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[Extended Abstract]

Large-Scale Wind Farm Optimization and Uncertainty Quantification

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Introduction

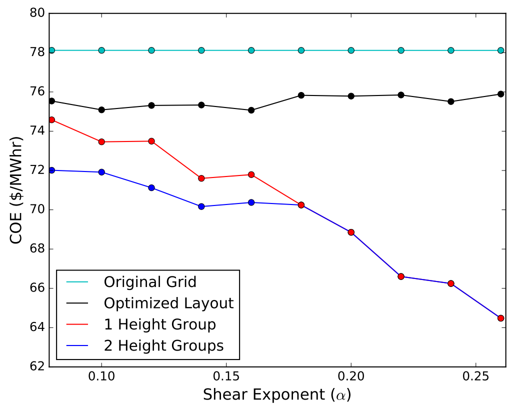
One of the major challenges currently faced by the wind energy industry is underproduction from wake interference. This problem is exacerbated by simplistic wind farm design optimization strategies. As a wind turbine produces power, it leaves behind a wake with less momentum for downstream turbines. This momentum deficit repeats across many turbines resulting in significant underproduction for the wind farm as a whole. Design of the wind farm layout to minimize these negative interactions is challenging because many variables are involved. Most existing wake models are noisy and discontinuous, and so typical practice in the industry is to use gradient-free methods. As a consequence, the problem is often simplified, for example by aligning turbines on grids, in order to reduce the number of variables to a few global spacing parameters. This reduction of problem scope has resulted in simplistic layouts that contribute to the significant problem of wind farms underproducing by about 10-30% relative to expectations [1].

Methods

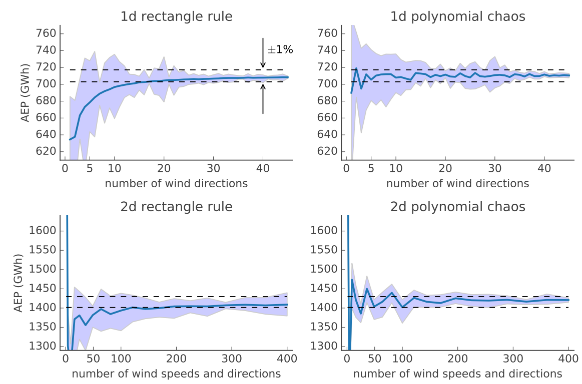
Our research has focused on enabling large-scale design optimization and uncertainty quantification of wind farm performance. First, we have developed analysis tools with exact gradients, using automatic differentiation and the adjoint method, to enable larger optimization problems. We modified wake models so that they were continuously differentiable and provided exact gradients, made the corresponding implementations open-source, and conducted design and scalability studies [2]. These changes allowed for a three orders of magnitude decrease in the required number of function calls, which has enabled large-scale design and control optimization studies of wind farms [3].

Second, we have shown significant benefits to integrating layout, control, and design optimization. Wind farms are designed with a single wind turbine, however significant benefits may be possible by utilizing two or more turbine types. Additionally, turbines are designed in isolation, and not for specific wind farm conditions. We are exploring wind farm optimization using turbines of different sizes and turbine design simultaneous to the design of the farm.

Turbines of different heights can minimize wake interference even more than pure positioning. Our work has focused on allowing simultaneous position optimization, yaw control, and tower sizing (including structural constraints and tradeoffs in capital costs). Significant benefits have been observed even with just two different tower sizes in the farm [4]. Figure 1a shows significant benefits to including two different tower heights, for sites with low wind shear (meaning the wind speed changes relatively slowly with height). Ongoing research is focused on allowing rotors of different sizes, optimizing with more than two height groups, and integrating yaw-control in the optimization.



(a) Optimized cost of energy as a function of wind shear exponent for four scenarios: the original wind farm grid, position is optimized, position and tower size are optimized, position and tower size are optimized and two different sizes are allowed in the farm. The two sizes is shown to be particularly beneficial at low wind shear.



(b) Each curve shows convergence in annual energy production versus the number of evaluations required in the integration. Polynomial chaos is shown to be more efficient than the rectangle rule both when considering uncertainty in the wind direction, and simultaneous uncertainty in wind direction and speed.

Figure 1. Some recently published and ongoing work.

Third, we have demonstrated the use of polynomial chaos to more efficiently predict annual energy production, and other statistics of interest for a wind farm [5]. Typical practice for evaluating annual energy production is to use the rectangle rule to compute the expected value of the power. However, as shown in fig. 1b, much fewer evaluations are necessary to reach a certain error threshold by careful use of polynomial chaos. Ongoing work is focused on comparing regression-based polynomial chaos (instead of the just quadrature-based), adding additional uncertain parameters, exploring multifidelity uncertainty quantification, and conducting optimization under uncertainty studies.

This presentation would focus on our latest results in large-scale integrated wind farm optimization, and efficient methods for performing optimization under uncertainty.

References

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