Optimization of Wind Farm Layout Based on Bastankhah Wake Model

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ABSTRACT

Limited by the space and topographic factors, wake effect cannot be avoided in the wind farm. Due to the wake of upstream wind turbine, the inflow wind speed for downstream wind turbine will be reduced. As a result, the wind farm has a significant decrease of annual power output. Considering the high construction and maintenance cost of the wind farm, it is necessary to optimize wind turbine positions in order to reduce the cost of power generation. In the present work, an optimization approach based on wake model and optimization algorithm is proposed for wind farm layout optimization problem. The Bastankhah wake model is applied to calculate the wake velocity field and predict the power output of wind farm. The wake velocity predicted by the Bastankhah model is also validated by CFD results. In addition, the Kriging model is selected to construct the surrogate relationship between the wind turbine positions and the power output of wind farm. To quickly obtain optimal wind farm layout, the genetic algorithm is adopted to achieve the optimization calculation based on the established surrogate model. By combing the wake model and the optimization model, the layout optimization for a wind farm consisting of thirty five wind turbines are conducted. It is shown that the power output of the wind farm can be increased by about 115% after the layout optimization, and the average wake loss of the wind turbine induced by the wake effect decreases from 64% to 23%.

KEY WORDS: wind farm; layout optimization; wake model; genetic algorithm.

INTRODUCTION

With rapid development of wind power industry, the scale and the capacity of wind turbine significantly increase. In order to capture more power from wind resources and reduce the cost of power generation, large number of wind turbines are usually clustered in the wind farm. However, limited by the space and topographic factors, the wake effect cannot be entirely avoided in the wind farm. Due to the wake effect of upstream wind turbine, downstream wind turbine suffers inflow condition with low wind speed and high turbulence intensity. This results in the decrease of power output and the increase of fatigue loads of the wind turbine. As a result, the life span of the wind turbine and the annual energy production of the wind farm are greatly reduced. Thus, it is important to optimize the wind turbine positions. The primary purpose of the optimization of wind farm layout is to maximize energy production while minimize the wake loss induced by the wake effect.

To find the optimal layout scheme of wind farm, the wake velocity field in the wind farm should be accurately modelled. In addition, the annual energy output of wind farm should also be evaluated as fast as possible to give timely feedback for the wind farm layout optimization (WFLO). Therefore, the body force method and computational fluid dynamic (CFD) method are not suitable for the WFLO problem due to the huge computation. Considering that the wake model has advantages of fast calculation and relative accuracy, it is widely used in the evaluation of annual power output of the wind farm. A number of wake models have been proposed to model the turbine wake characteristics in the previous study. These wake models are developed based on the wake distribution characteristics of the wind turbine obtained from experiment data and mathematical derivation. Based on the assumption of self-similar velocity deficit profiles, Jensen (1983) proposed the Park model for the wind turbine wake dynamics. The law of conservation of momentum was applied to derive the downstream wake velocity. This model was widely used in commercial software, such as WASP and WindFarmer. The wind farm layout program (FLaP) was also developed based on Park wake model (Lange et al., 2003). Katic et al. (1987) developed a wake model based on Prandtl turbulent boundary layer equations. The Prandtl's mixing length theory with self-similar velocity profiles was applied to calculate the mean wake velocity and the wake width of the turbine wake. Frandsen (2006) modified the wind velocity profile according to downstream distance from the wind turbine. Compared with other analytical wake models, Frandsen wake model over predicted the wake velocity and further led to larger aerodynamic power output of the wind turbine. Moreover, the field models with solving the Reynolds-averaged Navier-Stokes (RANS) equations were developed to obtain the wake velocity field in the wind farm. Ainslie (1988) proposed a wake model to calculate the wake behavior by solving the RANS equations. The influence of wake meandering on the wake deficits was taken into account. Furthermore,