Wind farm layout optimization in complex terrain with CFD wakes

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1 Introduction

Wind farm layout optimization is crucial for advancing wind energy in Europe, since often either the available area at a site is limited or the meteorological conditions do not clearly prefer a single instance of inflow conditions. Especially for on-shore wind farms in complex terrain wake situations may be significant and should not be ignored during the process of layout optimization. For a recent review on the topic of wind farm optimization and more than 20 years of related research see [1], also [2, 3]. A recent summary on the related topic of optimised wind farm control see [4].

The implementation of a multi-fidelity layout optimization software by DTU has recently been described in [5]. Also at Fraunhofer IWES a wind farm modelling and optimization framework is being developed, under the name *flapFOAM*. This software includes the option to apply a numerical wake model that is based on pre-calculated computational fluid dynamics (CFD) results to the layout optimization calculations [6]. For a recent study on the impact of wake models on layout optimization using this software, see [7]. Also wake transformation effects in complex terrain due to isolated hills have been modelled successfully, based on interpolation and rescaling of CFD simulations [8].

In this paper we present for the first time the optimization of a wind farm in complex terrain with CFD wakes and CFD background fields, for a realistic wind rose.

Clearly, the turbine positions are strongly constraint for real-life on-shore projects. Nevertheless optimization codes can give crucial input during the design phase, especially for complex sites where the optimal layout may not always be obvious. The reason for the usage of advanced models is that standard engineering-model approaches are known to be unreliable in such cases, and CFD-based methods may be the key for overcoming this issue.

2 Approach

Our method is a mixture of CFD and pure modelling. The background wind potential is obtained from CFD simulations and the wake effect is added, based on the superposition of single-rotor simulation results.

Background wind fields are defined as wind fields that do not contain wind turbine wake effects. They are simulated with CFD-RANS methods for a wind rose with 3 degrees resolution in the relevant wind directions. Each sector is modelled with a single wind speed bin and stratification effects are ignored.

For the CFD wake model, a single rotor in flat terrain is modelled with a uniform actuator disk in a three dimensional calculation domain, cf. Fig. 1. The Reynolds-Averaged-Navier-Stokes (RANS) equations are then solved numerically for

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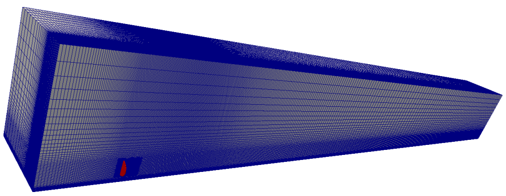

Figure 1: Cut through the mesh and the actuator disk (red).

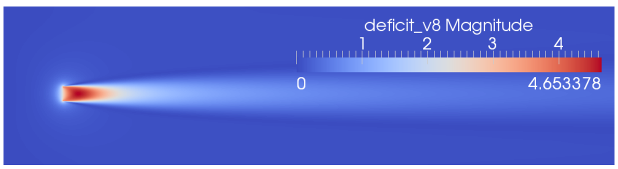

Figure 2: The CFD wake model deficit at 8 m/s inflow wind speed.

eight different inflow wind speeds at hub height, using OpenFOAM. We apply the $k - \epsilon - f_P$ turbulence model [9] which has been validated with wind turbine wake data. The obtained results are then mapped to a coarser mesh with maximally 10 m resolution, and the numerical wake model is created from the deficit data. During optimization, the wake model deficits are overlapped quadratically and added to the background fields.

Finally the layout is optimized using the Dakota optimization library [10], which recently has been linked to flapFOAM [7]. We apply a gradient-based optimization method and purely geometrical constraints. The cost function is given by the annual energy production (AEP) of the wind farm, since our main interest lies in aerodynamic phenomena.

3 Main body of abstract

A cut at hub height through a typical CFD wake model deficit field is shown in Fig. 2. The numerical wake model is obtained by interpolation at fourth order of accuracy between similar deficit fields, simulated for 3, 5, 8, 10, 12, 15, 18 and 20 m/s inflow wind speed, as reported at the EWEA conference 2014 [6].

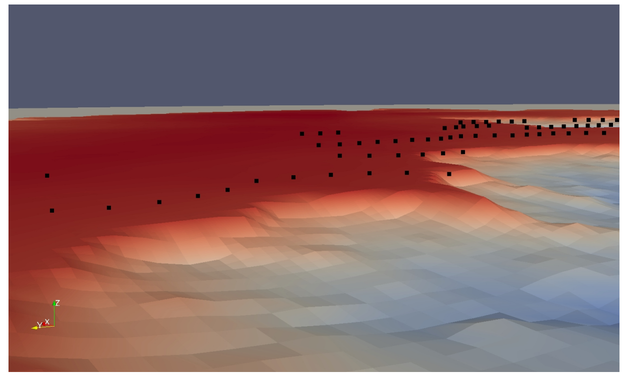

Figure 3: Wind turbines at the edge of the plateau.

We study a fictional wind farm with 64 wind turbines of 2.5 MW nominal power at a site in Bahia, Brazil, that has an altitude variation of 800 m, cf. Fig. 3. Furthermore it has plateau-like features that lead to interesting speed-up near the border. The wind direction is dominantly east and east-south-east.

The optimization is sensitive to local variations of the wind potential, as determined by the background wind field simulations. The wake effect is added to the wind field according to the above CFD wake model. Note that the calculations that are required for the optimization iterations are not CFD calculations, but simple superposition and interpolation tasks. Thus several thousand evaluations of the objective function and the constraints can be carried out within reasonable calculation time. In the studied case the optimization can be performed on a single core of a workstation computer in less than 72 hours[1].

This demonstrates that our method is appropriate for building the bridge between detailed CFD wake model research and applied wind farm optimization.

[1]This does not include the calculation time for generating the CFD wake model and simulating the background wind fields.

4 Conclusion

Standard engineering-model approaches are known to be unreliable for many complex on-shore sites. We address this issue by making CFD results available for wind farm layout optimization. In this paper we demonstrate that it is possible to perform layout optimization at a realistic site based on CFD background fields and CFD wakes within a few days on a single core of a workstation computer.

5 Learning objectives

- Optimize wind farm layout in complex terrain
- Use CFD results for wind farm optimization
- Learn how CFD wake research can be transferred to applied wind farm design methods

References

[1] J. F. Herbert-Acero, O. Probst, P.-E. Rethore, G. C. Larsen, and K. K. Castillo-Villar. A review of methodological approaches for the design and optimization of wind farms. *Energies*, 7(11):6930–7016, 2014.

[2] M. Samorani. The wind farm layout optimization problem. Technical report, PowerLeeds School of Buisness, 2010.

[3] A. Tesauro, P.-E. Rethore, and G. C. Larsen. State of the art of wind farm optimization. In *EWEA*, Copenhagen, Denmark, 2012.

[4] T. Knudsen, T. Bak, and M. Svenstrup. Survey of wind farm control–power and fatigue optimization. *Wind Energy*, 2014.

[5] P.-E. Rethore, P. Fuglsang, G. C. Larsen, T. Buhl, T. J. Larsen, and H. A. Madsen. Topfarm: Multi-fidelity optimization of wind farms. *Wind Energy*, 17(12):1797–1816, 2014.

[6] J. Schmidt and B. Stoevesandt. Wind farm layout optimisation using wakes from computational fluid dynamics simulations. In *EWEA conference proceedings*, Barcelona, Spain, 10–13 March 2014.

[7] J. Schmidt and B. Stoevesandt. The impact of wake models on wind farm layout optimization. In *Wake Conference*, Visby, Sweden, 2015.

[8] Jonas Schmidt and Bernhard Stoevesandt. Modelling complex terrain effects for wind farm layout optimization. *Journal of Physics: Conference Series*, 524(1):012136, 2014.

[9] M. Paul van der Laan, Niels N. Sorensen, Pierre-Elouan Rethore, Jakob Mann, Mark C. Kelly, Niels Troldborg, J. Gerard Schepers, and Ewan Machefaux. An improved k- epsilon model applied to a wind turbine wake in atmospheric turbulence. *Wind Energy*, pages n/a–n/a, 2014.

[10] Adams et al. Dakota, a multilevel parallel object-oriented framework for design optimization, parameter estimation, uncertainty quantification, and sensitivity analysis: Version 5.4 user's manual. Technical Report SAND2010-2183, Sandia Technical Report, 2009.