Optimization Under Uncertainty for Wake Steering Strategies

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Abstract

The current paradigm is to control wind turbines in wind power plants individually, maximizing the individual turbines' power generation by controlling the turbines to face the incoming wind as directly as possible. Wind-plant control has emerged as an exciting field as the understanding of wind plant aerodynamic interactions has matured. One strategy, known as "wake steering," offsets the turbines' yaw positions away from the incoming wind to "steer" the wake away from downstream turbines and maximize the wind power plant's energy yield. There are many uncertain aspects of wake steering: the tools used for measuring the state of the wind plant are subject to error, it is challenging to forecast the behavior of the atmosphere, and engineering wake models do not fully capture complex wind power plant aerodynamic interactions. We apply optimization under uncertainty to this problem, explicitly maximizing the expected power production given uncertainties in inflow speed and direction and individual turbine yaw alignments.

Keywords: *Wake Steering, Wind Plant Control, Optimization Under Uncertainty*

Introduction

As the wind industry matures, more effort is going into extracting as much power as possible from wind power plants. One exciting new operational strategy is to control the wind power plant as a whole, instead of the "baseline" strategy of operating each turbine to maximize its own energy capture. Wake steering is a novel plant-level controls approach that offsets the turbines' yaw positions away from the incoming wind, "steering" the wake away from downstream turbines. Previous work has noted that wake steering can significantly increase wind plant power production [1-4]. Recently, researchers from the National Renewable Energy Laboratory (NREL) performed a field test of wake steering in a utility-scale wind power plant [5]. Measurement errors and model uncertainties may result in wake steering strategies that perform worse than the baseline operational strategy; consequently, uncertainty must be carefully considered when designing wake steering strategies. We present a methodology to address these uncertainties by explicitly designing wake steering strategies around measurement uncertainties.

Approach

We used the FLOw Redirection and Induction in Steady State (FLORIS) engineering wake model [1] to assess the value of wake steering strategies and Sandia National Laboratories' Design Analysis Kit for Optimization and Terescale Applications (DAKOTA) to perform optimization under uncertainty (OUU) for the strategies. The FLORIS model approximates the behavior of wakes behind turbines as curved cones. We nested a sparse-grid sampling routine within DAKOTA's constrained optimization by linear approximation optimization algorithm (Figure 1), using untruncated Gaussian distributions of turbine yaw positions and inflow speed and direction. As a first step, we examined how yaw misalignment affects the design space, using a simple two-turbine test case to understand the fundamental effect; and a model of a utility-scale wind plant to understand how extreme yaw misalignment may affect wake steering strategies and assess the value of OUU. We used published values of inflow speed and direction uncertainty [6] and assumed the standard deviation of the yaw position uncertainty to be 12°.

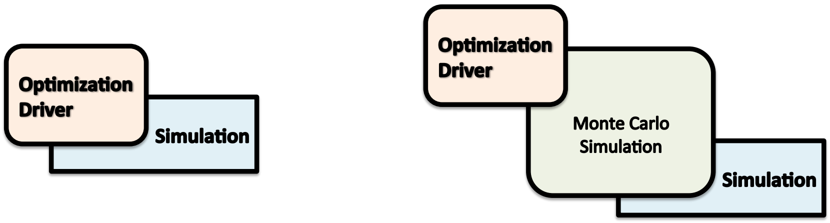

Figure 1: Classically, an optimizer deterministically optimizes a model (left). In OUU (right), an uncertainty quantification routine is used to simulate several possible scenarios. Statistics describing those scenarios are optimized.

Results

We found that introducing uncertainty significantly degrades the expected value of wake steering strategies. Generally, it is optimal to steer less when there is more uncertainty (Figure 2). In some cases, the deterministically formulated strategy performed worse than the baseline. We found that, when accounting for inflow speed and direction and yaw misalignments, the OUU solution produced 2.9% and 0.8% more annual energy than the baseline and deterministic strategies, respectively. In addition, the OUU strategy generally has less extreme yaw offsets than the deterministic strategy, which induces less wear and tear on the turbines.

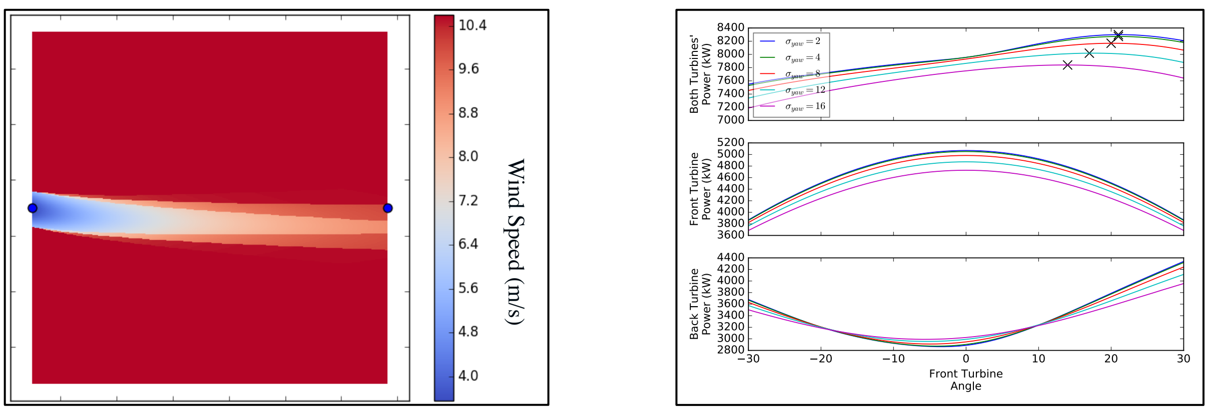

Figure 2: We examined a two-turbine setup (left) to understand the fundamental trade-offs in wake steering. As uncertainty in the two turbines' yaw positions increases, the optimal yaw offset of the front turbine decreases and the value of the stochastic solution (VSS) increases. The VSS is defined as the ratio of the expected power production of the OUU and deterministic wake steering strategies, evaluated with the same uncertainty used to generate the OUU solution.

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