PO. ID 175

Offshore wind power prediction through CFD simulation and the actuator disc model

Giorgio Crasto(1), Francesco Castellani(2), Arne Reidar Gravdahl(1), Emanuele Piccioni(2)

(1) WindSim AS, (2) University of Perugia, Department of Industrial Engineering

Abstract

Numerical simulation of wind turbine wakes is fundamental to the optimization of large off-shore wind farm installation.

Usually wind turbines are installed in arrays with spacing and orientation depending on the turbine characteristics and the local wind conditions; at this stage valuable information can be gained using wake models in order to maximize the overall energy production. Analytical wake models were successfully used for on-shore wind farm but for off-shore cases CFD (Computational Fluid Dynamics) models seem to give more reliable results.

In the present work numerical CFD simulations were performed using WindSim 5.0. In order to model a large offshore wind farm an actuator disc model was implemented to predict the interaction between the main wind field and the turbine wakes. With the actuator disc approach the power extraction can be modelled with reference to a device with no rotating elements, which simply extracts kinetic energy from a the flow.

The numerical model was validated using operational data of the Horns Rev offshore wind farm.

Particular emphasis was given to the development of the method to calculate the converted power and two different methods were implemented and compared.

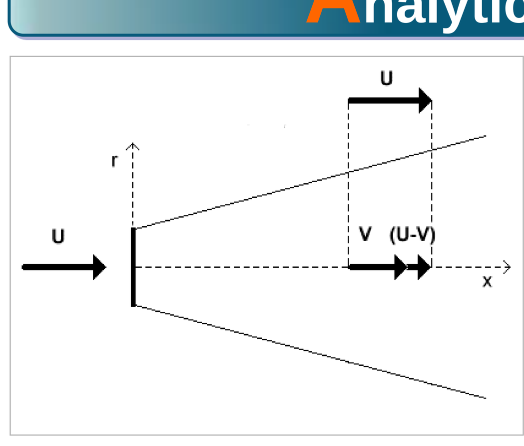
The first method uses the power curve of the wind turbine and the wind speed calculated at the rotor; in this case the undisturbed reference wind speed is evaluated using the axial induction factor.

The second method uses the wind speed multiplied by the maximum pressure drop across the rotor since such an expression can be integrated over the rotor swept area to compute the converted power.

The second method gave more reliable results especially when evaluating the power of wind turbines affected by other turbines' wakes.

Results demonstrate that the actuator disc model can give useful information on the evolution of wakes and on the expected power production of an offshore wind farm.

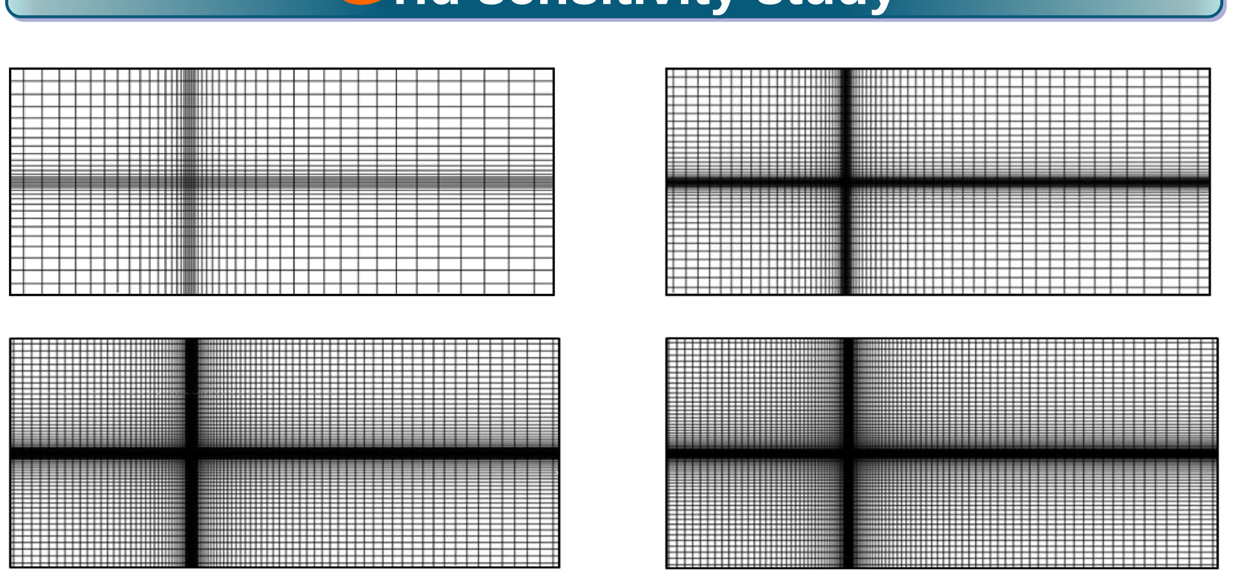
Analytical wake models



- Jensen (Wake Model 1) [1]
- Larsen (Wake Model 2) [2]
- Ishihara (Wake Model 3) [3]

Multiple (overlapping) wakes: $\delta u = \sqrt{\delta u_1^2 + \delta u_2^2 + \ldots + \delta u_n^2}$

Grid sensitivity study

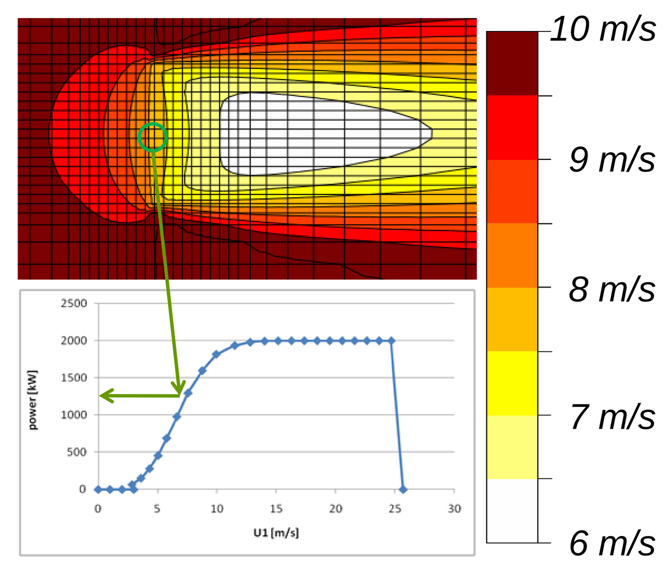


A grid sensitivity study on a single wind turbine has been performed. Discretization errors are reduced to an acceptable level using 16 subdivisions to describe the swept area.

Power estimation

Method 1, based on power curve:

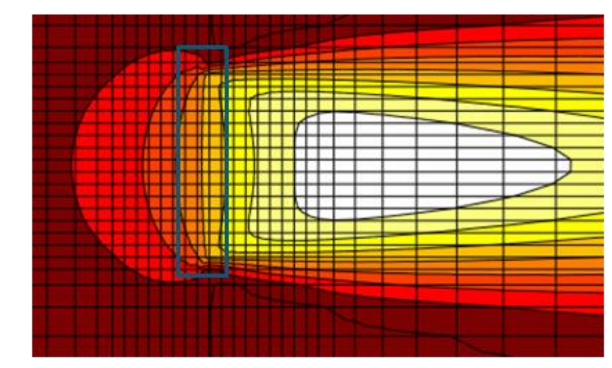
Wind speed map extracted at hub height:



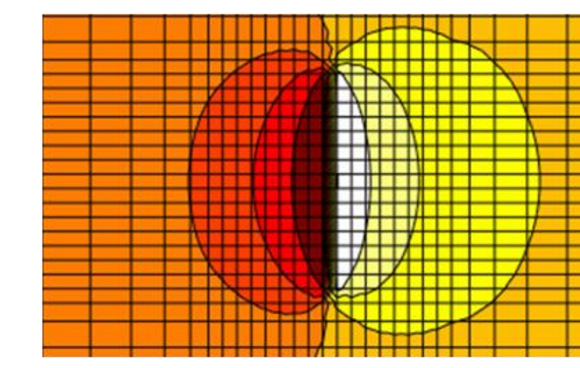
Power curve corrected with axial induction factor and Betz's theory. Evaluate the power entering in the corrected power curve with power vs. wind speed at rotor.

Method 2, based on power integral:

Wind speed on a horizontal plane at hub height

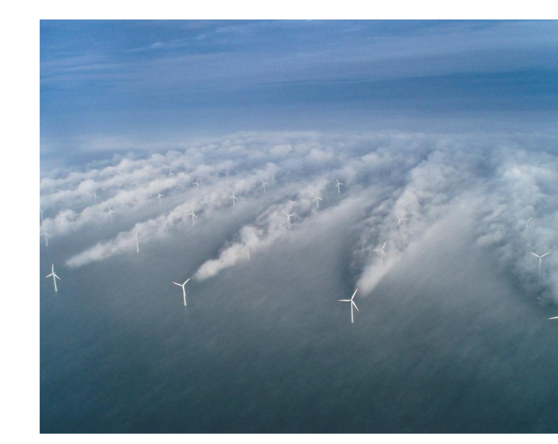


Pressure field on a horizontal plane at hub height



The power is finally estimated by performing the integral: $Power = \int_A u \, \Delta p \, dA$

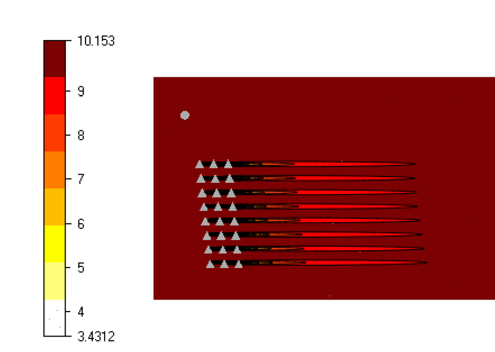
Comparison against production at Horns Rev



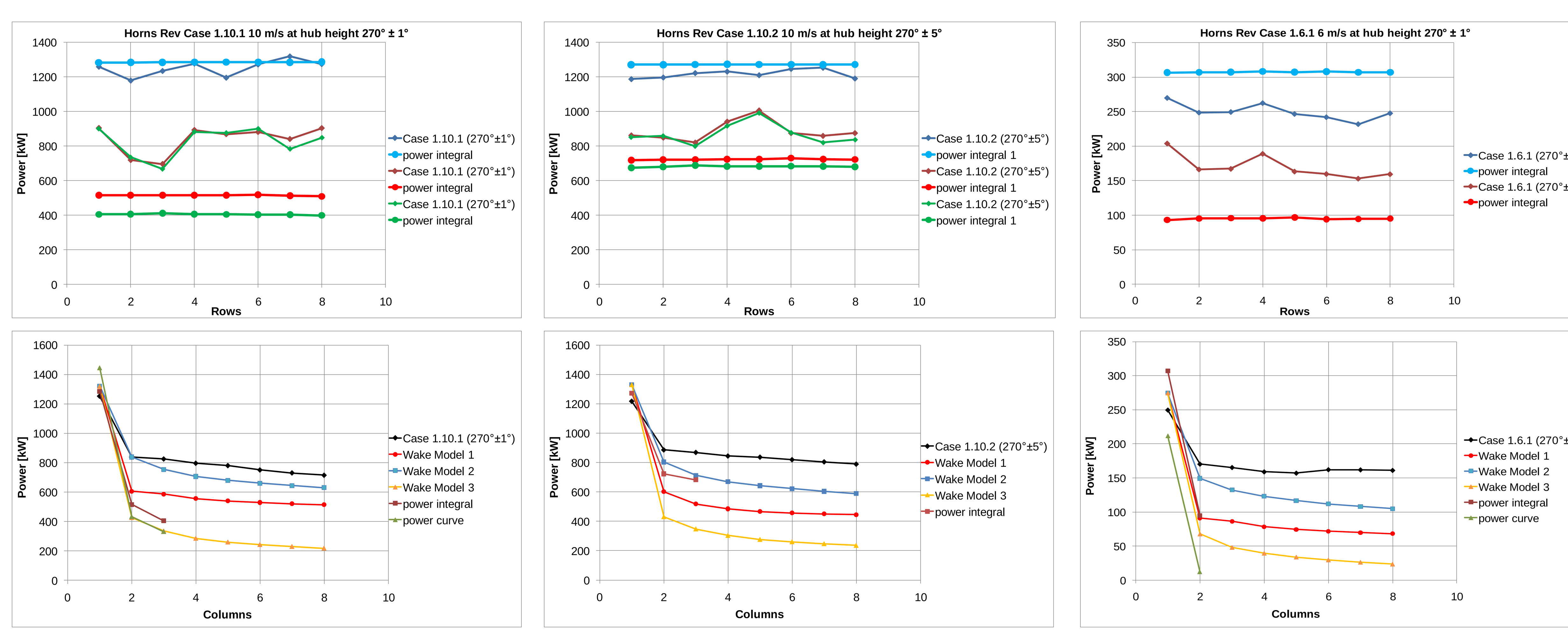
Horns Rev is an offshore wind farm located 13 km from the Danish coastline consisting of 80 wind turbines (Vestas V80)

The extension of the CFD model is 15 km (easting) x 9 km (northing) x 0.8 km, with a the following number of hexahedral cells: 304 x 562 x 29 = 4 954 592

The horizontal resolution is 8 m (10 rotor diameter subdivisions) for the results presented below. It was not possible to achieve 5 m resolution (16 rotor diameter subdivisions) in the wind farm area and some grid dependency is expected. Vertically the grid is uniform from the lower to the upper tip, from 30 m to 110 m asl, with 8 m resolution. Above the upper tip the grid is vertically expanded.



Power predictions for three cases of west wind



Conclusions

An actuator disc concept is applied to model the wakes of wind turbines in combination with RANS simulations. A pressure drop is applied over the disc. Three different ways of distributing the pressure drop have been implemented: uniform, parabolic and polynomial. The value of the pressure drop is calculated from the thrust coefficient and the axial induction factor from the Betz's theory. In the previous section power predictions for uniform distributions are presented.

Two methods to compute the power have been considered: extracting a wind speed at the rotor and applying the power curve or computing an integral of the power extracted by the disc. When comparing the results from the actuator disc simulations with the Horns Rev production data at 6 and 10 m/s the power drop from first to second row is predicted within a good approximation. The actuator disc technique described gives better predictions of power for higher wind speeds and wider directional sectors. In the cases presented the most performing methodology has resulted the Larsen model [2]. Since the actuator disc technique gave worse performance for narrower sectors, there is the suspect that the meandering should be included for them by unsteady RANS.

Since the grid sensitivity study pointed out that the actuator disc should be represented with 16 subdivisions along the diameters, there is the intention to repeat these validation cases with Actuator Discs having higher resolution.

Also the swirl of the wake can play an important role on the correct simulation of the wakes. This part of the wake flow will be also considered in future studies.

References

1. Katic, I., Højstrup, J., Jensen, N.O. "A Simple Model for Cluster Efficiency." EWEC Proceedings, 7-9 October 1986, Rome, Italy.
2. Larsen, C. G. *"A Simple Wake Calculation Procedure."* Risø-M-2760, 1988.
3. Ishihara, T., Yamaguchi, A., Fujino, Y. *"Development of a New Wake Model Based on a Wind Tunnel Experiment."* Global Wind Power 2004.