Abstract

The FarmFlow program is developed to calculate the wind turbine wake effects of offshore wind farms, i.e. the reduction of the wind speed and the added turbulence behind the wind turbines. In the FarmFlow model the turbulence characteristics have been modeled in the near wake regions behind the turbines. This has led to a significant increase of the accuracy of the wake loss simulations. The improvements to the turbulence modeling are based on the extensive database of measurements at the ECN Wind Turbine Test site Wieringermeer (EWTW).

Objectives

Offshore wind power is mainly produced by turbines located in large wind farms, in which large numbers of wind turbines are grouped together. Under these circumstances there is a mutual influence of wind turbines on each other due to aerodynamic wake effects. For the design of offshore wind turbines, as well as for optimization of the wind farm lay-out, it is important to accurately model the wake effects in the wind farm:

• reduced wind speed leading to reduced energy yield of the wind farm,
• increased turbulence levels leading to increased mechanical loads on turbines.

ECN has developed an advanced and validated tool that accurately calculates the wake effects of offshore wind farms.

Methods

FarmFlow is a software tool that is used to compute the wind flow in wind farms. It uses an improved version of the WakeFarm model, which computes the wakes behind wind turbines. It is based on a three-dimensional CFD model that solves the parabolized Navier-Stokes equations. Turbulence is modeled by means of the k-ε turbulence model. Since the WakeFarm model is three-dimensional, it is applicable in the atmospheric boundary layer. The basic flow field parameters (wind rose) and wind turbine properties (c_p and c_t curves) are used as input.

Due to the parabolization of the Navier-Stokes equations, axial pressure gradients in the wakes are neglected. This is a plausible assumption at some distance away from the wind turbines and allows for a fast numerical solution. However, in the near wake region pressure gradients are eminent, since in this region the wake expands and the flow decelerates. Therefore FarmFlow uses a hybrid method that models the wake expansion and flow deceleration directly through prescribed axial pressure gradients in the near wake.

The wake of a wind turbine is divided in a near wake, an intermediate wake, and a far wake. The near wake is the region where the wake expands as a result of the increasing pressure in flow direction. The near wake ends a few rotor diameters downstream the rotor plane, where the maximum velocity deficit at the centerline is reached and the pressure equals the free stream value. The near wake region is dominated by inviscid processes. In the intermediate wake region, the turbulent mixing is concentrated in an annular shaped shear layer, while at the centerline the velocity remains constant. The far-wake region is the region that is best modeled by the k-ε turbulence model. ECN has focused to improve the modeling in the near wake region. This region is poorly described by the k-ε turbulence model because most vorticity is concentrated in a sheet emanating from the blade tips. The FarmFlow model is improved by reducing the dissipation rate of the turbulent kinetic energy in the near wake region, matching the experimental results of the N80 2.5MW wind turbines in the ECN Wind Turbine Test Site EWTW.

Results

Conclusions

The ECN program FarmFlow is a compromise between simple empirical formula to very complex and time consuming flow solvers. The model has been improved by implementation of an adapted turbulence model in the near-wake region. The validated FarmFlow model accurately predicts the wake losses in offshore wind farms. Furthermore, the FarmFlow model estimates the turbulence levels in the wakes.

References

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We acknowledge DONG Energy A/S, Vattenfall AB and E.On Sweden, owners of the Horns Rev and Nysted wind farms.