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Offshore Turbine Wake Power Losses: Is Turbine Separation Significant?

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Abstract

This paper presents the results of a parametric study of wind turbine wake effects in a hypothetical offshore wind farm with varying turbine separation using a Computational Fluid Dynamics (CFD) model. Results are analyzed from a simulated 40 turbine farm with 60 layout options, 4 wind speeds and 10° directional bins. Results show that increasing turbine separation in one or both directions leads to greater power generation, though this effect diminishes for separations above 8 diameters. Similarly, turbulence intensity is shown to decrease with increases in turbine separation but with little variation beyond 8 diameters. For 3 out of 4 wind speeds when combined with a representative UK offshore wind rose the farm was shown to have an optimal layout orientation along an axis 350°-170°, though the difference in power produced between orientation angles was less than between changes in turbine separation.

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Keywords: CFD; Wind Turbine; Offshore Wind; Wakes;

1. Introduction

As the areas allocated for UK offshore wind farms become larger [1], developers are transitioning away from simultaneously locating turbines universally within the area, and towards the evolution of a wind zone by focusing on a series of flexible sub-zones within the allocated area [2]. This process has the financial benefits of staggering the capital expenses and supply chains into manageable size and timeframes whilst also ensuring each sub-zone has a period of operation when they can be more profitable before wake or blockage effects of the adjacent sub-zones

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develop. As a consequence of this, turbine locations in new developments with large zone allocations may be less restricted by the zone's shape than earlier offshore wind farms. This means long-term resource assessments become more significant to the turbine layout design in large farms which are less constrained by government-enforced construction boundaries. Given a constant number of machines, under these conditions developers must balance the costs of longer cables against the potential for higher power generation and lower turbulence induced fatigue.

It is well documented [3] that turbines located downstream of another turbine will be less productive and subject to higher turbulence induced fatigue. However, the UK offshore climatic wind rose exhibits a wide prevailing wind sector [4], suggesting that even if an offshore farm was developed with a regular turbine layout aligned with the local prevailing wind direction, such exact "down-the-line" events would only occur roughly 7% of the time (5% and 2% from South-west and North-east sectors combined, Ref [4] Fig 11). Although wake effects from such "down-the-line" events can have significant influence over turbine separation design despite their relative infrequency, the events of greater frequency where the wind is not aligned with the farm layout should also be considered for simulation during farm planning.

This work shows the results from computational fluid dynamics (CFD) simulations at a farm level for a theoretical offshore wind farm with 40 turbines and a combined rating of 144MW in 60 different turbine layout options, using 4 wind speeds and 10° directional bins weighted to be representative of the UK offshore climate. Although modern offshore wind farms contain significantly greater numbers of turbines, the layout is considered large enough to draw conclusions about optimal layout spacing within the computing resources available.

2. Method

The CFD simulations were made using Windmodeller to drive the Ansys CFX package of tools [5]. For simplicity and to reduce the computational requirements, all simulations used Reynolds-Averaged Navier-Stokes (RANS) steady state equations with a traditional logarithmic vertical wind profile neglecting the effects of atmospheric stability and utilised the actuator disk technique for further cost reductions. The circular domain was 8km in radius and 1km deep with average mesh resolutions of 50m and 45m respectively before automated mesh refinement down to 3m around turbine locations. The turbines simulated were Siemens SWT-3.6 (3.6MW) with a 107m diameter (D) and a hub height 78m above sea level. Turbines were arrayed in 5 rows and 8 columns where the row and column separation were constant within each simulation and varied incrementally from 4Dx4D to 8Dx11D between layout options resulting in 30 turbine separation distances. Staggering these layouts as in Fig1 provided another 30 spacing configurations. The 4 wind speeds used in the simulations were 5, 8, 10, and 15ms^{-1} as these are representative of the majority of UK offshore hub height wind speeds as well as being significant locations on the turbine power/thrust curves. Assuming 36 10° direction bins lead to 8640 individual simulation combinations, though utilisation of the layout rotational symmetry reduced this number to just 3360 individual simulations.

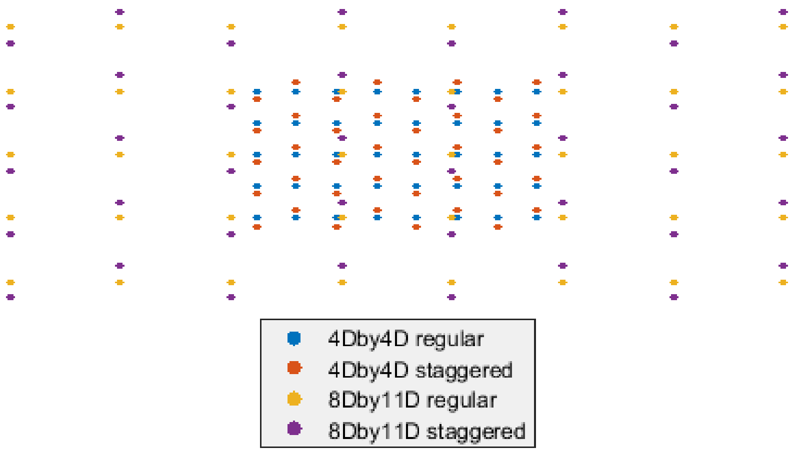

Fig. 1. Example relative turbine layouts showing the extremes in range of turbine separations.