Characterization of wind velocities in the upstream induction zone of a wind turbine using scanning continuous-wave lidars

As a wind turbine generates power, induced velocities, lower than the freestream velocity, will be present upstream of the turbine due to perturbation of the flow by the rotor. In this study, the upstream induction zone of a 225kW horizontal axis Vestas V27 wind turbine located at the Danish Technical University’s Risø campus is investigated using a scanning Light Detection and Ranging (lidar) system. Three short-range continuous-wave “WindScanner” lidars are positioned in the field around the V27 turbine allowing detection of all three components of the wind velocity vectors within the induction zone. The time-averaged mean wind speeds at different locations in the upstream induction zone are measured by scanning a horizontal plane at hub height and a vertical plane centered at the middle of the rotor extending roughly 1.5 rotor diameters (D) upstream of the rotor. Turbulence statistics in the induction zone are studied by more rapidly scanning along individual lines perpendicular to the rotor at different radial distances from the hub. The mean velocity measurements reveal that the longitudinal velocity reductions become greater closer to the rotor plane and closer to the center of the rotor. Velocity deficits of 1%–3% of the freestream value were observed 1 D upstream of the rotor, increasing at the rotor plane to 7.4% near the edge of the rotor and 18% near the center of the rotor while the turbine was operating with a high estimated mechanical coefficient of power (CP) of 0.56 yielding an estimated axial induction factor of 0.25. The velocity reductions relative to the freestream velocity become smaller when the turbine’s coefficient of power decreases; for a low CP of 0.16 resulting in an estimated induction factor of 0.04, the velocity deficits are 1% of the freestream value 1 D upstream of the rotor and only 6% at the rotor plane near the center of the rotor. Additionally, the mean radial wind speeds were found to increase close to the edge of the rotor disk indicating an expansion of the incoming flow around the rotor. Radial velocity magnitudes at the edge of the rotor disk of approximately 9% and 3% of the freestream longitudinal wind speed were measured for the abovementioned high and low CP values, respectively. Turbulence statistics, calculated using 2.5-min time series, suggest that the standard deviation of the longitudinal wind component decreases close to the rotor, while the standard deviation of the radial wind component appears to increase. When the turbine was operating with a high CP of 0.54 resulting in an estimated induction factor of 0.22, standard deviation decreases of up to 22% of the estimated freestream value and increases of up to 46% were observed for the longitudinal and radial components, respectively, near the center of the rotor.

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