Special Program in Applied Mathematics and Applied Mechanics

Development of a large-eddy simulation framework for wind energy studies

2014 - 11 - 19 (Wed.)
15:00 - 18:00
308, Mathematics Research Center Building (ori. New Math. Bldg.)

A modeling framework is proposed and validated to simulate turbine wakes and associated power losses in wind farms. It combines the large-eddy simulation (LES) technique with blade element theory and a turbine-model-specific relationship between shaft torque and rotational speed. In the LES, the turbulent subgrid-scale stresses are parameterized with a tuning-free Lagrangian scale-dependent dynamic model. The turbine-induced forces and turbine-generated power are modeled using a recently developed actuator-disk model with rotation (ADM-R), which adopts blade element theory to calculate the lift and drag forces (that produce thrust, rotor shaft torque and power) based on the local simulated flow and the blade characteristics. In order to predict simultaneously the turbine angular velocity and the turbine-induced forces (and thus the power output), a new iterative dynamic procedure is developed to couple the ADM-R turbine model with a relationship between shaft torque and rotational speed. This relationship, which is unique for a given turbine model and independent of the inflow condition, is derived from simulations of a stand-alone wind turbine in conditions for which the thrust coefficient can be validated. Comparison with observed power data from the Horns Rev wind farm shows that better power predictions are obtained with the dynamic ADM-R than with the standard ADM, which assumes a uniform thrust distribution and ignores the torque effect on the turbine wakes and rotor power. The results are also compared with the power predictions obtained using two commercial wind-farm design tools (WindSim and WAsP). These models are found to underestimate the power output compared with the results from the proposed LES framework.

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