Coordinated turbine control through axial-induction factor: wake characteristics and wind farm power optimization

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Abstract
Individual turbine control for maximizing the performance of an individual turbine often leads to suboptimal performance of the whole wind farm. To optimize the performance of the whole wind farm, advanced wind farm control strategies have been developed. In this work, we investigate the effects of axial-induction factor control on the wake characteristics of a utility-scale turbine and its potential for increasing wind farm power output.

Keywords: *Coordinated turbine control, Axial-induction factor, Wake characteristics*

Introduction
As of December 2015, the cumulative installed capacity of wind energy is about 74 GW for U.S. and 433 GW for the whole world [1]. With such increased penetration of wind energy in the worldwide, a tiny increase of wind farm efficiency can lead to significant economic and environmental impacts. Conventional turbine control algorithm aims at maximizing the power output of each individual turbine. This, however, often results suboptimal performance of the whole wind farm. To optimize the performance of the whole wind farm, advanced wind farm control strategies, such as coordinated turbine control through axial induction factor and yaw-based wake redirection method, have been developed. For instance, Fleming et al. [2] studied three different wake redirection methods including yaw-based, tilt-based and IPC (individual pitch control)-based methods for improving the wind farm overall performance using large-eddy simulation with actuator line model for turbine blades. Using large-eddy simulation, Annoni et al. [3] showed that the performance of a turbine array can be improved by derating the upwind turbines through axial induction factor control. The major difficulty to develop an effective wind farm control models originates from the limited knowledge of turbine wake dynamics under realistic atmospheric conditions and site-specific complex terrains. The objective of this work is to systematically investigate the wake characteristics of a turbine operating under suboptimal conditions and the potential for improving wind farm performance.

Numerical Methods
The CFD (computational fluid dynamics) code, Virtual Flow Simulator-Wind (VFS-Wind) [4] is employed for the wind turbine and wind farm simulations. In VFS-Wind, the governing equations are the three-dimensional, unsteady, filtered continuity and Navier-Stokes equations. The subgrid-scale stress is modelled by the dynamic eddy viscosity subgrid-scale stress model. Actuator surface models [5] for turbine blades and nacelle are employed for turbine parameterization. The governing equations are discretized in space using a second-order accurate central differencing scheme, and integrated in time using the fractional step method. An algebraic multigrid acceleration along with GMRES solver is used to solve the pressure Poisson equation. A matrix-free Newton-Krylov method is used for solving the discretized momentum equation.

Computational Results
The 2.5 MW Clipper turbine with rotor diameter 96 m and hub height 80 m is employed. Six different tip-speed ratios around the optimal condition are considered. Figure 1 shows the simulation results for these cases. Tip speed ratio of 7.8 is close to the optimal condition. It shows that the performance can be

increased for tip-speed ratios of 6.8, 7.2 and 8.3 for all the considered turbine spacings. For the tip-speed ratio of 8.8 and 9.3 cases, on the other hand, the performance is decreased for small turbine spacings while increased for large turbine spacings.

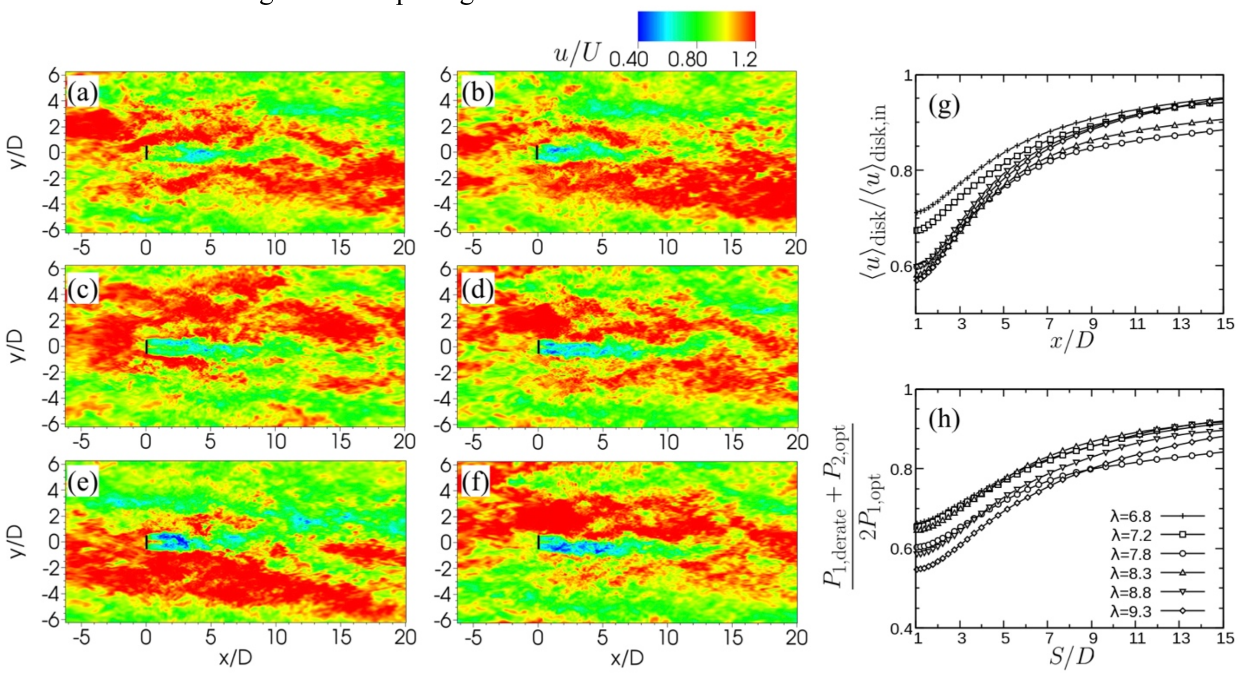

Figure 1 (a)-(f): Contours of instantaneous downwind velocity on the horizontal plane located at turbine hub height for (a) λ=6.8; (b) λ =7.2; (c) λ=7.8; (d) λ =8.3; (e) λ =8.8 and (f) λ =9.3. (g)-(h): Profiles of (g) Downwind variations of disk- and time-averaged downwind velocity; and (h) Ratios of the extracted power of two turbines (with the downwind turbine hypothetically placed at different downwind locations) to that of two stand-alone turbines operating in the optimal condition.

Conclusions

We investigated the wake characteristics of a utility-scale wind turbine operating under suboptimal conditions. We found that both increasing and decreasing the axial-induction factor can improve the available power for the downwind turbine. However, the effect on the dynamic loads of the downwind turbine is different. The potential of using the axial-induction factor control for utility-scale wind farm optimization will be investigated using high-fidelity simulation in the future work.

References

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