論 文 の 内 容 の 要 旨

論文題目　Numerical and analytical study of wind turbine wakes considering ambient environment and operational conditions

（周辺環境と運転条件を考慮した風車後流の数値予測と解析モデルの提案）

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Wind turbines in a wind farm operating in the downwind wake flow are subjected to two main problems: decreased energy production due to the velocity deficit and increased fatigue loading due to the added turbulence intensity generated by the upwind turbine. In addition, the different ambient environment and turbine operation conditions make the wind farm aerodynamics quite complicated. Therefore, an accurate and efficient evaluation of the wake effect is essential in the wind farm layout design and maintenance in order to improve the power efficiency and the lifetime of the turbine. This research focus on numerical study and analytical study of wind turbine wakes considering the ambient environment and turbine operational conditions. Wind turbine wakes under various conditions are simulated at first to investigate the behavior of wake flow and its interaction with atmospheric boundary layer. Then a new analytical wake model with high accuracy and efficiency is proposed based on the numerical study and theoretical analysis. Finally, application of the developed numerical and analytical model in real wind farm over the complex terrain are examined and validated.

In Chapter 1, the general background of this study, review of previous researches, objectives and outline of this thesis are presented.

In Chapter 2, the mathematical model utilized in this thesis for the numerical study of wind turbine wakes are illustrated. The fundamental concepts and governing equations for the Computational Fluid Dynamics (CFD) with Reynolds Stress Model (RSM), the Large Eddy Simulation (LES) and Delayed Detached Eddy Simulation (DDES) are firstly introduced. The Actuator Disk Model with Rotation (ADM-R) model based on the local disk wind speed is also presented, which is used to parameterize the wind turbine induced aerodynamic forces on the fluid. Finally, the method simulating the ground roughness and vegetations by using wall functions and canopy models are briefly described.

In Chapter 3, the systematic numerical simulations are conducted to study the wind turbine characteristics under various conditions. Firstly, two kinds of operating condition with different thrust coefficients under two types of inflow with different ambient turbulence intensity are simulated for a model and a utility-scale wind turbine. The predicted mean velocity and turbulence intensity in the wakes of two wind turbines are compared with those obtained from the wind tunnel tests to validate numerical models. Subsequently, eight simulations by the Reynolds Stress Model are conducted for different thrust coefficients, yaw angles and ambient turbulence intensities. The wake deflection, mean velocity and turbulence intensity in the wakes are systematically investigated.

In Chapter 4, a new Gaussian-based analytical wake model for wind turbines considering ambient turbulence intensities and thrust coefficient effects is developed. Firstly, the predictions of wake deficit and added turbulence intensity are modelled, which is derived based on the axial symmetry and self-similarity assumption. In addition, a new wake deflection model is then proposed to analytically predict the wake center trajectory in the yawed condition. The wake deflection model is then incorporated in the proposed Gaussian-based analytical model to consider the yaw angle effects. All the parameters of the proposed model are determined as the function of ambient turbulence intensity and thrust coefficient. The validation of new proposed analytical wake model is conducted under various conditions by comparison with numerical simulations and wind tunnel tests.

In Chapter 5, the procedure of application in real wind farm is presented based on the developed numerical and analytical models. A comprehensive wind farm field measurement conducted in the test site are firstly introduced. The wind field and turbine wake flows over the real terrain are simulated by a modified DDES for different wind directions and the accuracy is assessed by comparing with those measured by a LIDAR in the real wind farm. Subsequently, the escarpment induced terrain effects on the wind turbine wakes are systematically investigated. Finally, a hybrid framework for wake prediction in real wind farm is developed and verified by the numerical simulation, in which the local wind filed including terrain effects are predicted by a full CFD simulation and the turbine wake effects are presented by the new proposed analytical model.

Chapter 6 summarizes the conclusions of this study. A coupled BEM-CFD model is validated for wake prediction and the effects of ambient turbulence intensity, thrust coefficient and yaw angle are systematically investigated by using numerical simulations. A new analytical wake model is proposed and shows good performance for prediction of mean velocity and turbulence intensity under various ambient turbulence intensity, thrust coefficient and yawed conditions. The terrain effects on the wind turbine wake flow are investigated and the applicability of the new proposed analytical wake model in complex terrain is verified.