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A study of the wake effects on the wind characteristics and fatigue loads for the turbines in a wind farm

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ABSTRACT

With 9 multi-megawatt (MW) wind turbines and a total capacity of 22 MW, Yeongheung Wind Farm is one of the major wind farm projects in Korea. Because there are many wind turbines installed in a small area, the wake effects on the wind turbine power and load need to be investigated carefully.

This study analyzes the wind data measured before and after the construction of Yeongheung Wind Farm to examine the wake effect from the wind farm on the mean wind speed, wind shear, and turbulence intensity. Although mean wind speeds were similar in both periods, turbulence intensity and wind shear were significantly increased due to the wake effect by nearby turbines. Power performance and fatigue load analyses of the wind models for each time period were performed using the multi-MW wind turbine model. The wake effect caused the wind speed distribution of Period 2 to be lower than that of Period 1 in the wind speed range of 5–15 m/s, resulting in an about 7% reduction in annual energy production (AEP). Because there was only 0.4% difference in AEP loss between the results obtained using steady and dynamic power curve, we found that the mean wind speed had more influence on AEP than did turbulence intensity. From fatigue analysis, it was determined that the high turbulence intensity and the wind shear gradient in Period 2 caused the high fluctuation of loads, increasing the damage equivalent load (DEL) of Period 2 by 30–50% from Period 1. Although the wind speed distribution of Period 2 was certainly lower than IEC class IIIC, the fatigue loads showed up to 20% higher results for almost all load components. Therefore, we were able to confirm that high turbulence intensity significantly increases the fatigue load.

1. Introduction

As wind energy industries continue to grow in Korea, the total accumulated installation capacity reached 390 multi-megawatt (MW) in 2012, a 14% increase in two years. A number of large wind farms have been built at the shoreline and offshore locations in recent years, and more are scheduled to be constructed. Yeongheung Wind Farm, built by Korea South-East Power Co., is one of the major wind farm projects in Korea with a total capacity of 22 MW. It is the first wind farm with multi-MW wind turbines made by Korean manufacturers – Samsung Heavy Industries, Doosan Heavy Industries, and Unison. From 2010, nine wind turbines have been installed in two phases: three units with a combined capacity of 7.5 MW (1 × 2 MW, 1 × 2.5 MW, 1 × 3 MW) in the first phase, and six units with a combined capacity of 14.5 MW (2 × 2 MW, 3 × 2.5 MW, 1 × 3 MW) in the second phase. Located in the Sinnoru area in Oe-ri, Yeongheung-myeon, Ongjin-gun, Incheon, the wind farm generates approximately 42,013 MWh of power per year, which will be sold at the Korea Power Exchange. The project site is surrounded by sea and the average elevation of the site is 34.1 m with average wind speeds in the range of 5–6 m/s. Although the location of the wind farm is adequate for power generation, there are many wind turbines installed in a small area, as shown in Fig. 1. Therefore, the wake effects on the wind turbine power and loads need to be investigated carefully.

A number of numerical models have been developed to describe a wake effect in wind farm. Power losses in wind farm with small wind turbines were measured and compared with the predictions of two standard semi-empirical wake models, the Lissaman and the Risø model [1]. Although it has a very simple formula, the Rise model estimated the overall farm efficiency excellently. González-Longatt et al. [2] suggested a simplified explicit wake model to investigate the impact of the wake effect on both the steady-state

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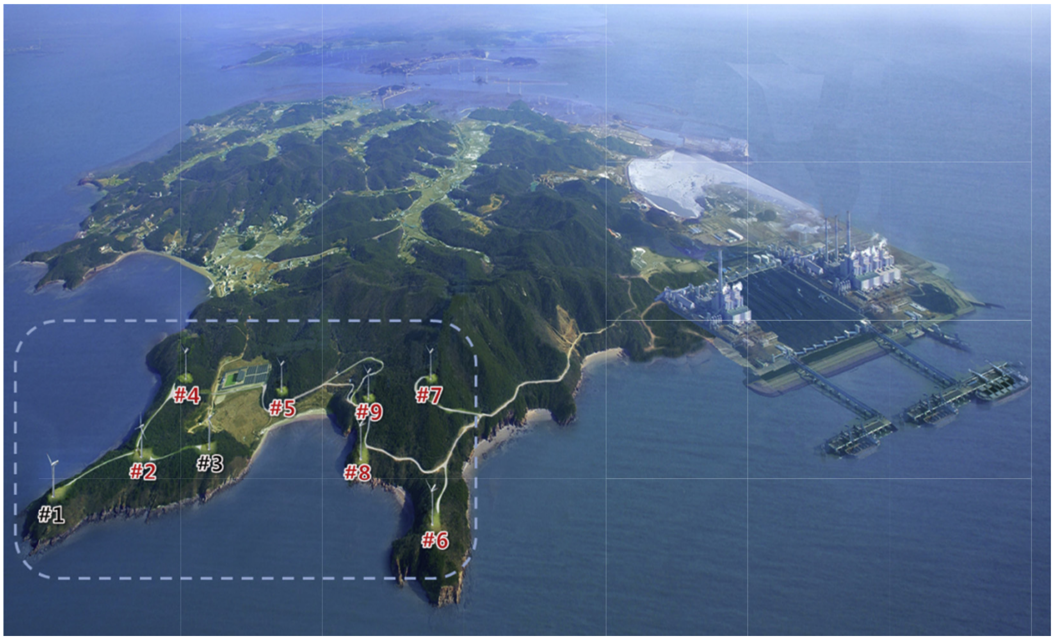

Fig. 1. Bird's-eye view of Yeongheung Wind Farm.

operation and dynamic performance in a wind farm. As a elaborate alternative to the explicit model, the implicit wake models were developed based on either Navier–Stokes or vorticity transport equations. A CFD model of wind turbine wake was investigated with 3-D Reynolds-averaged Navier–Stokes (RANS) equation [3]. They validated this approach with the measurements in complex terrain and compare the results with the predictions of WAsP.

Fig. 2. Diagram of the layout of wind farm and the location of Met Mast.

Vermeer et al. [4] summarized a numerous previous researches of experiments and analyses on the flow through the rotor, and reviewed both the near and far wake region.

Using these wake model and experimental data, numerous studies conducted about the wake effect on the wind speed and the performance of wind turbines in wind farm. In an investigation conducted by McKay [5], there was an average wind velocity deficit of over 30%, corresponding to power coefficient losses of 0.2, in the wake region. Christiansen and Hasager [6] investigated the effect of large wind farms of Hons Rev and Nysted in Denmark using satellite synthetic aperture radar (SAR). They concluded that a mean wind speed decrease is found in the downstream of wind turbine array, leaving a velocity deficit of 8–9% on average. In the study of Barthelmie et al. [7], a power loss of 50–60% have been shown in direct wind turbine alignment cases with the wake of an upstream wind turbine. Turbulence mode in wind farm indicates turbulence increase in the order of 20% in absolute terms for flow directly along the row, which is in agreement with the measurement result. Energy extraction of various wind farm layout was investigated with a mathematical model for wake effect [8], and the drop in the extracted energy reach over 30% with respect to the wind farm layout. Jadhav and Roy [9] examine the impact of wind turbine wake on economic dispatch of power system, and showed the wake effect affects the overall cost of operation and transmission losses significantly. Currently, a distance of 5 rotor diameters (5D) is generally maintained for minimum turbine spacing in order to prevent excessive wake influences [10]. However, it is not feasible to place turbines far enough apart to eliminate interaction completely. Consequently, many researchers conducted studies for optimal wind farm layout to minimize wake effect and maximize power production [11–13].

The downstream wake of a wind turbine can have a detrimental effect on not only the performance but also the fatigue loads of another wind turbine operating within this region. There are several researches conducted with field experiments at coastal sites [14,15] that drew conclusions that the wake effect is very important for fatigue loads of wind turbines operating in wake, especially for sites with low terrain roughness and low ambient turbulence