the power coefficient, however, depends on several parameters which are explained more in the paper. The same but degraded trend also occurs in the case of roll and yaw disturbances. Moreover, the mean value of blade pitch angle which is an index of control effort is being increased.

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1- Introduction

The advantages of offshore wind turbines lead us to harvest energy from offshore wind. Although the installation of offshore wind turbines is more expensive than the onshore type, fewer complaints about noise problems make them attractive [1]. Moreover, the wind energy potential is considerable at the offshore. Statistics [2] show that the rated capacity of offshore wind turbines has grown 62 percent over the past decade. If the offshore wind turbine is used in deep sea regions, the floated platform is utilized instead of a fixed foundation. The floating platforms can move due to waves and currents which can be either rotational or translational. These movements can alter the overall performance of offshore wind turbines. The schematic of a model offshore floating wind turbine is shown in Fig. 1.

Tran and Kim [3] have studied the effects of platform pitching motion of Offshore Floating Wind Turbine (OFWT) on the performance of benchmark wind turbine using the Computational Fluid Dynamic (CFD) approach. It is shown that the aerodynamic loads of the OFWT are sensitive to platform movements. The variation of power and thrust depend on the frequency and amplitude of the platform pitch motion. Tran et al. [4] also have studied the effects of prescribed OFWT surge motion on the aerodynamics of the wind turbine. The National Renewable Energy Laboratory (NREL) 5 MW was used as the baseline wind turbine in this investigation. The study of this motion was performed by CFD and Unsteady Blade Element Momentum (UBEM) methods.

In this investigation, the aim is to study the effects of rotational motions of a floating platform on the performance of the 5MW NREL wind turbine. For this sake, the unsteady blade element method is used with considering the effects of pitch angle control system.

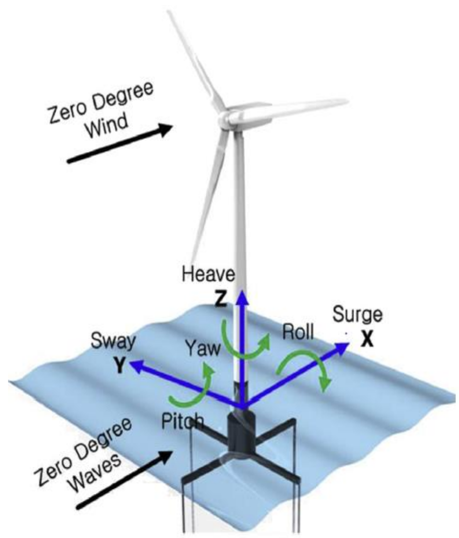

Fig. 1. Schematic of a floating offshore wind turbine

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Table 1. Turbine characteristics

Property	Value
Rated Power	5 MW
Number of Blades	3
Rotor, Hub diameter(m)	126, 3
Gearbox ratio	97: 1
Overhang (m), Shaft tilt (deg)	5, 5
Hub height(m)	90
Blade inertia, Generator inertia (kg/m^2)	11776047, 534.116

2- Methodology

2- 1- Baseline wind turbine

The NREL 5 MW horizontal axis offshore wind turbine is selected in the current study as there are many previously researches and attempts focused on different aspects of the system. It can be viewed as a baseline wind turbine in the present study. This wind turbine can be either utilized in onshore and offshore regions. The wind speed that rated power reaches is about 11.4 m/s with the rotational speed of rotor about 12.1 rpm. Some of the main characteristics of this wind turbine are listed in Table 1. It should be noted that this particular wind turbine uses a pitch angle control system to control the output power in overrated condition.

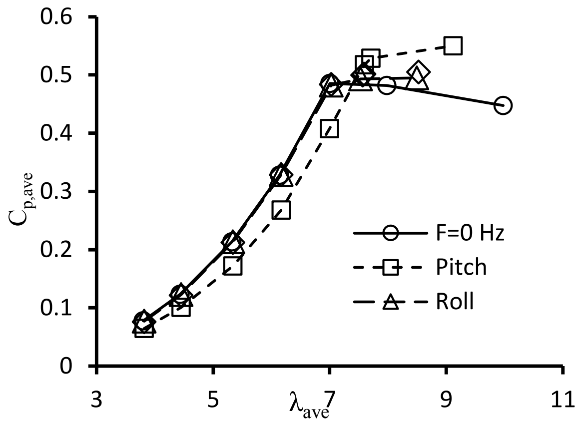
2- 2- Basics of aerodynamic modeling

The unsteady aerodynamic effects of disturbed-OFWT are obtained by using UBEM together with unsteady dynamic stall and dynamic wake models. It should be noted due to translational and rotational applied motions on the platform, the probability of occurrence the stall and wake interaction would be more in the offshore horizontal axis wind turbines. The reason for using UBEM method in this study, in addition to simplicity and accuracy, is the ability of these methods to be jointed or coupled with pitch regulated control system model.

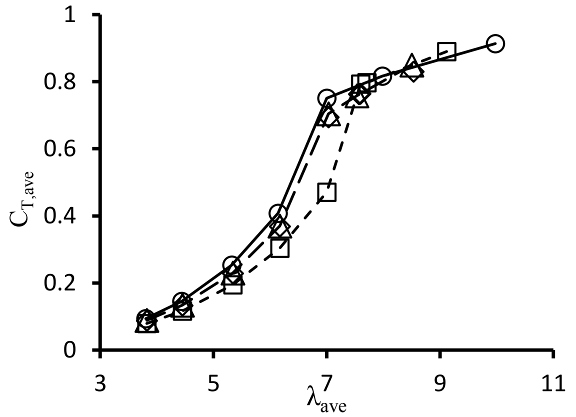
The UBEM method that is used in this study gains the theory proposed by Hansen. This method is capable of predicting the aerodynamics of wind turbines. The classic Blade Element Momentum (BEM) is a combination of momentum and strip theories. Unsteady BEM is also gained from these theories, but the effects of induced velocities due to thrust generation at rotor plane and time marching are added into the base model. The rotational motion of the OFWT is defined as the following equation, which is a sine function with an amplitude (Amp) and a frequency (F):

$$\theta = Amp.\ Sin(2\pi Ft) \qquad (1)$$

To take into account the time delay, a dynamic wake model should be used. Applying this model is necessary in order to capture the time behavior of aerodynamic loads when the thrust is altered by changing the pitch angle of blades. In this investigation, because of the presence of a pitch control system, using one of the dynamic wake models is crucial. Moreover, to consider dynamic stall effects which can be happened in some portions of wind turbine blades, the Leishman-Beddoes methods are used. This phenomenon initiates with the formation of a vortex at the leading edge that sheds along the chord of the airfoil from leading edge to trailing edge. This vortex causes that the maximum lift coefficient increases at dynamic stall situation, which is higher than the static maximum lift coefficient.



(a)



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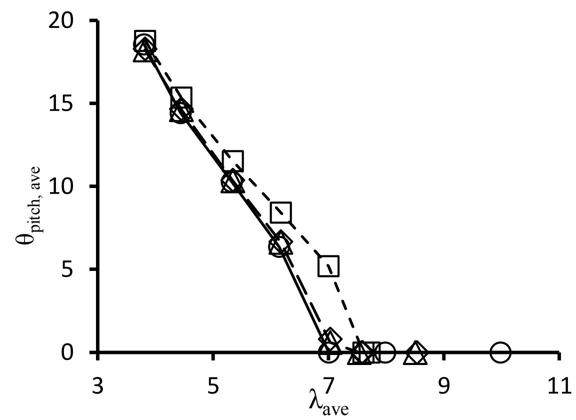

(c)

Fig. 2. Averaged aerodynamic characteristics (F=0.1 Hz, Amp= 2 deg)"

2- 3- Pitch Angle Control System

In this investigation, in order to maintain the rated condition, the pitch angle control system is gained. This system uses a Proportional-Integral (PI) controller. The calculated pitch angle will be applied at hub via an actuator as a whole blade twist angle in addition to structural passive twist distribution. It should be noted that the control system was simulated in MATLAB/Simulink software.

3- Results and Discussion

In this part, the effect of pitching, yawing and rolling motions applied to the platform, is being investigated. The frequency of oscillation is set to be 0.2 Hz and the amplitude is 2 deg. To show the effects of these motions, the mean values of power coefficient, thrust coefficient, and pitch angle control system are calculated. The results are shown in Fig. 2. It can be seen that the platform pitching motion affects the performance of wind turbine more than other motions. In the case of pitching motion input, reduction of mean power coefficient for tip speed ratios less than 7 is expected. For high tip speed more than a critical TSR, the trend is reversed with respect to the fixed-platform case.

4- Conclusions

In this paper, the effects of a floating platform rotational motions on the performance of 5 MW offshore wind turbine are investigated. The results show the rotational motion of the floating platform affects the performance of the wind turbine, especially in pitching motion case.

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