別紙４－１（課程博士（英文））

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Abstract (Doctor)

Title of Thesis	Analysis and analytical modeling of wake aerodynamics behind horizontal-axis wind turbines

Approx. 800 words

The wake transition mechanism behind an isolated non-yawed horizontal-axis wind turbine (HAWT) has been investigated using a low-cost analytical model. The wake itself is defined as the region downstream of the HAWT identified by reduced wind speed. There are two main regions within the wake flowfield behind the HAWT: (i) the near-wake region (ii) the far-wake region. Within the near-wake region, the velocity profile resembles a double-Gaussian shape with two local minima located around the blade midspan due to the suboptimal shape of the blade root and the effect of tip vortices at the blade tip. Meanwhile, within the far-wake region, the wake is completely developed and forms a single-Gaussian shape distribution. Within a full-wake region, it was clarified that the wake expands linearly in an anisotropic manner. All the mentioned wake characteristics are considered in the present study to model the wake transition mechanism within a full-wake region of the HAWT. The preliminary study was conducted to investigate the wake characteristics within the near-wake region using high-fidelity large eddy simulation (LES) data by finite element code FrontFlow/blue (FFB). It was clarified that the wake profile could be approximated by bimodal distribution. The wake was found to recover faster in the lateral direction than in the vertical direction, thus confirming the anisotropic manner of the wake expansion. In addition, it was observed that the wake tends to expand linearly with the downstream distance behind the HAWT.

Results in the preliminary study were considered in further work to propose an anisotropic double-Gaussian wake model for predicting the wake transition mechanism within a full-wake region behind the non-yawed HAWT. The transition of the wake velocity from the double-gaussian (DG) shape in the near-wake region to the single-Gaussian (SG) shape in the far-wake region by considering the anisotropic wake expansion has been successfully modeled. The effectiveness of the proposed model was validated using LES results and lidar measurements. It was shown that the proposed model could give good agreement with the benchmark datasets. In addition, the performance of the proposed model was compared to the other analytical models based on the top-hat and single-Gaussian shapes. In general, the proposed model has better performance than the other analytical models to predict the wake shape distribution, particularly within the near-wake region where the wake formed the double-Gaussian velocity profile.

Another work in this study intended to propose a linear wake expansion function for the DG analytical wake model. The proposed expansion function for the DG model was constructed from several existing formulations based on the conservation of mass and momentum. By considering the physical and statistical approaches, a linear wake expansion function was derived, thus allowing its direct usability without a prior adjustment/tuning of the wake expansion parameter. The effectiveness of the expansion function was validated with the LES and experimental measurement results, and its performance was also compared to the existing expansion function with tuning. It was clarified both qualitatively and statistically that the proposed expansion function could provide reasonable estimations of the wake expansion within full-wake regions and had comparable results with the tuned expansion function. These results indicate the practicability of the proposed expansion function for the DG wake model to predict the wake recovery within a full-wake region of the HAWT. Furthermore, the proposed expansion function was also evaluated to predict multiple wakes behind three aligned turbines. In general, the result shows that the analytical prediction could give a good agreement with the benchmark dataset from high-fidelity LES by FFB. This indicates the ability of the proposed expansion function to be used in predicting multiple wakes behind the HAWTs in addition to the single wake cases.