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CFD Investigations of Wake Flow Interactions in a Wind Farm with 14 Wind Turbines

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Because the wake flow interaction phenomenon among wind turbines has a great influence on aerodynamic power output, wind speed deficit turbulence stress, and wake vortex structure, the wake interaction for the optimal arrangement of wind farm has recently attracted increasing attention. This paper presents a validation of aerodynamics for the two offset model wind turbines on the actuator line model and computational fluid dynamics (CFD) technique. The numerical results of the present simulations are compared with those produced by testing on Blind Test 3 and other simulation models. On the basis of the simulations results, the present study shows good agreement with the experimental results. Besides, considering the uniform inflow condition, a numerical method is harnessed to simulate the complex phenomenon of wake interaction in a wind farm containing 14 wind turbines. Large eddy simulations combined with an actuator line model are conducted in the in-house CFD code FOWT-UALM-SJTU solver, which is an extension based on OpenFOAM. The motivation for this work is to create a sound methodology for performing the simulation of large wind farms. To better understand the wake interaction phenomenon, the aerodynamic power coefficients and basic features of both the near and far wake, including the distribution characteristics of the mean wake velocity and vortex structures, are studied in detail.

INTRODUCTION

With the rapid development of wind energy technology, recent years have witnessed an increasing number of wind farms being built around the world to meet the demand for higher maximum wind power capacity (Jeon et al., 2013). Wind farms composed of large-capacity wind turbines are set to become the future trend of development of wind energy (Abderrazzaq and Hahn, 2006). However, wind turbines built in clusters will inevitably be affected by the wake of upstream and neighboring turbines, which leads to the decreased inflow wind velocity and increased turbulence intensity (Sanderse et al., 2011). Decreased total production of power and increased levels of fatigue loads are imposed on the turbines in the wind farm as a result of the phenomenon of wake interaction. Therefore, numerical simulations of a wind farm containing multiple wind turbines are carried out to study characteristics of aerodynamic power and the significant wake interference effect, which have very important scientific significance and practical reference value for wind farm layout optimization.

To study the complex phenomenon of wake interaction in wind farms, some scholars attempted to model the flow field in wind farms based on a simple single wake model. The wind wake model mainly describes the influence range of the wake and the wind speed at all positions in the wake area. The Park wake model, a kind of one-dimensional wake model, is extensively applied to model the flow field currently. The Park wake model was proposed by Katic et al. (1986) based on the Jensen model. It can analyze the wake interference in wind farms, and this theory is applied to the wind energy resource assessment software WAsP, which has a reliable accuracy. Inspired by the one-dimensional wake model, a wide spectrum of other wake models has been proposed, the dimensions of which are extended from one dimension to two or even three dimensions (Larsen et al., 1996; Schlez et al., 2001; Sanderse et al., 2011). Nevertheless, these wake models suffer a common disadvantage that the actual turbulent characteristics in the wake cannot be well captured. This flaw may lead to the underestimation of wake interference in the wind farms and the inability to accurately predict the aerodynamic loads because the significant effect of wake meandering is disregarded (Troldborg et al., 2011). Several researchers also attempted to use wind tunnel experiments to study the wake characteristics of a single wind turbine or the wake interaction in wind farms composed of small model wind turbines. Vermeer et al. (2003) researched the wake for a single turbine and wind farms with the uniform, steady, and parallel flow conditions using a wind tunnel experiment. Khosravi et al. (2015) carried out a wind tunnel experiment with single 1:300 scale model wind turbine, and the Froude number criterion is satisfied. The experimental results show that the wake effect of a wind turbine subjected to surge motion is much farther than a wind turbine without motion. Krogstad and Eriksen (2015) presented an experimental investigation of the aerodynamic load, wind velocity defect, and turbulent kinetic energy distribution in the wake of two model wind turbines with two different layouts, the results of which were compared with a wide range of methods. The drawback of the wind tunnel experiment is that a low Reynolds number and scale effects cannot be eliminated relative to the full-scale model. On the contrary, the advantage of CFD approach, which provides necessary information about wake characteristics, is that it can avoid the scale effect in the model experiment and handle the large Reynolds number problem well. From the work of Zahle et al. (2009) and Choi et al. (2013, 2014), numerical simulation of full three-dimensional (3-D) wind turbine models through resolving the blade geometry with its boundary layers is computation-

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