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Extension of an Aeroelastic Actuator Sector Model for wind turbine parametrization in a coupled Large Eddy Simulation framework

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1 Introduction

Wakes originating from upstream turbines in wind farms have detrimental effects on power production and structural lifespan of turbines in downstream rows. In recent years, Large-Eddy Simulations (LES) have proved to be a valuable tool for simulating large wind farms and developing dynamic wind turbine control strategies, such as induction control and yaw control, for overall increase in windfarm efficiency [1]. To correctly model the physics behind complex wake interactions and capture the effect of these control strategies, accurate parameterization of wind turbine forces on the LES grid is essential. Additionally, two-way fluid structure interaction coupling is required to evaluate the effect of the control strategies on turbine structures. Computational time and cost are large limiting factors for accurate representation of wind turbine structural and flow dynamics. To make two-way coupled wind farm simulations for long time horizons computationally feasible, Vitsas and Meyers developed an Aeroelastic Actuator Sector Model (AASM) which includes a multibody dynamics module coupled with a pseudospectral large-eddy simulation solver, SP-Wind [2]. However, in its current form the AASM does not have provisions to represent the effect of turbine tilt and precone. The model also lacks the capability of yawing the turbines, hence making simulations to test yaw control strategies impossible. This work aims to extend the AASM to include the capability of yawing, tilting and preconing a wind turbine rotor. The aeroelastic model is upgraded and the effect of incorporating yaw, tilt and precone angles is investigated by comparing turbine power and structural loading statistics against simulations without these geometric angles.

2 Methodology

In the original formulation of Vitsas and Meyers, the deformation analysis of the flexible rotor and tower bodies is determined in a finite-element floating frame of reference (FFR) framework. Bryant angles are used to describe the orientation of the rotor's body frame with respect to the global orientation. With the assumption that rotation about the low-speed shaft is the only rotational degree of freedom to contribute to the dynamic behaviour, yawing and tilting motion are accounted for quasistatically. In this work, to include turbine yaw and tilt angles, they are added to the yaw and tilt degrees of freedom of the Bryant angles rotation matrix. Preconing is included by multiplying the Bryant rotation matrix by another rotation matrix to account for rotation in the negative tilt direction, and extending the quasistatic assumption to precone angles. As the azimuthal rotation matrix is partitioned by 120 degrees to account for a 3 bladed rotor, each blade is coned in the upstream direction individually.

For the calculation of aerodynamic forces, the incoming velocity components are multiplied successively by the yaw, tilt, azimuth and precone rotation matrix. Finally, the relative velocities, angle of attack and sectional lift and drag forces are calculated at each blade segment, which are used to determine the torque and power output of the turbine.

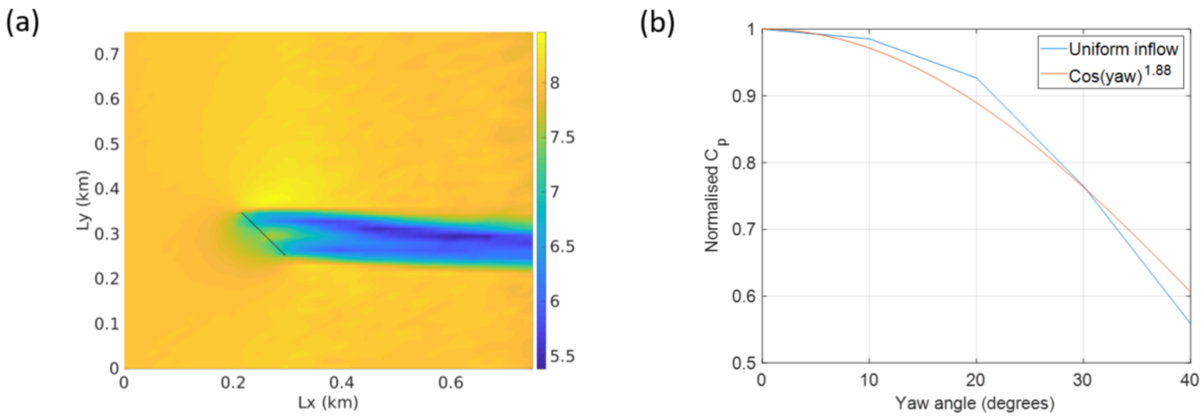

Figure 1: (a) Horizontal velocity U (m/s) at hub height plane for 40 degrees yaw angle (b) Reduction in power coefficient with yaw angle, normalized by 0 yaw case.

Simulations are conducted in SP-Wind for yaw, tilt and precone angles ranging from 0 to 40 degrees and uniform inflow velocity of 8 m/s on the NREL 5MW turbine. Size of the domain for all the simulations is 2π x π x 1 km with 256 x 192 x 125 grid points respectively. Comparisons are made on the basis of power coefficient C_P and Damage Equivalent Loads (DEL) [3].

3 Results and Discussion

Results of reduction in power and increase in out of plane root bending moment DEL with increasing yaw angles are comparable to those found in literature, with C_P reducing as a function of $cos\gamma^{1.88}$ [4][5]. Similar trends can be observed for change in performance for increasing tilt and precone angles. Furthermore, inclusion of prescribed precone and shaft tilt angles in NREL 5MW turbine simulations resulted in more accurate power capture.

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