TopFarm: Multi-fidelity Optimization of Offshore Wind Farm

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ABSTRACT

A wind farm layout optimization framework based on a multi-fidelity model approach is applied to the offshore test case of Middelgrunden, Denmark. While aesthetic considerations have heavily influenced the famous curved design of Middelgrunden wind farm, this work focuses on testing a method that optimizes the profit of offshore wind farms based on a balance of the energy production, the electrical grid costs, the foundations cost, and the wake induced lifetime fatigue of different wind turbine components. The multi-fidelity concept uses cost function models of increasing complexity (and decreasing speed) to accelerate the convergence to an optimum solution. In the EU TopFarm project, three levels of complexity are considered. The first level uses a simple stationary wind farm wake model to estimate the Annual Energy Production AEP, a foundations cost function based on the water depth, and an electrical grid cost function. The second level calculates the AEP and adds a wake induced fatigue cost function based on the interpolation of a database of simulations done for various wind speed and wake setups with the aero-elastic code HAWC2 and the Dynamic Wake Meandering (DWM) model. The third level includes directly the HAWC2 and DWM models in the optimization loop in order to estimate both the fatigue costs and the AEP.

The novelty of this work is the implementation of the multi-fidelity, the inclusion of the fatigue costs in the optimization framework, and its application on an existing offshore wind farm test case.

INTRODUCTION

Establishment of large wind farms requires enormous investments, putting steadily greater emphasis on optimal topology layout and control of these. Today, the design of a wind farm is typically based on an optimization of the power output only, whereas the load aspect is treated only in a rudimentary manner, in the sense that the wind turbines are required only to comply with the design codes.

Wind farm layout optimization is a relatively new research topic, with the first article on the subject written by Mosetti and colleagues in 1994. The following article on the topic came nearly a decade later, with Costa et al. (2004). Since then the topic has become gradually more popular to reach around ten journal and conference articles produced every year (see Samorani, 2010 and Réthoré, 2010 for a more exhaustive review). The vast majority of the research work on this topic has been focused on the types of optimization algorithm used to solve the problem, keeping the various cost functions as simple as possible. A notable exception to this observation is the work of Elkinton (2007), which presents a rather sophisticated modeling of different costs function, in particular the electrical grid and foundation costs. While most consider the power losses due to wake effect, none consider the costs associated the wake induced fatigue loads on the wind turbine components. However, a complete optimization of layout and control of these farms requires, in addition to the power production, a detailed knowledge of the loading of the individual turbines. This is not a trivial problem. The power production and loading, related to turbines placed in a wind farm, deviate significantly from the production and loading pattern of a similar stand-alone wind turbine subjected to the same (external) wind climate.

To achieve the optimal economic output from a wind farm, an optimal balance between capital costs, operation and maintenance costs, fatigue lifetime consumption and power production output is to be determined on a rational background. The overall objective of the TopFarm project is to establish this background in terms of advanced flow models that include dynamic wake effects, advanced and fast) aeroelastic models for load and production prediction, dedicated cost and control strategy models, and subsequently to synthesize these models in an optimization algorithm subjected to various kinds of constraints, as e.g. area constraints and turbine interspacing constraints. The design variables for the optimization algorithm are the relative position of the wind turbines (including the possibility for positioning a given number of turbines in one or more wind farms).

When involving a computational demanding iterative process, it is of crucial importance that the resulting models of the complex wind field within a wind farm can be “condensed” into fast, though accurate, flow simulation tools. The basic strategy for achieving this goal goes through a chain of flow models of various complexities, where the advanced and computational very demanding CFD based models, together with available experimental evidence, are used to formulate, calibrate and verify simpler models ranging from simplified CFD models to more engineering stochastic type of models.

Aeroelastic modeling is needed to calculate the loads for each of the turbines in the wind farm. It is a challenge on one hand to keep computational costs limited, while on the other hand to have accurate values for the loads of each turbine. In this work, a simplified approach is taken, where the fatigue load calculations is based on a database of pre-calculated load cases for turbines in wake operation. Total lifetime equivalent loads can then be found by summing up contributions from individual load cases.

When aiming at an economic optimization of wind farm topology, a cost model is essential, encompassing both financial costs and operating costs. Only costs that depend on wind farm topology (including wind farm infrastructure, wind turbine foundations, production and loading) are relevant. In the context of this work these...