Interactive design of wind farm layout using CFD and model reduction

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Abstract

A theoretical framework for model reduction of the steady state Reynolds Averaged Navier-Stokes (RANS) equations for solving wind farm flow problems is presented. The method is developed for an interactive wind farm layout design tool considering offshore or flat terrain conditions.

Test cases are verified with corresponding flow field solutions from CMR-Wind, a Computational Fluid Dynamics (CFD) simulator. The developed method computes flow fields within seconds rather than several hours for full CFD simulations and provides accurate approximations to CFD solutions for application for interactive design of wind farms.

Objectives

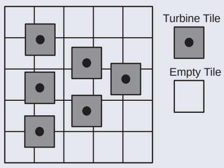
The overall objective is to reduce the Cost of Energy of offshore wind farms by more optimal placement of turbines with respect to power losses due to wakes and maintenance costs due to wake induced fatigue loads.

Our first step is to develop an interactive tool for layout design, which can later interact with other software tools for layout assessment and optimization.

By basing our method on Computational Fluid Dynamics (CFD) and the full RANS equations, we believe that we can offer a method that is more accurate than the current state of the art for fast flow field assessment.

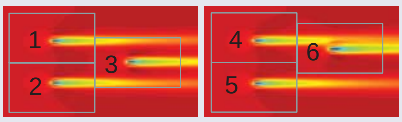
Methods

- ***Tile*** *– a subdomain of the wind farm*
- ***Snapshot*** *– the CFD solution within a tile for a given simulation.*
- ***Modes*** *– the set of orthogonal vectors/functions representing the reduced space*



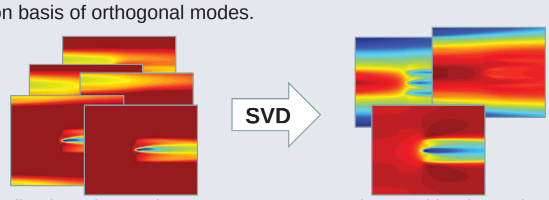
1. Run multiple RANS CFD simulations for varying setups (turbine positions, wind speeds). Extract snapshots for each simulation.

Example with two CFD simulations. Three tiles per Simulation.



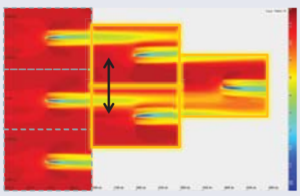
Extract six snapshots

2. Apply Singular Value Decomposition (SVD) to produce a reduced space solution basis of orthogonal modes.



Collection of snapshots — Orthogonal basis modes

3. Interactively move tiles into arbitrary configurations. Solve the RANS equations and boundary matching in the reduced space spanned by the solution basis.

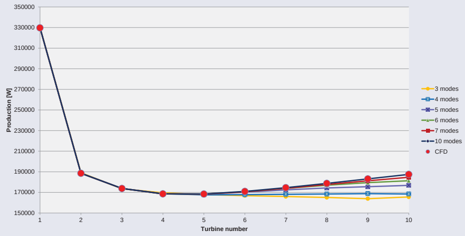


4. Compare solutions to RANS CFD solutions. If necessary improve the solution basis by running more CFD simulations and repeating steps 1-4.

Results

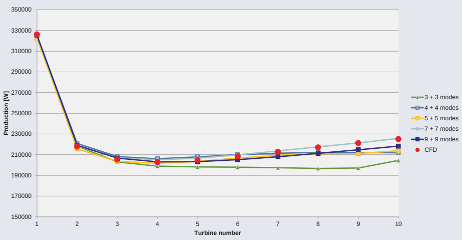
The simulations consisted of ten turbines with a uniform distance aligned with a neutrally stratified ambient flow over a surface with roughness length of 3 cm. The turbines were of type BONUS 2MW with a hub height of 76 m. The CFD simulations were performed with CMR-Wind [1].

1. Solution bases were created from a CFD simulation with turbine distance of 5 rotor diameters using only snapshots from the first N turbines. *These bases were used to test how well they could predict the power production of each of the ten turbines.*



The power production of each turbine. The basis constructed from the first 3 turbines of the CFD simulation is labeled 3 modes etc. The deviation of the total production is less than **3.5%** compared to CFD when using 3 or more modes.

2. Solution bases were created from two different CFD simulations with turbine distances of 5 and 9 rotor diameters respectively. The bases were constructed from the first N turbines of each CFD simulation. *These bases were used to test how well they could predict the power production of each of the ten turbines for turbine distances of 6, 7 and 8 rotor diameters.*



The power production of each turbine with a distance of 7 rotor diameters. The basis constructed from the first 3 turbines of each CFD simulation is labeled 3 + 3 modes etc. The deviation of the total production is less than **3.3%** compared to CFD when using 4 + 4 or more modes.

Model reduction result for a turbine distance of 7 rotor diameters, using a basis constructed from 4 snapshots each from the 5 and 9 rotor diameter CFD simulations.

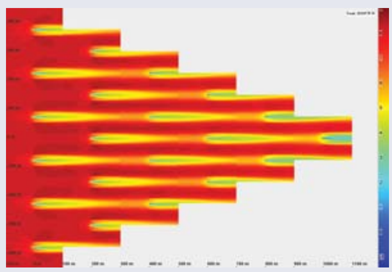
Conclusions

A model reduction technique based on CFD has been presented [2]. For the test cases, the model reduction technique provides accurate approximations of the CFD results in **seconds rather than hours**.

We have previously presented the ability to simulate cases where the user can interactively move turbines in the crosswind direction [3].

Here we have shown that the model reduction technique is able to simulate the multiple wake effect for a long row of turbines from a relatively small set of basis modes.

Full three dimensional fields are computed, including the turbulent kinetic energy.



21 turbines, simulated in the reduced space within a second.

Future plans and perspectives:

- Verify the model reduction technique for more general setups and for more wind speeds and wind directions.
- Assess the wake induced fatigue loading on turbines by coupling the flow field and turbulent kinetic energy field to an external tool.

References

1. Khalil M. and Sælen, L. 2013 . Near and far wake validation study for two turbines in line using two sub-grid turbine models. EWEA conference, Vienna, Austria, 4-7 February 2013.
2. Heggelund, .Y, Khalil, M., Jarvis, C. and Sælen, L., Interactive design of wind farm layout using CFD and model reduction, EWEA Offshore 2013, Frankfurt, Germany, 19-21 November 2013.
3. Heggelund, Y., Skaar, I.M., and Jarvis, C., 2012, Interactive design of wind farm layout using CFD and model reduction of the steady state RANS equation, 11th World Wind Energy Conference, Bonn, Germany. 3-5 July 2012.