Loads in wind farms under non-neutral ABL stability conditions – a full-scale validation study of the DWM model.

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Abstract
The purpose of this study is twofold: To validate a generalized version of the DWM approach for load prediction under non-neural atmospheric stability conditions, and to demonstrate the importance of atmospheric stability for wind turbines operating in wind farm conditions.

Keywords: *Wind farm, Wakes, Loads, Atmospheric stability*

Introduction

For wind farm (WF) *production* estimation *stationary* WF flow field modeling as provided by e.g. full CFD RANS models or fast linearized CFD RANS models [1] may suffice. However, for *load estimation* of wind turbines (WT's) exposed to wake affected inflow conditions, a *non-stationary* WF flow field description is inevitable. Insisting on models reflecting the basic physics of the problem, high-fidelity DNS or LES CFD type of simulations are valid approaches. In a WF design context these are, however, presently excluded due to their excessive computational demand, and for such purposes we therefore have to resort to medium-fidelity type of simulations. One such approach is the Dynamic Wake Meandering (DWM) model [2] which, coupled with an aeroelastic model, previously has been validated against full-scale WT load data [3], [4] for neutral atmospheric boundary layer (ABL) conditions.

The DWM model has recently been generalized to non-neutral ABL stability conditions [5], [6], and its capability regarding WT load predictions in turn used to obtain insight in fundamentals of WF loading under such conditions [7]. However, a proper validation still remains. The purpose of the present work is thus to validate the generalized DWM model regarding load prediction under non-neutral ABL conditions, and at the same time demonstrate the importance of ABL stability with regard to loading of WTs operating in WF conditions.

Approach and results

The study utilizes the Lillgrund off-shore WF as validation case. The Lillgrund WF constitute an interesting case study for WF model validation, because the WT interspacing is small, which in turn means that wake effects are significant. The Lillgrund WF consists of 48 Siemens SWT-2.3-93 WT's, and one of these is instrumented with strain gauges resolving blade, main shaft and tower loads, respectively. These measurements have been made available by Siemens Wind Power, and they constitute probably one of the most comprehensive sets of wake affected wind turbine load measurements ever recorded. The measurement period extends from 2008-06-03 to 2013-03-19 – i.e. over a period of almost 5 years. Unfortunately, these measurements are not accompanied with meteorological mast measurements allowing for ABL stability classification. To compensate for this shortcoming, we have obtained access to meteorological measurements from the nearby Drogden off-shore light tower, which allows for ABL stability classification. We will assume that the proximity of the Drogden light tower to the Lillgrund WF, which is of the order of the extent of the WF, justify the use of these data to quantify the ABL stability at the Lillgrund site.

Classifying the load data according to ABL stability conditions allows for a one-to-one comparison of WT load simulations and measurements *conditioned on ABL stability condition*. The simulations are performed using the generalized DWM approach coupled to the state-of-the-art aeroelastic code HAWC2. As for the generalized DWM model, a spectral tensor including the effect of buoyancy [8] is used to drive the stochastic wake meandering.

For a multitude of wake situations (i.e. a variety of mean wind speeds and mean wind directions) the measured data set displays a considerable scatter as illustrated in Figure 1. The study will illuminate to which degree this scatter can be attributed to ABL stability effects, and at the same time serve as a full-scale validation study of the coupled DWM/HAWC2 approach. Both blade and tower fatigue loads are analyzed, and important differences between rotating and non-rotating WT component loading will be touched on regarding the impact of ABL stability.

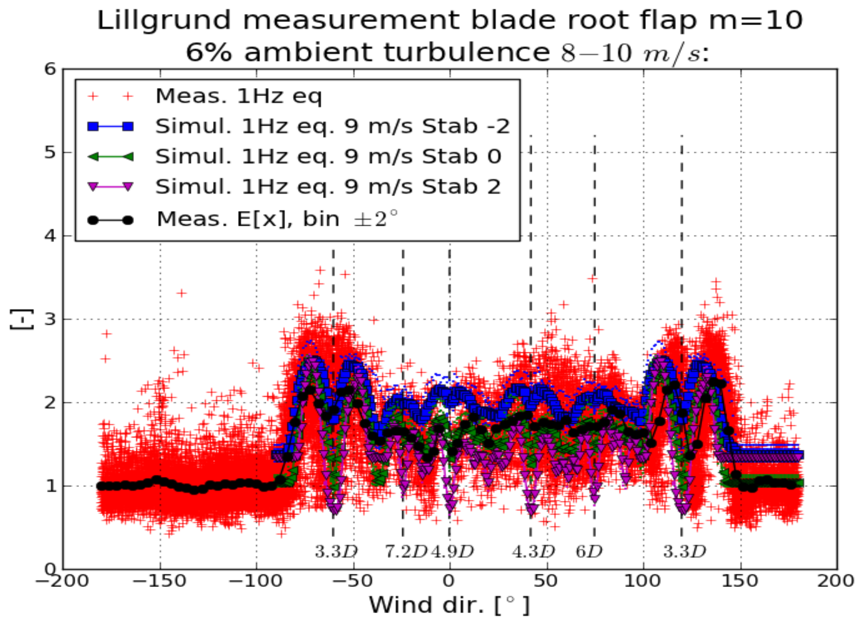

Figure 1: Normalized predicted and measured fatigue blade root flap moments from the Lillgrunden WF for a complete 360 deg. polar. The simulations are performed for an ambient mean wind speed equal to 9m/s, and the measurements are associated with the mean wind speed bin interval [8m/s; 10m/s].

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