High-Fidelity CFD simulation of floating wind turbine using DFBI approach

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Abstract

This paper presents CFD investigation of well known 5-MW floating wind turbine under platform surge response. The aerodynamic performance of the floating turbine under surge motion is compared to the typical floating turbine under a fixed-platform condition. In this work, an overset mesh technique was adopted to handle the complex motion of a full-scale floating wind turbine. It is multiple disconnected grids used to discretize the computational flow domain. Moreover, the Dynamic Fluid Body Interaction (DFBI) and Volume of Fluid (VOF) approaches are employed to accurately capture the aero-hydrodynamic interaction, and to model the water-air interface surface. A systematic comparison of aerodynamic performance, hydrodynamic responses, and the catenary analysis results between CFD simulation and the corresponding data obtained from FAST and OrcaFlex based on the Blade Element Momentum (BEM) model was performed.

Keywords : Dynamic Fluid Body Interaction, Floating Wind Turbine, Overset Mesh

1. Introduction

The offshore turbine rotor is connected to its floating foundation via a long tower, thus the aerodynamic loads in terms of torque and thrust influence the hydrodynamic response and the platform motion. Meanwhile, the turbine rotor orientation and its position are also affected by the six degrees of freedom platform motion. In addition, the dynamic excitation due to the coupled wind-wave loads, the mooring system, and the ballast options further complicate the analysis of the entire Floating Offshore Wind Turbines (FOWTs). Computational Fluid Dynamics (CFD) approach can be directly estimated the hydrodynamic loads on a floating platform in both transvers and inline directions. It has also been included the effect the flow separation induced by the viscous flow. Furthermore, CFD simulation has the ability to investigate the complex flow interference between the turbine rotor and its own wake on the side, and between the rotor and the floating platform on the other side. From this regard, a systematic comparison between CFD results of full-scale FOWT with the corresponding data obtained from various numerical tools is essential. Several studies have been conducted using CFD simulation to investigate the hydrodynamic load and dynamic response for different types of floating platforms, such as Spar-buoy concept [1], Semi-submersible platform [2-5].

In the present work, a high fidelity CFD simulation of a full-scale semi-submersible floating offshore wind turbine is conducted using an overset meth approach to accurately grasp the influence of semi-submersible platform surge response on the aerodynamic behavior and wake characteristics of the 5-MW FOWT. The aerodynamic performance of the floating turbine under surge motion is compared with the typical floating turbine under fixed-platform condition.

2. Model Statement

In the present work, the OC4-DeepCWind semi-submersible floating offshore wind system is adopted for the modelling and performance analysis. In order to verify the accuracy of the engineering numerical tools for offshore wind turbines, the Offshore Code Comparison Collaboration (OC4) project was implemented in 2010 under the International Energy Agency Wind Task 30 [6, 7]. The OC4 semi-submersible floating system comprises the well-known NREL reference wind turbine with rated capacity 5-MW, nacelle, tower, and floating support platform structure. Semi-submersible structures are suitable for water depth typically of 75 m up to hundreds of meters. Fig.1 shows the full configuration of the NREL baseline 5-MW FOWT.

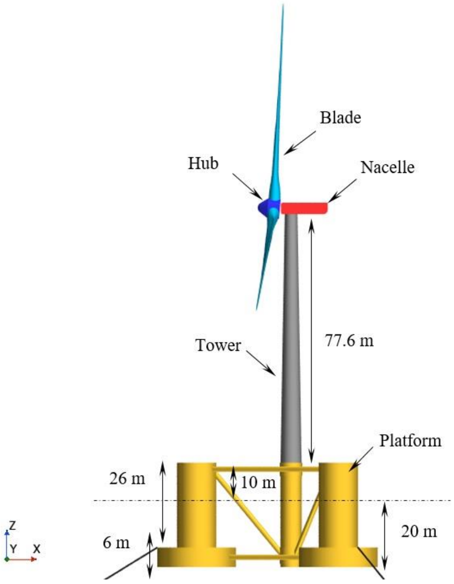

Fig.1 Full configuration of phase II of OC4 floating offshore wind turbine system

3. Numerical Considerations

All CFD models require initial and boundary conditions. Fig.2 depicts the flow domain and the defined boundary conditions of the current investigation. The velocity inlet was applied at the upstream boundary and seafloor. A pressure outlet is given for both the downstream outlet and the top surface. The entire flow domain is extended 1200 m in (x) direction and 500 m in both y and z directions.

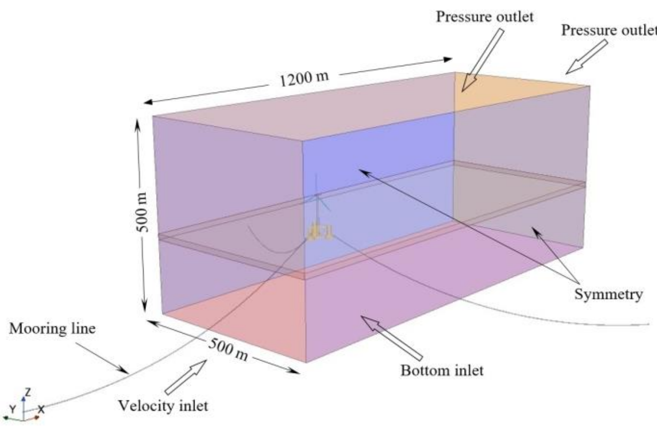

Fig.2 Flow domain and defined boundary conditions

4. Computational Domain

The present investigation was conducted using an overset mesh technique to handle the complex motion of a full-scale FOWT. It is multiple disconnected grids used to discretize the computational flow domain. Depending on the position of the cells within the computational domain, they can be used as active, passive, and accepter cells. As the VOF was adopted to solve the position and the shape of the free surface wave, it is necessary to apply proper local mesh refinement at the free surface. In order to accurately capture the high gradient flow properties within the boundary layer region, prism layers (10) were created near the structure surfaces with cell growth ratio normal to the wall and first layer thickness of 1.2 and 0.3mm, respectively. Fig.5.3 gives insight of present mesh resolution of the entire computational domain.

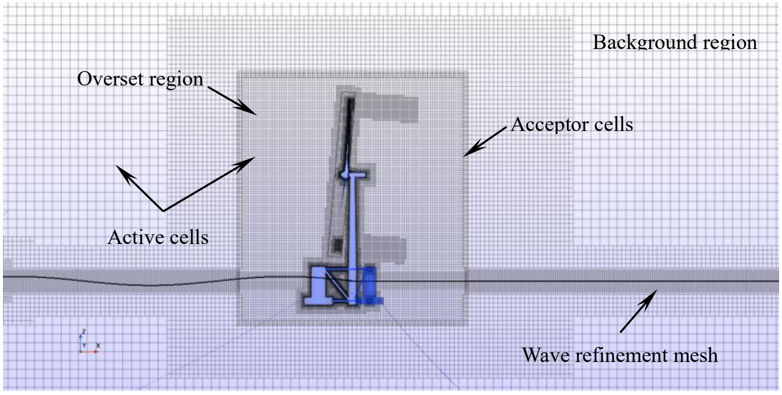

Fig.3 Computational domain for full-scale FOWT

5. Results and Discussions

The simulation was conducted at a rated wind speed of 11.4 m/s, where the rotor speed remains constant at 12.1 rpm. , the time step size was determined to be 0.0275 s for the transient simulation of the FOWT. The investigation was performed under an extreme wave height of (7.58 m), whereas the wave period and water depth are 12.1s and 200 m, respectively. The hydrodynamic impact of the platform under surge displacement condition on the aerodynamic behavior and wake characteristics of the reference NREL 5-MW wind turbine is numerically investigated using various simulation tools. Fig. compares the time histories of the platform surge response between CFD results and the corresponding data from potential codes (FAST and OrcaFlex). Overall, the results seem quite similar with slight discrepancies can be captured between the different codes. It is observed that the time histories of the surge displacement feature an oscillating sinusoidal periodic motion at the same frequency as the incident wave.

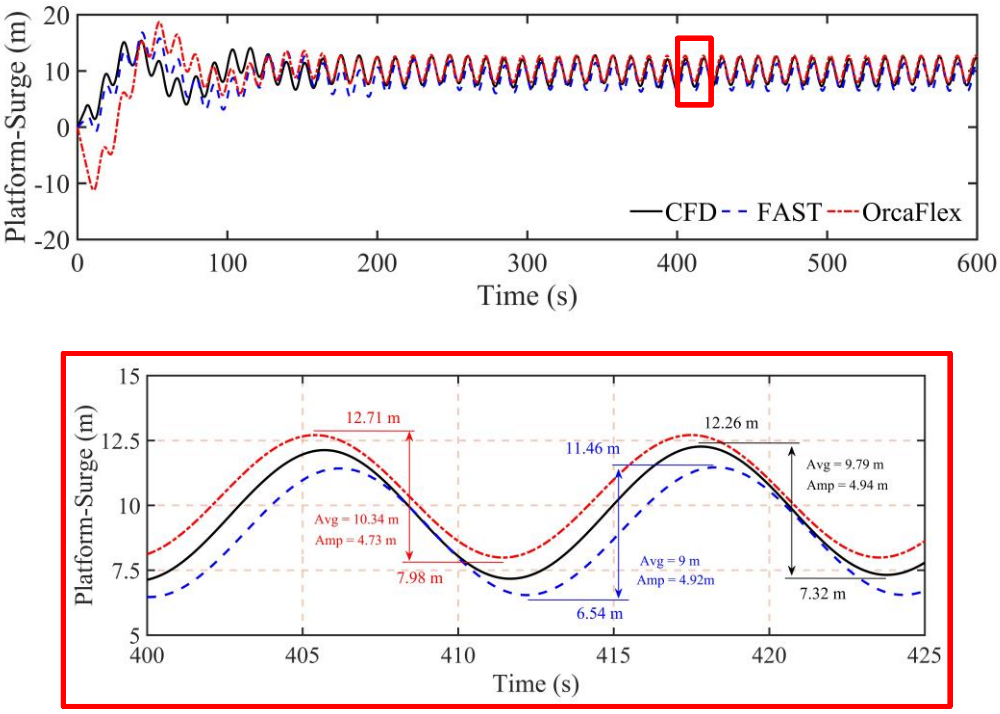

Fig.4 Comparison of time histories of the platform-surge response

Fig.5 demonstrates the correlation between the relative velocity and the power generation. As the floating turbine moves periodically, the power output fluctuates in the same period as the surge displacement. When the floating turbine surges backward (A-C), the relative velocity normal to the rotor plane decreases, thereby, reaching its minimum value at position (B). As the relative wind velocity decreases, the predicted power generation decreases compared to that obtained from a fixed-bottom turbine. On the contrary, when the floating turbine experiences forward motion (C-E), the relative wind speed increases to its maximum value at position (D). Therefore, the power generation obtained from the floating turbine also increases compared to that obtained from the fixed-bottom turbine due to the augmented relative wind velocity.

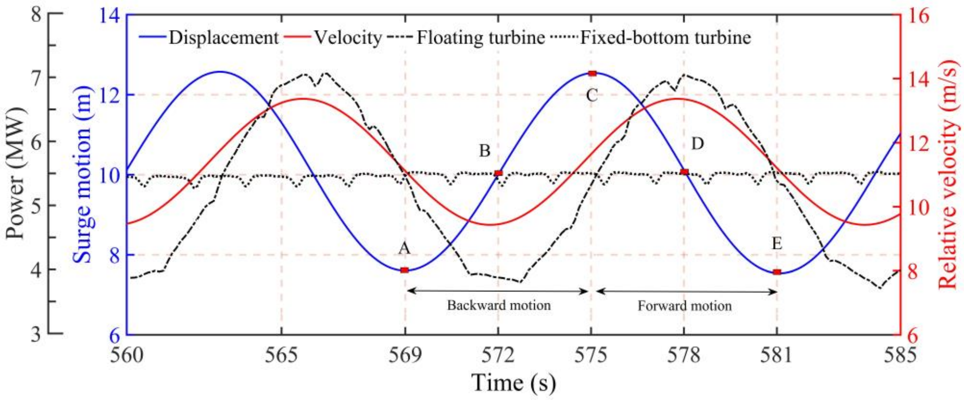

Fig.5 Correlation between relative velocity and power generation

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