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COMPARISON OF MEASURED AND SIMULATED LOADS FOR THE SIEMENS SWT 2.3 OPERATING IN WAKE CONDITIONS AT THE LILLGRUND WIND FARM USING HAWC2 AND THE DYNAMIC WAKE MEANDER MODEL.

Torben J. Larsen[1)], Gunner Larsen[1)], Helge A. Madsen[1], Kenneth Thomsen[1)], Søren M. Pedersen[2)]

[1)] Technical University of Denmark
[2)] Siemens Wind Power A/S

DTU

Abstract

The DWM model[1,2], which is about to be included in the new edition of the IEC61400-1 ed. 4 standard, is validated by comparing simulated and measured fatigue loads for the Swedish Lillgrund off-shore wind farm. This farm consists of 48 Siemens SWT-2.3-93 turbines, and one of these (C-8) is intensively instrumented with strain gauges resolving blade, main shaft and tower loads. Using recordings from this turbine, the model validation is performed for a variety of wind directions and mean wind speeds.

The DWM model basically simulates the non-stationary wind farm flow field by treating wind turbine wakes as passive tracers transported downstream by the mean flow field superimposed by a meandering process driven by the large scale cross wind turbulence components. For the ambient mean wind speed regime between 3m/s and 14m/s this approach was previously successfully validated against full-scale measurements from a Vestas V90 turbine located in the Dutch Egmond aan Zee Wind farm[3] for a specific wind direction, where the turbine in focus was located as 6'th turbine in a row spaced with 7 rotor diameters(D).

Whereas the Egmond ann Zee wind farm is characterized by a "conventional" turbine inter spacing, the layout of the Lillgrund wind farm is characterized by very small turbine inter spacing's; i.e. down to 3D. This makes the present Lillgrund load validation case a unique supplement to the previous conducted validations.

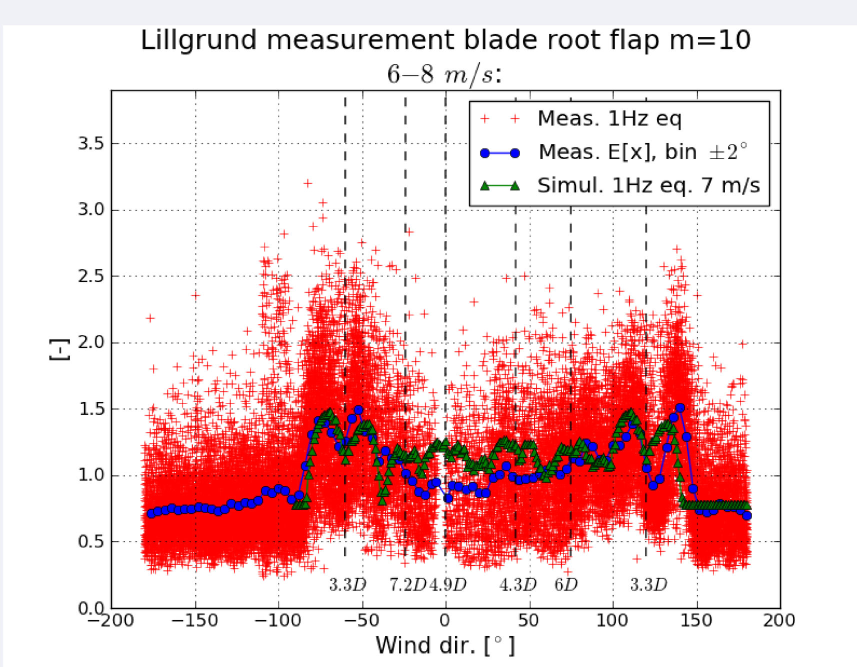
Approach

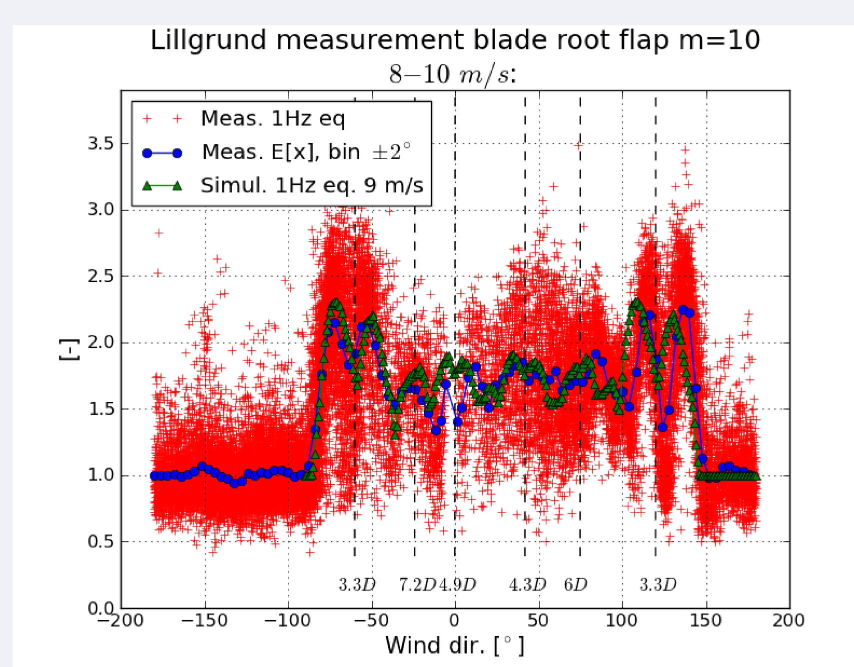
Fatigue blade flap loads was selected for the present validation. The Palmgren-Miner approach was used to quantify the fatigue loading in terms of fatigue equivalent moments, and a Wöhler exponent of 10 was assumed for the blade composite structure.

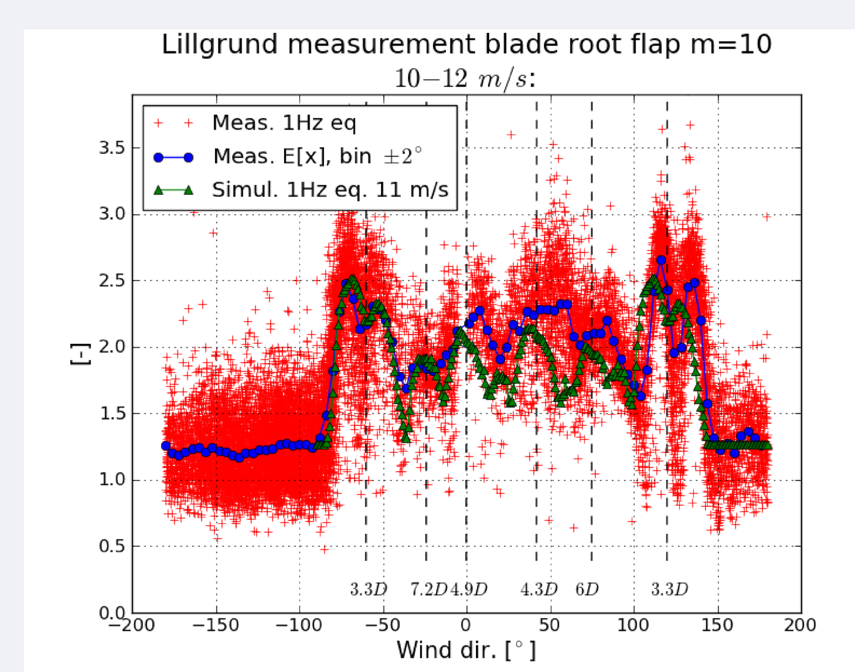
The validation scenario includes load cases associated with normal turbine operation with mean wind speeds ranging from 6m/s to 25m/s. Six mean wind speed bin regimes were defined and considered: 6m/s-8m/s; 8m/s-10m/s; 10m/s-12m/s; 12m/s-14m/s; 14m/s-16m/s; and 16m/s-25m/s. A measured wind speed dependent turbulence intensity (TI) was used, reflecting the offshore wind speed dependent "surface" roughness. However, no attempt was done to resolve TI as function of upstream fetch (i.e. direction). In the mean wind speed regime 6m/s-14m/s a TI of 5.8% was used - gradually increasing to 9.5% at 25m/s.

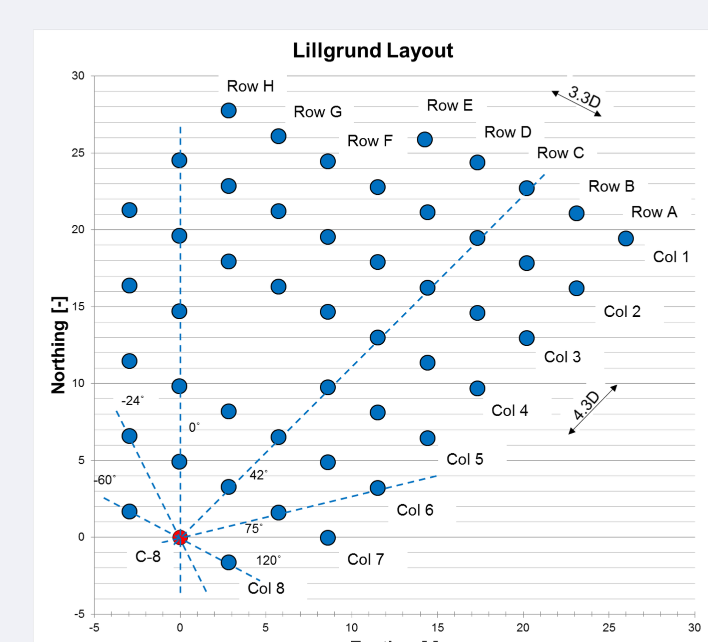
Simulated and measured blade root fatigue equivalent moments have been compared bin wise for a complete direction rose, which includes a multitude of load cases ranging from ambient inflow conditions over single wake cases to various types of multiple wake inflow cases.

Results

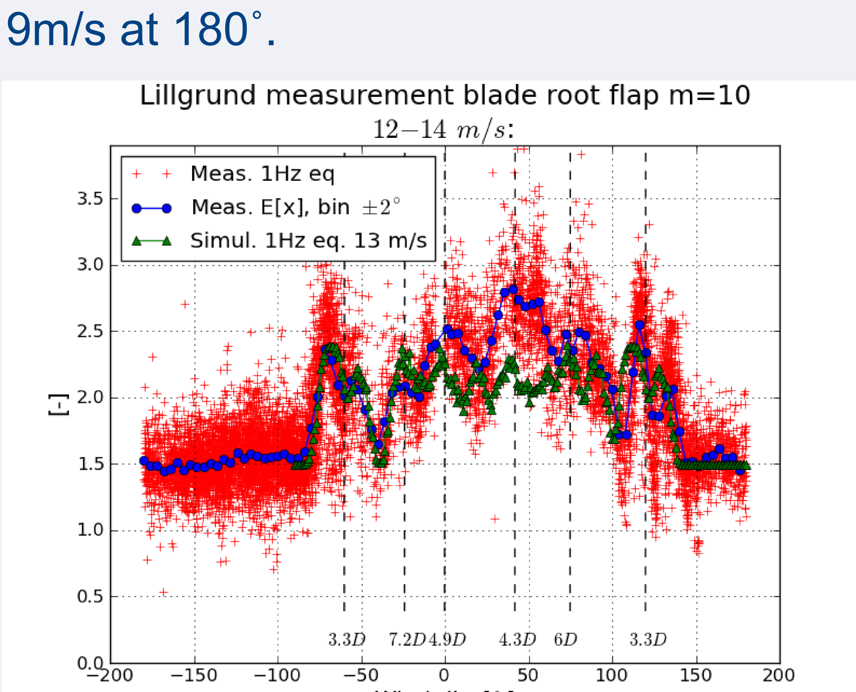


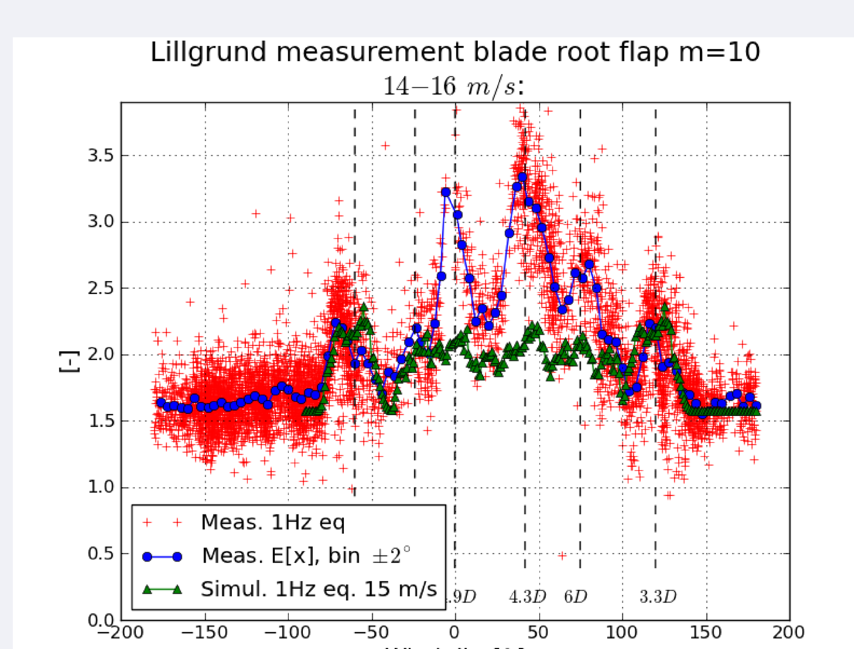


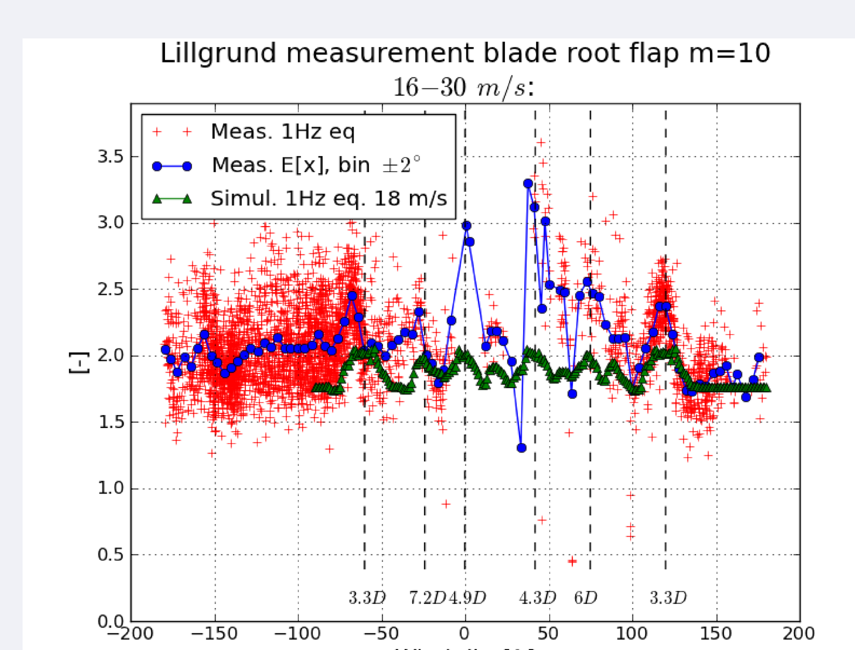


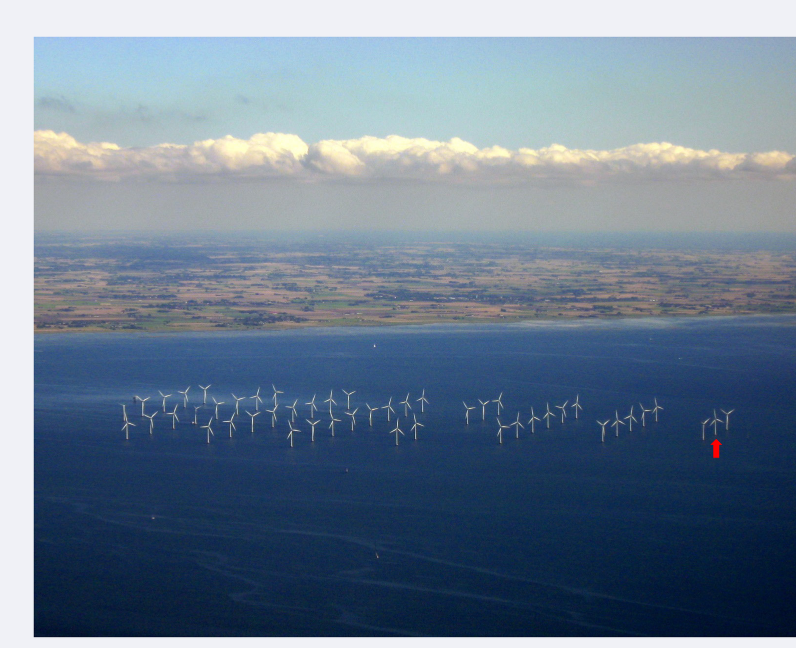


For the wind speeds below rated there is an excellent agreement between measured and simulated loads truly confirming the DWM approach. This is seen both for the 3.3D single wake situation as for the multiple wake situation in the North-Eastern sector. Blade fatigue load levels are increased with a factor 2.1 in the 3.3D single (half) wake, whereas the load level in the multiple wake sector is approximately 1.8. The instrumented turbine is C-8, see figure above. Loads are non-dimensioned with the load level at 9m/s at 180˚.









For wind speeds above rated there is also excellent agreement for the 3.3D single wake situation. The measured load level are however significantly higher than the simulated for the multiple wake sector. An explanation of this is expected to be addressed to the DWM implemented handling of multiple wake, where each deficit is calculated without influence of previous upstream turbines. Using an increased deficit depth for the nearest turbine increased the load level at 15m/s at 42˚ from 2.2 to 2.6.

Conclusions

Validation of the DWM model using full-scale load data from Lillgrund, which is characterized by low inter spacing between turbines, has shown that the DWM model predicts the flapwise fatigue loads quite satisfactorily for single turbine wake situations as well as for deep array operation. Up to about 12m/s the single wake operation gives the highest loading as seen both in measurements and in the simulated results. At higher wind speeds the measurements show the highest loading in the deep array operation, which is not captured by the model. The main cause of this deviation is thought to be that the simple method used in the DWM model to determine the aggregated deficit from the upstream turbines is less accurate at high wind speeds. A first investigation of this conjecture is confirmed by a simple ad hock model change using an dual-wake scenario. However, the predicted load levels are still below the measured values and further work on this complex situation therefore needed.

Acknowledgements

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