Models and perspectives of wake dynamics and turbulence

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Summary

We report on results of the project "Gigawatt Wakes" and related works in the German offshore wind farm "Alpha Ventus" and in the wind tunnel at ForWind in Oldenburg. Unique and extended measurement campaigns of the RAVE initiative allowed for a detailed study and modeling of offshore wind turbine wakes. Wind tunnel measurements complement these investigations. The combination of several approaches leads to an enhanced insight into wake dynamics and wake turbulence.

1 Introduction

Wind parks are growing both in numbers of turbines and in installed power per turbine, especially offshore. This development increases the impact of wake effects on energy yield as well as on operational loads and lifetime.

Within the project "Gigawatt Wakes" funded by the German ministry for economic affairs and energy, flow and wake properties in large offshore wind farms have been investigated. Here we report on selected results of this project from the German wind farm "Alpha Ventus". We complement these results by recent wind tunnel investigations concerning model turbine wakes.

2 Lidar measurements of wake turbulence

Wind velocity measurements using long-range lidar systems have been performed to investigate the turbulence structure of offshore wind energy converters (WEC). A simple correction of the lidar volume avaraging using FINO 1 ultrasonic anemometers uncovered an $f^{-5/3}$ decay of the power spectral density as in idealized turbulence. Moreover, a detailed study of intermittency in the wake center showed a close correspondence to Kolmogorov's 1962 theory of turbulence.

3 Reduced-order wake model using POD

A new ansatz of wake modeling was developed. Cross sections of the wake flow are analyzed by Proper Orthogonal Decomposition (POD). This allows for a reconstruction of flow patterns using just a few principal components. For the reconstruction of loads on a downstream WEC, however, an additional background field of small-scale turbulence had to be added. The combination of both methods in a flexible modeling framework leads to strongly reduced models adapted to the respective application.

4 Wake tracking for an extended DPM

In the Disc Particle Model (DPM), wakes are modeled as a series of independent discs of velocity deficits which superimpose at the location of a downstream WEC. An important question for the dynamics of those models is the lateral movement of the discs. From lidar measurements of the lateral wake dynamics, combined with wind direction measurements at FINO 1, a mechanism of the lateral dynamics could be identified, and the wake structure could be disentangled from the meandering flow.

5 Turbulence interaction in wind tunnel wakes

A detailed wind tunnel study confirmed and extended findings from field measurements. Increased and homogeneous turbulence was found in the wake center, while the interaction of wake turbulence with ambient turbulence lead to pronounced intermittency in the mixing region. This region was also observed in field measurements.

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