Dynamic Responses and Wake Characteristics of a Floating Offshore Wind Turbine in Yawed Conditions

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ABSTRACT

A coupled large eddy simulation and aero-hydro-moor-servo dynamics code is used to perform numerical simulations of a floating offshore wind turbine (FOWT) under yawed conditions. The atmospheric boundary layer wind field is simulated by large eddy simulation (LES) with sufficient simulation duration as the inflow wind condition. Two cases with 15° and 30° yaw angles of wind turbine are performed, and the results of aerodynamics, hydrodynamics and wake characteristics are compared and analyzed with that of non-yaw scenario. It is concluded that the rotor power of FOWT decreases with increase of yaw angle, whereas the rotor thrust of 15° yaw angle is slightly larger than that of non-yaw situation. There is no distinct difference of platform surge motion and pitch motion between the 15° yaw angle and non-yaw scenario, whereas the two motions of 30° yaw angle are significantly less than that of non-yaw scenario. The platform sway motion increases with the increase of yaw angle due to the crosswise component of rotor thrust of wind turbine. What’s more, faster wake recovery and more significant wake deflection with increase of yaw angle is observed, which is beneficial for the inflow wind condition and power generation of downstream wind turbine.

KEY WORDS: Floating offshore wind turbine; Yawed conditions; Large eddy simulation; Aero-hydrodynamics; Wake characteristics.

INTRODUCTION

In recent years, the wind energy has become a hot topic due to its advantages of non-pollution, renewable and rich resources (Rohrig et al., 2019). The wind energy harvesting consists of two parts: onshore and offshore. Compared to onshore wind energy, the offshore wind energy resources are more abundant, and without the limitations of land space and noise (Li et al., 2020). In addition, the most of wind energy resources are distributed in deep water area, i.e., more than 80% of offshore wind resources are available in sea area with depth > 60 m. The bottom-fixed offshore wind turbine is not suitable for deep water scenario, because the construction cost of bottom foundation will increase dramatically with the increase of water depth, which is commercially expensive and impractical. One possible solution is to change the fixed foundation to floating foundation. Consequently, in order to harvest the wind resources in deep water area and ensure it is commercially feasible, the design and development of floating offshore wind turbine (FOWT) becomes an attractive work (Ramachandran et al., 2022).

In contrast to prototype and scale-down basin experiment, the numerical simulation of FOWT is cheaper for the cost, and the computational cost is more affordable with the significant advancement of high-performance computer. Therefore, the numerical simulation becomes a powerful and indispensable tool for the design and development of FOWT. In order to yield accurate analysis results and support the design of FOWT, Tran and Kim (2016) proposed a high-fidelity computational model using overset mesh technique. The numerical results of unsteady aerodynamics, platform hydrodynamic responses and mooring tension forces showed a good agreement with the test data and numerical results calculated by NREL FAST code. Zhang and Kim (2018) also performed high-fidelity numerical analysis of a semi-submersible FOWT by using overset mesh technique in commercial software STAR CCM+. Their results revealed that the rotor thrust of FOWT is increased by 7.8% compared to that of onshore wind turbine, whereas the rotor power is decreased by 10%.

For the numerical analysis of FOWT, the high-fidelity overset mesh technique is computationally expensive and time consuming (Xu et al., 2022), which limits its further application in numerical investigation of FOWT. Trolldborg et al. (2007) pointed out that the actuator line model (ALM) used for wind turbine aerodynamics can improve the computational efficiency by representing the wind turbine as body force, and the accuracy of results can be guaranteed by solving the Navier-Stokes equations. Consequently, Cheng et al. (2019) developed an aero-hydrodynamic model of FOWT namely FOWT-ALM-SJTU based on the combination of the ALM and an in-house two-phase CFD solver. In order to reflect the unsteady aerodynamics of FOWT, an additional velocity induced by the motions of floating platform was modified into the conventional ALM. Huang and Wan (2019) presented a systematic study on the interaction between wind turbine and floating platform by using the validated and verified FOWT solver FOWT-ALM-SJTU, and they noted that the local angle of attack is significantly altered by surge and pitch motions of floating platform. After that, Huang et al. (2021) developed an aero-hydro-elastic numerical framework of FOWT. The elastic ALM is proposed to predict the blade deformation of FOWT based on the integration between the ALM considering additional velocity induced by platform motions and the one-dimensional finite element method structure model.

Among the above numerical studies of FOWT, the inflow wind condition