**Wind Farm Layout Optimization with Loads Considerations**

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**Wind Plant Design Wind Farm Layout Optimization**

**Introductory Summary**

Wind farms can achieve important energy output increases through turbine layout optimization. However, another benefit of layout optimization can be to decrease the loads caused by turbine waking. In this paper, we optimize wind farm layout to maximize energy production, while using a surrogate model to constrain loads. Our preliminary results show that by constraining turbine waking (which relates to fatigue loads), average waking can be reduced by about 20% with only a marginal 2% reduction in wind farm energy production, compared to an optimized wind farm that does not consider waking constraints.

**Keywords:** *layout optimization, FLORIS, loads, surrogate model*

**Introduction**

Wind turbines extract energy from the air passing by, reducing the wind speed and increasing the turbulence. The decreased wind speed from turbine waking can cause wind farm energy production to be 10% lower than expected [1]. Wind farm layout optimization has often been used to reduce turbine waking and maximize energy production [2]. However, in addition to decreased power production, waked turbines are subjected to more turbulent inflow, increasing the fatigue loads on the structure by up to 15% and reducing the turbine lifetime [3]. ­­­­­Wind farm layout optimization which only aims to increase power production often results in wind turbines that are fully or partially waked by others for certain wind conditions. In this research, we will perform wind farm layout optimization to maximize energy production while accounting for structural damage from full and partial waking.

**Methods**

Our methodology consists of three main components: wind farm energy calculation, structural modeling, and optimization. We use the National Renewable Energy Laboratory (NREL) 5 MW reference turbine for turbine parameters and the power curve [4]. For wind speed calculations, we use a version of the FLORIS wake model which has been modified to allow for gradient-based optimization [5]. Total velocity deficit is defined as the L2 norm of the loss contribution from each wake. The effective wind speed at a partially waked turbine is determined as an area weighted average across the rotor.

Wind turbine fatigue calculations are computationally expensive compared to the other engineering models used in wind farm design. FAST is a software package developed at NREL that analyzes the dynamic response of a wind turbine, including fatigue loads [6]. It is a powerful program that can analyze a wide variety of inflow situations, but is computationally intensive and not well suited for optimization. We will run FAST for a variety of different inflow conditions, and create a surrogate model of the turbine loads with different waking conditions. This is similar to our previous work, in which we created a surrogate of turbine loads and rotor mass as a function of rotor diameter and rated power [7]. The surrogate model will allow us to quickly calculate loads on the turbines within an optimization where the model will be called hundreds or thousands of times.

In this study, our objective function is the annual energy production (AEP) of the wind farm, with the x and y location of each wind turbine as the design variables, meaning our optimization will have on the order of one hundred design variables. We will constrain the fatigue loads on each wind turbine such that they do not exceed a given accumulated damage during a twenty-year lifespan. We will vary the damage threshold and determine how the optimal power production is affected by more stringent loads constraints. In addition to loads constraints, we will also constrain turbine spacing and enforce wind farm boundaries. We will use the optimizer SNOPT, which is a gradient-based optimizer well suited for large-scale nonlinear problems [8]. Because gradient-based optimization is sensitive to the starting points, we will use the recently developed Wake Expansion Coefficient method to reduce the multi-modality of the design space and ensure that we can search more of the design space, increasing the probability of finding the global optimum [9]. In addition, we will use many randomly generated starting locations.

**Preliminary Results**

Figure 1: Pareto front showing how optimal annual energy production is affected by constraints on average turbine waking



Figure 1, which shows some preliminary optimization results, shows the relationship between achievable AEP and average turbine waking. For these results, average turbine waking was defined as the average amount of the swept rotor area that is waked throughout the wind farm. Turbine waking in these results stands in for our FAST surrogate model, with the understanding that waked turbines experience higher fatigue loads than un-waked turbines. Increased loads from partial waking are not considered in these results, but will be accounted for in our surrogate model.

We optimized the layout of a twenty-turbine wind farm, with fifteen random starts for each optimization and a unidirectional wind rose. This Pareto front was achieved by first optimizing the layout with only turbine spacing and boundary constraints to obtain the maximum AEP, and finding the associated average waking. We then repeated this optimization with an additional constraint on average turbine waking. By considering the turbine waking as a constraint, it can be significantly reduced (20%) for only a marginal decrease in AEP (2%). We expect our final results to be similar, in that we will be able to reduce fatigue damage in a wind farm with negligible effect on the AEP. This is due to the multi-modality of the wind farm layout design space. There are many solutions that produce a near identical AEP, but vary widely in turbine fatigue damage. By constraining fatigue during optimization, we can take advantage of the design space multi-modality, and find the solutions with high AEP and low fatigue.

**Conclusions**

Wind farms can achieve energy output increases through turbine layout optimization. In addition to increased energy, layout optimization can also be used to decrease fatigue loads caused by turbine wakes. By using a surrogate model to calculate loading on wind turbines, we will optimize wind farm layout for maximum AEP, while safely constraining turbine loads to maintain the lifetime of the turbines.

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