NEW DEVELOPMENTS IN PRECISION WIND FARM MODELLING

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Keywords: wind farm, wake model, close spacing, offshore, close spacing, eddy viscosity, WindFarmer

Summary

For over 20 years, Garrad Hassan and Partners Ltd have been offering cutting edge technology in wind energy consultancy services. The technologies used for wind farm analysis are also made available to the wider wind energy community in form of the GH WindFarmer software. Starting with the highly accurate and comprehensively validated eddy viscosity wake model, further improvements of the wind farm energy yield prediction model have recently been implemented and the models tested in challenging new project environments. The models, results and validations presented in this paper concentrate on cases of closely spaced turbines and large offshore wind farms where traditional models can predict the wind farm energy yield up to 20% higher than is achieved in practice depending on layout and wind conditions.

It has been found that traditional wake models do not model the wake accurately downstream of very closely packed lines of turbines. The newly implemented model is based on the eddy viscosity wake model but now additionally takes account of the merging of adjacent wakes which is expected to occur with tight spacing. This merging is postulated to lead to overall stronger wake effects but also reductions in horizontal velocity gradient and reductions in added turbulence intensity in the wake.

It has been shown in the past that offshore wake effects are well represented by the WindFarmer Eddy Viscosity model. Very large offshore wind farms however represent a challenge. Due to the spatial extent of such wind farms simple superposition of the wake and the wind profile is not anymore sufficient. The wind profile itself is modified by the wind turbines in a large wind farm. We have developed a model that considers this effect and allows more accurate energy prediction for large offshore arrays.

Introduction

In modern wind farms, the decrease in energy yield or increase in array losses arising from wake effects (Figure 1) ranges typically from 5 % to over 15 % depending on the wind farm layout. Knowledge of turbine wakes and their interaction is essential not only to predict the reductions in wind speed and corresponding yields but also helps to assess the additional loading on the turbines generated by the increased turbulence in the wakes.

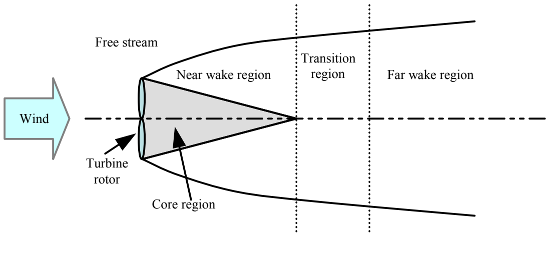

Figure 1 Wake structure

Dominant in industrial applications are models based on fundamental physical equations but including empirical assumptions to simplify the problem to an extent that it can be solved in an acceptable timeframe. These models are part of wind farm design software packages and have been proven to demonstrate good agreement with experimental and operational data in most situations [1-3]. An overview is given in [4].

Amongst over 40 GW of wind farm capacity analysed by Garrad Hassan over the past 21 years, a small number of the wind farms have stood out because of difficulties with modelling their annual energy yield. These wind farms have special features that make them unlike the majority of wind farms built worldwide. The observed wake losses for specific layouts and wind conditions can be up to 20% above those modelled with standard software tools.

One group of wind farms comprised multiple rows of very closely spaced turbines (Figure 2). Such wind farms are typically in locations with either uni- or bi-directional wind regimes. Inter-turbine distances from 1.1 to 2.5 times the rotor diameter (D) are typical. Along-wind inter-row distances are typically 6 to 9 D.

Another group of wind farms, few of which have been built so far, is that of very large offshore arrays. These wind farms consist from 20 up to several hundred turbines and have a depth of five or more turbines.

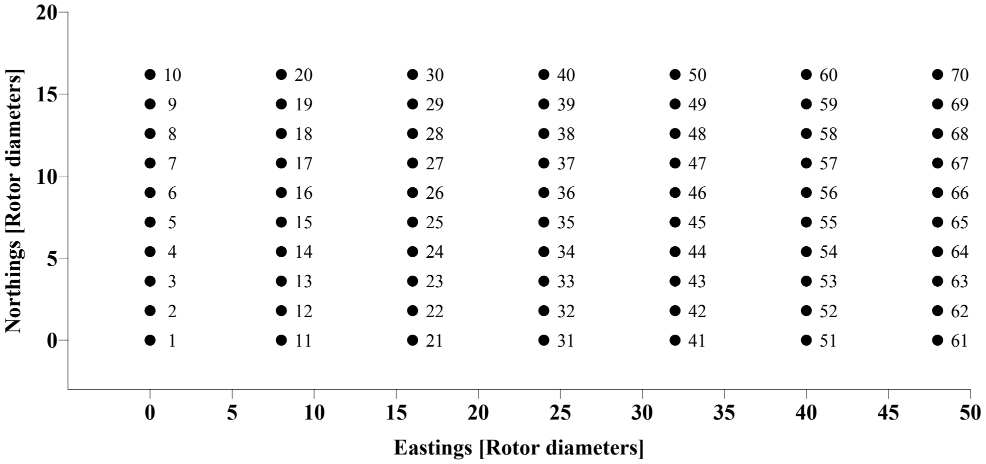

Figure 2 Example of a typical close spaced wind farm with spacing of approximately 1.8 D within the rows and 8 D from row to row.

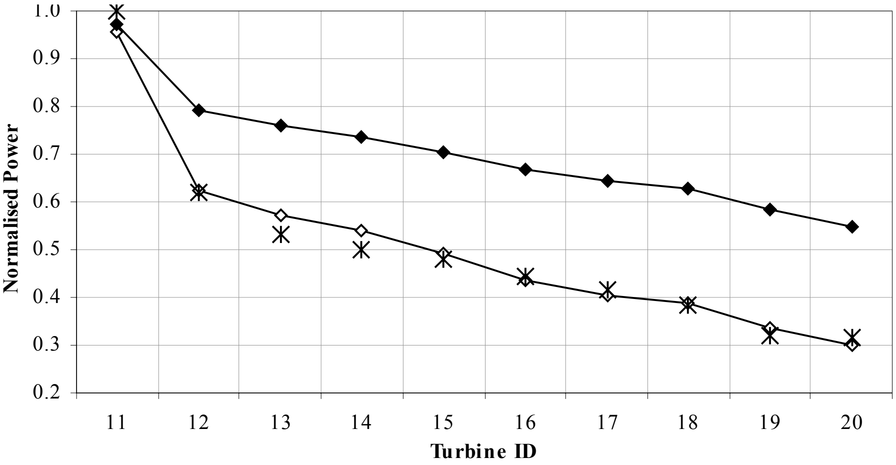

Figure 3 Row 2 (Turbines 11-20) of the example wind farm with close spacing.

Closely spaced wind farms

From practical experience, Garrad Hassan was aware of the problem with closely spaced wind farms and made significant downward adjustments of yields forecast. Whilst these pragmatic, experience-based adjustments satisfied the immediate need for accurate predictions, a better understanding and an improvement of analysis tools was required and this requirement stimulated the improvement of the model.

New wake model for closely spaced turbines

Published data and investigations concerning wakes with a distance of approximately 2 D or less behind a wind turbine rotor are extremely rare [1, 5-8]. Even fewer data are published from the wake of two or more adjacent turbines with an inter-turbine spacing of less than 2 D [9-11]. To improve general understanding and prediction accuracy for these particular cases, Garrad Hassan has undertaken an internal re-analysis of several closely spaced wind farms.

A new model [12,13] has been implemented to this effect with the following changes:

- For close spaced turbines the momentum deficit is allowed to add up cumulatively
- The added turbulence is reduced in the wake
- The Gaussian profile is replaced by a blunt profile taken from [14]

The last change is as necessary as it is radical because it results in an overall higher momentum deficit. In short this model predicts a change of the thrust characteristic of a turbine in a closely spaced wind farm compared with a single turbine of the same type.

The modified model has been able to reproduce the energy yield of several closely spaced wind farms to a high degree of accuracy.

Large offshore wind farms

Offshore wind farms benefit from generally lower turbulence intensity. This, however, causes wakes to be more pronounced and sustained longer. Existing commercial and research-type wake models have been validated in the Endow project [1] against data from offshore wind farms. The predictions from the eddy viscosity model [15] as implemented by Garrad Hassan have shown excellent agreement with the production data without the need for any manual adjustment to offshore conditions.

The Horns Rev wind farm (Figure 4) and data iare presented elsewhere in detail [16]. The good performance of the Eddy Viscosity Model was again visible for the first few rows of turbines of the Horns Rev offshore wind farm.

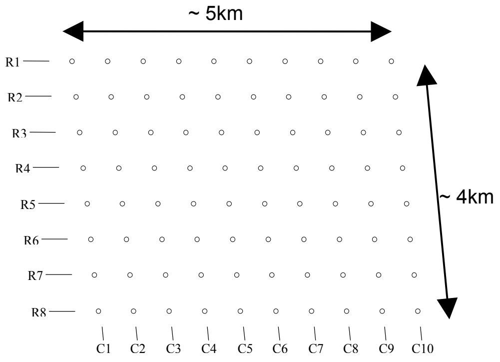

Figure 4 Large offshore wind farm (Horns Rev)

However further downwind, deeper into the wind farm, the modelling turned out to be increasingly less accurate. This type of effect is not observed in large onshore projects.

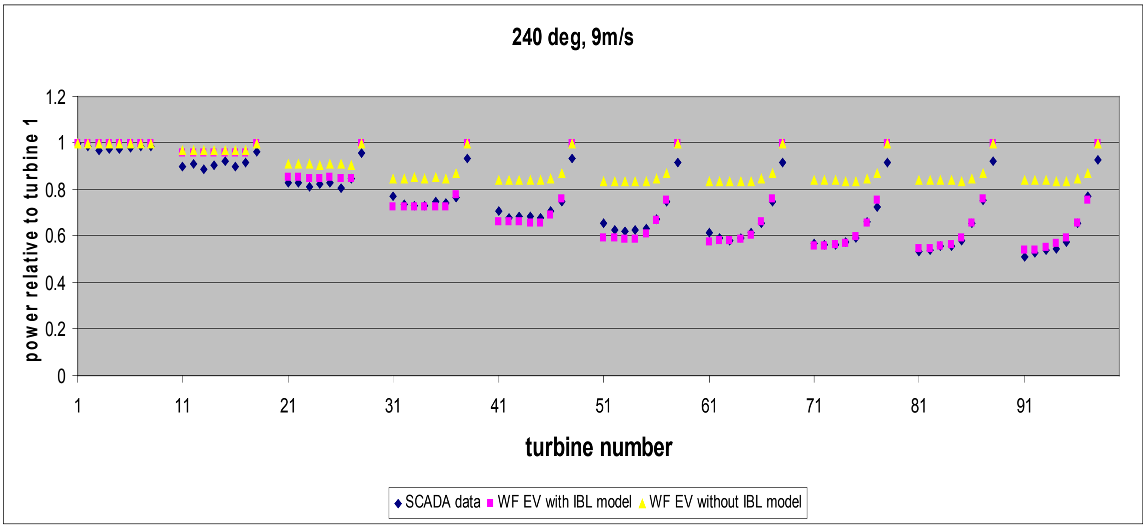

Figure 5 Energy Yield Horns Rev (240 deg,9 m/s) data compared with new and old model

New model for large offshore wind farms

As the effect seen in the data from Horns Rev and other offshore wind farms is not visible in onshore wind farms we need to identify what effects that are specific to offshore could be the cause for the discrepancy.

The most plausible explanation for this effect has indeed been under discussion since the dawn of the wind energy industry, e.g. [17]: The wind turbine does not only react passively to the wind regime but at the same time is part of it. Weather systems are not considered to be affected significantly at the scale of developments considered. However locally, by the presence of wind turbines, the boundary layer profile is modified.

A wind farm area can in this model be represented by an area of higher roughness. Due to the lower roughness offshore such an area of increased roughness has a pronounced effect, similar to a forest onshore. Onshore, on the other hand, such effect would be masked by the higher terrain roughness.

Based on this explanation we have developed a model that does not require the wind farm to have a particular shape. Instead of modelling an area of increased roughness we model the disturbance caused by each individual turbine. This allows us to consider the effect for a wider variation of wind farm layouts during the design phase and optimisation of a wind farm layout.

The model comprises simply of two components

- Calculation of internal boundary layer height
- Vertical offset of the boundary layer

On the basis of this model the ambient wind speed is corrected. The wake model itself stays unchanged. The model results are presented in Figure 5. The model reproduces well the results from Horns Rev for different wind speeds and directions.

Extreme caution is required with regards to the application of the offshore correction for large wind farms. The model has not yet been validated against multiple wind farms. As soon as data from such wind farms become available an update of the model is likely and therefore the current model results should be seen as preliminary.

Conclusions

The wake losses downstream from rows of very closely spaced turbines are much higher than predicted by conventional models. A modified, pragmatic approach to model the higher wake deficits has been presented and compared with operational data from a number of wind farms.

The prediction accuracy for wind farm cross-wind close-spacing and also for large offshore wind farms has been improved significantly.

The two new models are available to the wind energy community through their implementation within GH WindFarmer, Garrad Hassan's wind farm design software.

Acknowledgements

The authors are grateful for the access to the data from operational wind farms used in the work presented in this paper.

We would like to thank Elsam Engineering for making available the Horns Rev offshore wind farm data.

The work on large offshore wind farms is supported in part by the European Commission under contract #19945 (SES6) "UPWIND.

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