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A Large-Eddy Simulation Study of Vertical Axis Wind Turbine Wakes in the Atmospheric Boundary Layer

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In a future sustainable energy vision, in which diversified conversion of renewable energies is essential, vertical axis wind turbines (VAWTs) exhibit some potential as a reliable means of wind energy extraction alongside conventional horizontal axis wind turbines (HAWTs). Nevertheless, there is currently a relative shortage of scientific, academic and technical investigations of VAWTs as compared to HAWTs. Having this in mind, in this work, we aim to, for the first time, study the wake of a single VAWT placed in the atmospheric boundary layer using large-eddy simulation (LES). To do this, we use a previously-validated LES framework in which an actuator line model (ALM) is incorporated. First, for a typical three- and straight-bladed 1-MW VAWT design, the variation of the power coefficient with both the chord length of the blades and the tip-speed ratio is analyzed by performing 117 simulations using LES-ALM. The optimum combination of solidity (defined as Nc/R, where N is the number of blades, c is the chord length and R is the rotor radius) and tip-speed ratio is found to be 0.18 and 4.5, respectively. Subsequently, the wake of a VAWT with these optimum specifications is thoroughly examined by showing different relevant mean and turbulence wake flow statistics. It is found that for this case, the maximum velocity deficit at the equator height of the turbine occurs 2.7 rotor diameters downstream of the center of the turbine, and only after that point, the wake starts to recover. Moreover, it is observed that the maximum turbulence intensity (TI) at the equator height of the turbine occurs at a distance of about 3.8 rotor diameters downstream of the turbine. As we move towards the upper and lower edges of the turbine, the maximum TI (at a certain height) increases, and its location moves relatively closer to the turbine. Furthermore, whereas both TI and turbulent momentum flux fields show clear vertical asymmetries (with larger magnitudes at the upper wake edge compared to the ones at the lower edge), only slight lateral asymmetries were observed at the optimum tip-speed ratio for which the simulations were performed.