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Optimizing wind farm layout via LES-calibrated geometric models inclusive of wind direction and atmospheric stability effects

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The energy generation at a wind farm is controlled primarily by the average wind speed at hub height. However, two other factors impact wind farm performance: 1) the layout of the wind turbines, in terms of spacing between turbines along and across the prevailing wind direction; staggering or aligning consecutive rows; angles between rows, columns, and prevailing wind direction); and 2) atmospheric stability, which is a measure of whether vertical motion is enhanced (unstable), suppressed (stable), or neither (neutral). Studying both factors and their complex interplay with Large-Eddy Simulation (LES) is a valid approach because it produces high-resolution, 3D, turbulent fields, such as wind velocity, temperature, and momentum and heat fluxes, and it properly accounts for the interactions between wind turbine blades and the surrounding atmospheric and near-surface properties. However, LES are computationally expensive and simulating all the possible combinations of wind directions, atmospheric stabilities, and turbine layouts to identify the optimal wind farm configuration is practically unfeasible today.

A new, geometry-based method is proposed that is computationally inexpensive and that combines simple geometric quantities with a minimal number of LES simulations to identify the optimal wind turbine layout, taking into account not only the actual frequency distribution of wind directions (i.e. wind rose) at the site of interest, but also atmospheric stability. The geometry-based method is calibrated with LES of the Lillgrund wind farm conducted with the Software for Offshore/onshore Wind Farm Applications (SOWFA), based on the open-access OpenFOAM libraries. The geometric quantities that offer the best correlations (>0.93) with the LES results are the blockage ratio, defined as the fraction of the swept area of a wind turbine that is blocked by an upstream turbine, and the blockage distance, the weighted distance from a given turbine to all upstream turbines that can potentially block it.

Based on blockage ratio and distance, an optimization procedure is proposed that explores many different layout variables and identifies, given actual wind direction and stability distributions, the optimal wind farm layout, i.e. the one with the highest wind energy production. The optimization procedure is applied to both the calibration wind farm (Lillgrund) and a test wind farm (Horns Rev) and a number of layouts more efficient than the existing ones are identified.

The optimization procedure based on geometric models proposed here can be applied very quickly (within a few hours) to any proposed wind farm, once enough information on wind direction frequency and, if available, atmospheric stability frequency has been gathered and once the number of turbines and/or the areal extent of the wind farm have been identified.