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Modeling and uncertainty quantification for cooperative wind farms at utility-scale

Michael Howland

Esther and Harold E. Edgerton Assistant Professor of Civil and Environmental Engineering

MIT

ABSTRACT:

Wind turbines located in wind farms are operated to maximize only their own power production. Individual operation results in wake losses that can reduce energy 10-20%. Wind farm flow control has demonstrated potential to increase collective power production. To achieve the maximum farm power production, the models used for wind farm decision-making must be both accurate and computationally efficient. The potential for flow control depends, in part, on the power reduction of yaw misaligned turbines. In the atmospheric boundary layer (ABL), the sheared wind speed and direction may change significantly over the rotor area, resulting in a relative inflow wind to the blade airfoil which depends on the radial and azimuthal positions. In order to predict the power production for an arbitrary yaw misaligned turbine based on the incident ABL velocity profiles, we develop a blade element model which accounts for wind speed and direction changes over the rotor area, and the model is validated using experimental data from a utility-scale wind farm. The blade element model is coupled with an aerodynamic wake model to establish a collective flow control model. Leveraging the flow control model, we designed a physics-based, data-assisted wake steering control method to increase the power production of wind farms, which utilizes data assimilation and gradient-based optimization. The method was first validated, demonstrating that it predicts the true power maximizing operation, and then tested in a multi-turbine array at a utility-scale wind farm, where it statistically significantly increased the energy production over standard, individual operation. Collective control can increase the generation potential of wind farms through software modifications, without additional turbines or hardware. To enable reliable decision-making for cooperative wind farm design and control under inflow wind uncertainty, we develop a framework for efficient uncertainty quantification (UQ) of computationally intensive numerical ABL flow models. We validate the methodology for efficient parameter UQ in an idealized general circulation model (GCM) and in large eddy simulations (LES) of the stratified ABL.

BIOGRAPHY:

Michael F. Howland is the Esther and Harold E. Edgerton Assistant Professor of Civil and Environmental Engineering at MIT. He was a Postdoctoral Scholar at Caltech in the Department of Aerospace Engineering. He received his B.S. from Johns Hopkins University and his M.S. from Stanford University. He received his Ph.D. from Stanford University in the Department of Mechanical Engineering. His work is focused at the intersection of fluid mechanics, weather and climate modeling, uncertainty quantification, and optimization and control with an emphasis on renewable energy systems. He uses synergistic approaches including simulations, laboratory and field experiments, and modeling to understand the operation of renewable energy systems, with the goal of improving the efficiency, predictability, and reliability of low-carbon energy generation. He was the recipient of the Robert George Gerstmyer Award, the Creel Family Teaching Award, and the James F. Bell Award from Johns Hopkins University. At Stanford, he received the Tau Beta Pi scholarship, NSF Graduate Research Fellowship, a Stanford Graduate Fellowship, and was awarded as a Precourt Energy Institute Distinguished Student Lecturer.