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Modeling turbine wakes and power losses within the Horns Rev offshore wind farm using large-eddy simulation

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A recently-developed large-eddy simulations (LES) framework is implemented to predict multiple wake flows and the associated power losses within the Horns Rev offshore wind farm under near-neutral stability conditions. A tuning-free Lagrangian scale-dependent dynamic subgrid-scale (SGS) model is used for the parametrization of the SGS stresses. The turbine-generated power outputs and the turbine-induced forces (e.g., thrust, lift, drag) are parameterized using two models: (a) the traditional actuator-disk model without rotation (ADM-NR), which uses the 1D momentum theory to relate the power output and the thrust force with a representative velocity over the rotor (e.g., the disk-averaged velocity); and (b) the 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 blade and flow characteristics. In general, the predicted power outputs obtained using the ADM-R are in good agreement with observed power data from the Horns Rev wind farm. The ADM-NR tends to underestimate the power output. A similar under-prediction is obtained using industry-standard wind-farm models such as the Wind Atlas Analysis and Application Program (WAsP). Simulations using different inflow conditions show that the mean wind direction has a strong effect on the spatial distributions of the time-averaged velocity and the turbulence intensity within the farm. These, in turn, affect the power output and the fatigue loads on the turbines. When the prevailing wind direction is parallel to the turbine rows (i.e. a full wake condition), the velocity deficit and the power losses are largest, and the turbulence intensity levels are highest and have a symmetric pattern (dual-peak at hub height) on both sides of the turbine wakes. A detailed analysis of the turbulence kinetic energy budget in the full wake condition shows an important effect of the increased turbulence level on the magnitude and spatial distribution of the shear production and transport terms.