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Robust Wind Farm Layout Optimization Using Pseudo-Gradients*

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Wind farms form an ever increasing share of the world's electricity production capacity. But now that wind energy subsidy schemes are coming to an end, the *cost per unit of electricity* produced must become structurally lower than the fossil fuel-based power plants society wants replaced. Optimization of the farms' design [1] is essential to achieving this.

So the objective is to minimize the expected cost per unit of electricity. This objective depends on the expectation for the amount of electricity produced and for the farm's cradle-to-grave costs. We here assume those costs to be fixed, so that the objective becomes maximization of expected electricity production. So we ignore aspects such as cable layout and their impact on the design. Effectively, we consider a fixed number of turbines whose positions can be chosen; this set of positions is called the *wind farm layout*. However, we must consider the period over which the electricity is produced: The farm lifetime production is important, but so is yearly production, as large inter-year variation poses financial risks.

Therefore, we are studying the effect of inter-year variation of the wind resource. A site's *wind resource* is represented by the joint probability distribution of wind directions and wind speeds encountered there over time. Specifically, we wish to create optimized layouts that are *robust* against this inter-year variation. For us—comparing layouts whose profiles of yearly expected production are undominated—, this means that we prefer layouts with a more constant relative performance. We have not fixed a formalization of this robustness concept, but would like to explore imprecise probabilistic options.

Calculating the expected power production of a wind farm given a layout and wind resource is computationally expensive, because for each of the many required pairs of wind speed and wind direction a complex *wake* pattern must be computed. Also, when optimizing, the layout changes each iteration and computationally non-trivial constraints must be satisfied. Of course, considering yearly variation in wind resources yet again multiplies the computational effort required.

Even when using simplified wake models runs, our robustness study would be practically infeasible using the classical optimization algorithms [2]. Therefore, we have designed a more efficient optimization approach. It (i) takes downwind, crosswind, and inter-turbine unit vectors, (ii) multiplies these by the power deficits caused by the wakes, and (iii) takes the expectation over the wind resource to create *pseudo-gradients*, to be used instead of real gradients. It has been shown to be competitive with other approaches in terms of optimal objective value, but substantially faster.

We have used pseudo-gradient-based optimization to perform layout optimizations for a realistic site and for a set of wind resources that consists of 35 yearly ones, their average, one with a uniform wind resource, and one with just a single wind direction. Moreover, because wind resource normalization is not needed for the derivation of pseudo-gradients, we also considered the lower and upper envelopes of the 35 yearly wind resources as optimizer inputs.

Some conclusions: (i) Inter-year wind resource variation is substantial, i.e., about half the probability mass shifts around. (ii) For the different layouts *generated by our algorithm*, the inter-year production differences for one layout are larger than differences between different layouts for one single year. (iii) The set of layouts with undominated production profiles is relatively small, mainly due to the fact that relative performance of layouts is mostly stable over the years. (iii) Among these, there exist robust layouts as we defined them, but in a trivial sense, as they are more optimal in general over all yearly wind resources considered. (iv) Therefore, there is no real trade-off achieved yet between robustness and optimality.

Further investigation is warranted to determine (i) the impact of the optimization algorithm and its parameter settings, as the results appear to depend chaotically on these settings and (ii) the relevance of optimizing for a specific wind resource.

References

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