Review of paper wes-2019-89:

Measuring dynamic wake characteristics with nacelle mounted LiDAR systems

by Inga Reinwardt[1], Levin Schilling[1], Peter Dalhoff[1], Dirk Steudel[2], and Michael Breuer[3]

[1]Dep. Mechanical Engineering & Production, HAW Hamburg, Berliner Tor 21, D-20099 Hamburg, Germany

[2]Dep. Turbine Load Calculation, Nordex Energy GmbH, Langenhorner Chaussee 600, D-22419 Hamburg, Germany

[3]Dep. of Fluid Mechanics, Helmut-Schmidt University Hamburg, Holstenhofweg 85, D-22043 Hamburg, Germany

Brief summary

The author's present LIDAR measurements of the wake flow behind two different turbines (a 3 MW N117 turbine and a 2.4 MW N117 turbine) in a small wind farm of 5 closely spaced turbines with individual spacing's between 2.51 and 4.71 D. Measurements were carried out for different inflow conditions with turbulence intensities from 4 to 22%. The processing of the measurements comprises a determination of the wake deficit centre by fitting a Gaussian curve to the 11 measured wind speeds. With the deficit centre located the measured points are moved to the meandering frame of reference (MFR), interpolated to a grid and then the mean deficit based on all the individual scans, e.g. 37, for a 10 min time series is determined.
A comparison between the modelled wake degradation in the MFR and the measured is then conducted. The simulations are carried out with two different versions of the Dynamic Wake Meandering (DWM) model. These versions differ only in the description of the quasi-steady wake deficit. Based on the findings from the LiDAR measurements the formulation of the quasi-steady wake deficit in the DWMmodel was adjusted, so that the recalibrated model coincides very well with the measurements.

Overall comments

The subject of the paper on full-scale measurements of the wake characteristics in the fixed frame of reference (FMR) as well as in the meandering frame of reference (MFR) is of considerable importance for the research community as this is the basis for improving our insight into wake flow physics and providing input for improving our modelling capability of wakes. This is important for a more precise prediction of the AEP losses in wind farms as well as of the increased turbine loading.

However, the measurement task is also quite complicated, e.g. due to the considerable size of the wake of a MW turbine and due to the atmospheric flow conditions which means that the wake deficit is masked by this turbulent flow.

The discussion and consideration of this complexity of the measurement task and in particular how it affects the measured wake characteristics should be improved in the final version of the paper. This is important for the use of the results in the paper by the research community. In general, also a more precise description of approaches, experimental set-up and interpretation of results should be contained in the final version of the paper.

Specific comments

Abstract

The sentence: “the formulation of the quasi-steady wake deficit in the DWM model has been adjusted” is not precise.

It´s proposed to describe that it´s the correlation of the impact of ambient turbulent to the eddy viscosity that has been investigated and that an improved correlation function (parameter) has been determined based on the present measurements.

1. Introduction

Satisfactory description of previous work within the field and the intro to the contents of the present paper at the end.

2. Wind farm

Line 68:

- What is the instrumentation in the met. mast ? Please describe in the paper.

Line 76:

- What type of load measurements and have they been used for DWM simulations on the turbines?

3. Data filtering and processing

Line 86:

- … “and sorted in accordance with ambient wind speed, ambient turbulence intensity, windshear, atmospheric stability, and wind direction”.
    - is it 10 min, mean values that the data are sorted on basis of ?

4. Wind speed deficit in MFR calculation

Line 119:

- … “In the analysis presented here only results from a horizontal line scan are analyzed, so that no vertical meandering is considered and the measurement results are fitted to a one-dimensional Gaussian curve defined as follows:”
    - In my view this is an important limitation of the experimental set-up. Overall the impact is that the depth or strength of the deficits are smaller than if the 3D location of the deficits was used. The impact can be investigated using a DWM model and simply set the vertical meandering

to zero. Please discuss this limitation of the measurement set-up and what impact it has on the final result.

Line 137:

- … "After averaging, the plausibility of the results is inspected. If the calculated minimum mean wind speed in the MFR is higher than the minimum mean wind speed in the FFR, it is assumed that the Gauss fit failed and the results are no longer considered.
    - Besides this plausibility check I would propose to show the standard deviation of all the measurement points around the average MFR from the individual scans, just for a few cases. This will give information about how much averaging is behind the final MFR deficits.

Line 148:

- In figure 2 as I understand the procedure:
    - – shouldn´t the x axis after the interpolation be in y/d units and not in deg. ?. Likewise in Figure 3b.

5 LiDAR simulation

Line 159:

- Were the lidar simulations with the DWM model shown in Figure 3 carried out with ambient turbulence or only a meandering turbulence – please specify?

Line 160:

- … "Whenever the wind speed deficit is mentioned in subsequent validations, it implies the neglection of the vertical meandering, which has only a marginal impact on the shape of the wind speed deficit in the FFR.".
    - As the meandering turbulence components scales with 0.8 and 0.5 in horizontal and vertical direction relatively to the streamwise turbulence component I am not convinced that this statement is correct. Please expand on this eventually based on simulations with the DWM model.

6 Dynamic wake meandering model

Line 175:

- … "It compares directly to the LiDAR measurements after transforming the measurements into the MFR as explained in the last section".
    - As mentioned above the measured wake deficit might be less sharp (deep) due to neglecting the vertical meandering and due to the averaging of many individual deficits impacted by ambient turbulence.

Line 189:

- … “The error that inherently comes with this assumption is accommodated by using the wind speed deficit two rotor diameters downstream (beginning of the far-wake area) as a boundary condition for the solution of the thin shear-layer equations. “
  - It might be important to point out here that the eddy viscosity model in the DTU DWM implementation is run from the rotor plane and downstream with the fully expanded wake deficit (eq. 6 and 7) as boundary conditions but where a fit of the deficit at 2D downstream to Actuator Disc simulations determined eq. 8 and the filter function for non- turbulent flow.

Line 272:

- … “It shows that for lower turbulence intensities and moderate to high turbine distances the wind speed deficit degradation is too low.”
  - Maybe write “was too low in the model version from 2010 – ref J. Sol. Energy Eng., 132, 041 014, 2010. ” The deviations were the reason to recalibrate the model as presented in the 2013 paper.

7 Measurement results

Line 289:

- … “The corresponding mean wind speed deficit is illustrated in Figure 6(b).”
  - In order to evaluate what this mean deficit it would be valuable if the standard deviation of the 11 raw measurement points for each scan are shown

Line 310:

- … “The reason is probably the wake of other turbines in the wind farm”.
  - It could also be due to wake rotation as seen in 3D CFD rotor simulations in sheared inflow. It shows that high velocity flow at one side of the rotor is rotated down towards the ground and the opposite on the other side of the turbine.

Line 323:

- … “In this range both turbines operate under optimal and most efficient conditions resulting in maximum energy output from the wind. The thrust coefficient is constant in this region. Therefore, the axial induction and the wind speed deficit normalized by the turbine’s inflow wind speed are also expected to be constant for similar ambient conditions over this wind speed range.”
  - Its mentioned “.. expected to be constant”. What is actually used in the DWM simulations ?

   - Further down at line 368 is mentioned : “.. that the axial induction of both turbines is slightly different under partial load conditions.” So is the detailed aero loading of each of the two turbines are simulated ?

8 Comparison between measurements and DWM model simulation

Line 358:

- … “For lower turbulence intensities and higher distances (greater than 3D) there is a relatively large discrepancy between measurements and simulations. A similar observation was made in Larsen et al. (2013).”
   - This comment was on the model before the recalibration so it should be deleted if pointing to the “DWM-Egmond model”

Line 362

- As concerns the results in Figure 10 and Figure 11 for the DWM-Egmond model they seem not to agree with simulations with our DTU implementation of the DWM model, however with the uncertainty of just assuming a similar turbine operation but without knowing the details of the turbine
   - The authors are encouraged to share and upload more details of their simulations so that the results can be checked with an original implementation of the so-called DWM-Egmond model.
   - Further, it is proposed to show a figure with e.g. the mean velocity of the wake deficit or the mean velocity cubed (to show reduction in power of the downstream turbine) and otherwise in the same way as Figure 9. The mean velocity is a more robust characterization of the wake deficit than the minimum value velocity within the deficit. The minimum value can easily be influence by the details of the aerodynamic modelling of the turbine.

Some final conclusive remarks

- There is no discussing of the impact of the findings. Changing the wake recovery characteristics have obviously an impact on power production and loads.
   - For the Egmond aan Zee case the DWM model was as mentioned calibrated to the power reduction of the second turbine in a row relative to the first one for different spacings and turbulence intensities. Using this calibration an overall good correlation of simulated and measured loads was found.
   - Have the present recalibrated model been used for power and load simulations and compared with measurements in the present wind farm?
- The reviewer finds that due to the above mentioned uncertainties/limitations related to the measurements of the deficits in the meandering frame of reference there will be a bias of the measured deficits being more smooth. Please comment on this view.

Final conclusion of review

The reviewer can recommend publication of the paper considering the above comments/questions and not least work together on a check of the DWM-egmond simulations by comparing with the DTU implementation of the DWM model as this is the basis for the use of the DWM model in certification.

(IEC 61400-1 Ed.4: IEC 61400-1 Ed. 4: Wind energy generation systems - Part 1: Design requirements, Guideline, International Electrotechnical Commission (IEC), 2019.