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On the Effects of Directional Bin Size when Simulating Large Offshore Wind Farms with CFD

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Introduction

The most significant difference to an offshore wind farm resource assessment compared to onshore locations is the lower surface roughness values resulting from the lack of vegetation and terrain. As such, turbine wakes take longer to dissipate, and thus have a greater significance for the mean wind speeds and turbulence intensity encountered by turbines downstream. The greater influence of turbine wakes offshore, combined with the often regular turbine layouts of offshore farms, result in significant losses in power generation, and thus asset value, when the wind blows along a line of turbines. To reduce the risk to financial investment, computer simulations are often run to predict the expected wake losses of wind farms before they are built. As using Computational Fluid Dynamics (CFD) models to simulate numerous scenarios can be time consuming, it is important to use best practice to minimise the number of runs required to accurately capture the farm wake loss. This work investigates the number of simulations required to predict the production losses due to turbine wakes for a single scenario to an acceptable accuracy without compromising on the time required for such an investigation.

Method

For this work, CFD simulations are validated against production from the Nysted offshore wind farm in the Danish Baltic Sea. There are 72 turbines in a regular grid of 9 rows and 8 columns, with the columns offset such that the westerly 'down-the-line' direction investigated is 278° as shown below in figure 1. Production data are available from December 2006 through to February 2008 and are supplemented by meteorological data from MastM1. Although it is known that atmospheric stability significantly alters the turbine wake behaviour and is measurable using data from MastM1, there is no standard for defining the various stability categories and the required filtering process significantly reduces the quantity of available data. Therefore, this work will assume neutral atmospheric stability in both field data and simulations. To help focus on wake effects, only events where the hub height wind speed measured at MastM1 corresponds to the peak in the turbine thrust coefficient, 7.5±1m/s. In order to increase the number of validation data events, each row of 8 turbines within the farm are considered a subset, independent of the rest of the farm. Thus, if a turbine in the fourth row is undergoing maintenance, it is assumed this will not affect the productivity of turbines in other rows, although the whole fourth row of turbines are excluded from the analysis for the duration of the downtime. To prevent effects from the farm edges biasing the data, both the most northerly and southerly rows of turbines are ignored. The production values from the other 7 rows (minus any rows with data problems) are averaged together for each 10-minute event.

Figure 1 Layout of turbines and meteorological mast at the Nysted offshore wind farm. Turbines rows are separated by 5.9 rotor diameters (D) whilst the columns are separated by 10.4D.

It is known that the flow through a large offshore wind farm is not uniform in direction, i.e. variations occur due to the Coriolis effect, turbulent eddies and wake meandering. To account for this, it is common practice to investigate data from a narrow direction sector, called a direction bin. Wider bins result in a larger experimental data sample, although are more likely to suffer from incorporating events where the turbines which are expected to suffer wake losses are actually outside the wakes of the upstream turbines, creating misleading results. Therefore, this work will consider the five directional bins shown in Table 1 below:

Table 1 List of direction bins used in this work

Case Name	Directions Included	Bin Size	Events
Case A	278±0.5°	1°	173
Case B	278±1.5°	3°	485
Case C	278±2.5°	5°	687
Case D	278±3.5°	7°	977
Case E	278±4.5°	9°	1238

Results

Figure 2, below, shows the power produced at each turbine position for each case study, normalised by the power generated by the free-stream turbine. Based on the results of previous studies [1] and indicated in Figure 3, simulations of Case A tend to significantly over-estimate the wake losses. With each subsequent case study, the wider bin size results in a lower simulated wake loss as the uniformly averaged collection of simulations becomes more biased towards flow directions further from the centre. The full paper will explore the use of non-uniform weighting (e.g. Gaussian) of simulations from different directions within a bin and compare with observations at the Nysted wind farm.

Figure 2 Average power generated by each turbine position, normalised by the production of the free-stream turbine

Figure 3 Average power simulated at each turbine position, normalised by the production of the free-stream turbine. For CaseC, multiple simulations have been uniformly averaged whilst CaseA shows the results from a single simulation.

Discussion

Since this study assumes neutral stability for the measured data, there are a significant number of measured events for each case study resulting in production power ratios for each case study that are statistically similar to each other, with the largest difference between CaseA and CaseC at turbine position 6. However, the simulation results for these two case examples shown in figure 3, deviate most in the first half of the farm, before converging their wake loss predictions by position 7. The separation in results early in the farm is likely to be a result of how the simulation averages are calculated, here given a uniform weighting, whereas Table 1 suggests a non-uniform distribution of measured wind flow directions. The full paper will explore the use of non-uniform weighting (e.g. Gaussian) of simulations from different directions within a bin and compare with observations at the Nysted wind farm.

Conclusion

Using CFD to simulate the wake losses of large offshore wind farms can be very time consuming. This is particularly true when large directional sector are considered. It is possible to reduce these time costs through the smarter use of fewer simulations and by analysing the variability of measured field data before simulations are made. However, these findings may be site specific, depending on the turbines and their layout within the offshore wind farm.

Works Cited

[1] P. Argyle, Computational Fluid Dynamics Modelling of Wind Turbine Wake Losses in Large Offshore Wind Farms, Incorporating Atmospheric Stability, Loughborough University, 2015.