Layout Optimisation Brings Step Change in Wind Farm Yield

Summary

Efficient use of optimisation driven simulation has enabled the optimum number and layout of wind turbines for a specific site to be identified, resulting in a predicted increased lifetime return of over €55 million compared to the same number of turbines in an alternative arrangement.

The integrated design optimisation workflows in the dezineforce service enabled the alternatives for the number and arrangement of turbines to be assessed. Computational Fluid Dynamics (CFD) tools from Ansys: ICEM-CFD and CFX were used to understand the impact of turbine layout on wind farm yield for investment cost.

Introduction

Concerns about global warming, the desire for ‘green’ energy sources and the development of economically viable turbines for wind power generation have resulted in demand for new wind farms. Each of these farms differs in the number of turbines installed and the local geographic and meteorological conditions. It is therefore difficult to define definitive generic design rules for the layout of the turbines that can be effectively applied to any specific site.

Wind farm simulations are usually constrained by the computational requirements of such complex models. Work has been completed by dezineforce subscriber, Intelligent Fluid Solutions, to produce a simplified model of a wind turbine, which has been validated using a combination of experimental measurements and higher fidelity CFD simulations. The developed model was combined with the dezineforce optimisation tools, which allowed the investigation of alternative wind farm layouts.

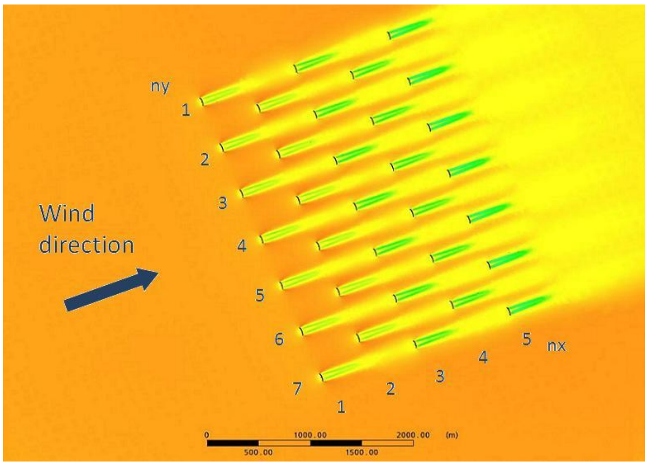

Figure 1: Illustration of staggered turbine arrangement and parameterised variables

Design Challenge

For a specific site, the objective of the work is to determine the number and arrangement of turbines that will produce the best total power per cost ratio.

The site considered is a flat site, 2km by 3km with no significant upstream flow influences. The variables considered are the number of turbines and turbine layout; although parameters for wind speed and angle can be readily added to the model, as can geographic site-specific details. The general configuration is shown in Figure 1 with simulation results showing the wake shadowing effects of subsequent rows.

Total power for a specific layout is calculated from the sum of the power generated by each turbine, calculated from the local velocity conditions at that turbine location. Installation cost is comprised of two parts; a fixed component and a variable component. Fixed component costs arise from items such as site preparation, grid connection, construction etc. Variable costs are related to the number of turbines installed. Operational costs have not been considered in this case. The combination of these generates a power per cost value in Watts per Euro (W/€).

A simple staggered turbine arrangement was parameterised based on the number of turbines in the first row, spaced uniformly across the site width, and the total number of rows, spaced uniformly through the entire site depth, with alternate rows containing one less turbine. A maximum of 9 rows with 13 turbines in the first row allow for the guideline spacing often used for wind farm design but also permits arrangements outside these limits.

Design Solution

Integrated workflows using an optimisation method based on a combination of Design of Experiments (DoE) techniques, response surface methods and a number of update loops were used to drive the process and identify a subset of the layout options for evaluation.

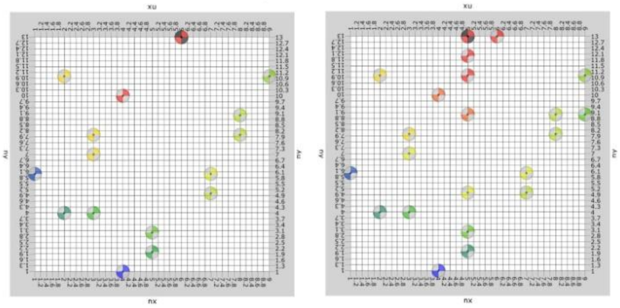

Figure 1: Sample points evaluated using CFD for the initial DoE (left) and final population (right)

This approach enables the cost function to be obtained for all layout options, based on only 16 initial simulations and a final total of 22 simulations, from a possible total of 117 designs. The parameter combinations simulated are represented in Figure 2. Response surface methods are particularly useful for this application given the size and duration of the computations required to assess each layout; each simulation taking between 3 and 15 hours to solve.

Once the initial simulations, specified by the DoE, have been carried out, a number of search and update loops are performed during which the design search and optimisation software decides which additional layouts need to be simulated to improve the quality of the response surface. Benefiting from the dezineforce compute cluster, once the problem had been defined, the simulation and optimisation was completed in less than 3 days.

Insight into the layout alternatives was gained using the online visualisation tools to view the response surface, Figure 3. This is a maximisation problem so the higher the surface the larger the power per cost value. The plot shows that the objective (in W/€) increases in value as the number of turbines in each row (ny) increases and also as the number of rows (nx) nears five.

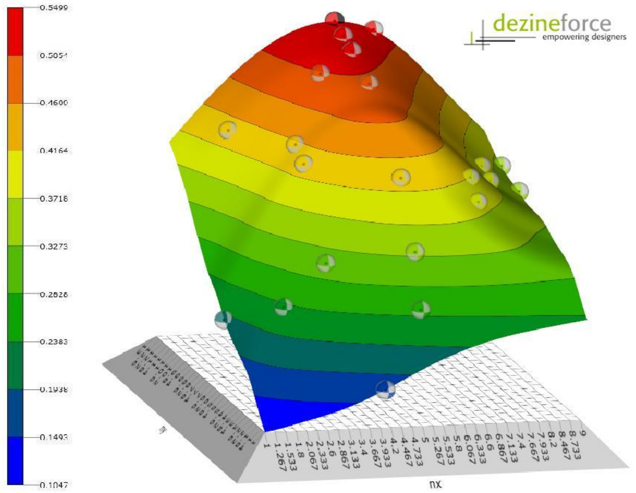

Figure 1: Visualisation of the response surface

The layout with the largest value of the power per unit cost is easy to identify; 5 rows with 13 turbines in the first row (P1 in Figure 4), a total of 63 turbines. For this layout the objective value is 0.5495 W/€. An alternative design with the same number of turbines in a different layout, 6 rows with 11 turbines in the first row (P2 in Figure 4), no simulation data is available but using the interactive tools available to examine the response surface, we see that the predicted yield is approximately 0.504 W/€, a significant power reduction due to the aerodynamic interference between turbines. Based on a mean value of €0.05 per KWhr, averaged over a 25 year lifetime, this difference in yield equates to an increased lifetime return of over €55 million.

The response surface can also be used to explore alternative designs such as maximising the number of turbines or limiting the total number of turbines for the site. For example, the maximum number of turbines considered in this case study is 9 rows with 13 turbines in the first row, equating to 113 turbines in total. Examining the response surface (P3) indicates that this would produce a power per cost ratio of approximately 0.344 W/€, very significantly less cost effective than either design with just over half the number of turbines.

Points P4 and P5 show another comparison between different layouts when the total number of turbines is limited to 50, resulting in a variation between 0.288 W/€ and 0.544 W/€, emphasising the value in assessing the layout alternatives prior to construction.

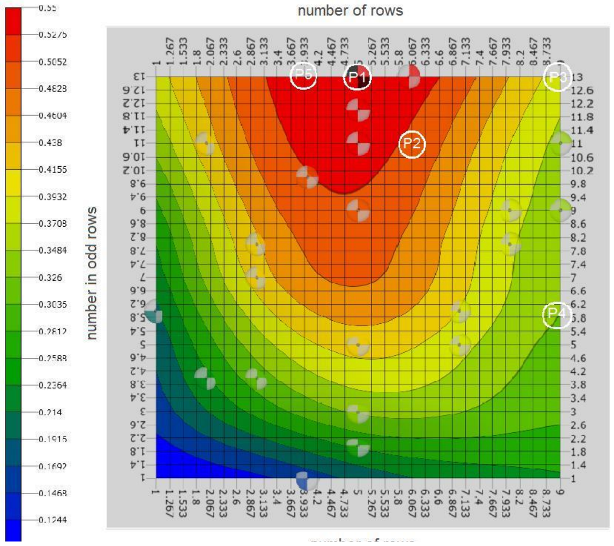

Figure 1: Study of the response surface

Although this case study considers two variables, the method used can be applied to problems with alternative parameters. The same approach can also be used to characterise the expected performance of a farm based on the local wind rose by varying the wind speed, direction and availability to enable an understanding of the annual yield.

Benefits

Through the use of the dezineforce service, the number of turbines and the layout that will achieve the best power-cost yield was identified for a specific wind farm site. The capitally intensive nature of wind farm installations and the impracticality of altering turbine placement after installation, reinforce the importance of maximising total yield for the installation cost in advance of construction.

The method used can be applied to any specific wind farm site, allowing for local topographical features and wind conditions to determine the layout that will generate the greatest yield per unit of installation cost. In addition, using the same approach, the variation in wind direction and strength can also be included to determine the impact of the variation of local conditions over time.

This case study was completed by Intelligent Fluid Solutions (www.intelligentfluidsolutions.co.uk) using the dezineforce service that provides subscriber access over the web to engineering analysis and optimisation workflows in a high productivity computing environment. The yield improvement demonstrated was made possible through the integration of commercial computational fluid dynamics, a rich suite of design search and optimisation tools and the supporting computational and data infrastructure.