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Surrogate-based Particle Swarm Optimization for Large-scale Wind Farm Layout Design

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Abstract

Wind farm layout optimization (WFLO) is the process of optimizing the location of turbines in a wind farm site, with the possible objective of maximizing the energy production or minimizing the average cost of energy. Conventional WFLO methods not only limit themselves to prescribing the site boundaries, they are also generally applicable to designing only small-to-medium scale wind farms (<100 turbines). Large-scale wind farms entail greater wake-induced turbine interactions, thereby increasing the computational complexity and expense by orders of magnitude. In this paper, we further advance the Unrestricted WFLO framework by designing the layout of large-scale wind farms with 500 turbines (where energy production is maximized). First, the high-dimensional layout optimization problem (involving 2N variables for a N turbine wind farm) is reduced to a 6-variable problem through a novel mapping strategy, which allows for both global siting (overall land configuration) and local exploration (turbine micrositing). Secondly, a surrogate model is used to substitute the expensive analytical WF energy production model; the high computational expense of the latter is attributed to the factorial increase in the number of calls to the wake model for evaluating every candidate wind farm layout that involves a large number of turbines. The powerful Concurrent Surrogate Model Selection (COSMOS) framework is applied to identify the best surrogate model to represent the wind farm energy production as a function of the reduced variable vector. To accomplish a reliable optimum solution, the surrogate-based optimization (SBO) is performed by implementing the Adaptive Model Refinement (AMR) technique within Particle Swarm Optimization (PSO). In AMR, both local exploitation and global exploration aspects are considered within a single optimization run of PSO, unlike other SBO methods that often either require multiple (potentially misleading) optimizations or are model-dependent. By using the AMR approach in conjunction with PSO and COSMOS, the computational cost of designing very large wind farms is reduced by a remarkable factor of 26, while preserving the reliability of this WFLO within 0.05% of the WFLO performed using the original energy production model.

Keywords: large-scale wind farm; layout optimization; surrogate-based optimization; concurrent surrogate model selection; predictive estimation of model fidelity; particle swarm optimization.