Recalibrating Wind Turbine Wake Model Parameters – Validating the Wake Model Performance for Large Offshore Wind Farms

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Summary
As part of the Danish PSO sponsored project '*The Necessary Distance between Large Wind Farms at Sea* ' EMD International A/S has implemented a number of wake models in the WindPRO software. In this paper we report the preliminary results of a case study on Horns Rev offshore wind farm, where the actual observed wake losses are compared with calculations using the implemented wake models. The wake loss can be analyzed by sector and wind speed, which in the future allow for improved parameterization of the models. This case study indicated that the traditional N.O. Jensen wake model is more precise at predicting the observed wake loss than the other tested wake models, at least when the current default parameters are used.

Introduction
The aim of the analysis is to verify/improve existing wind turbine wake models through model parameter adjustments, so that they can be utilized in large offshore wind farms. The analysis includes parameter sensitivity studies on three different wake models, the N.O. Jensen model [1], the Ainslie model (Eddy Viscosity) [2] and the G.C.Larsen model (Prandtl BL-equations) [3]. The performance of each of the models is compared to data based on the performance of offshore wind farms. The focus of the analysis is – primarily – to predict energy output for the wind farm as well as for single wind turbines in the farm. The secondary objective is to predict the mean wind speeds and turbulence in the wakes.

Motivation
Most wind turbine wake models - used in wind farm evaluations today - are based on the single wake flow downstream of a wind turbine. The flow from each of the single wakes is then added into a combined effect – using a simple empiric combination model. This model is normally a 'quadratic wind speed-deficit model'. In connection to the Danish research project, '*The Necessary Distance between Large Wind Farms at Sea* ', EMD has implemented two alternative wake models as alternative to the widely used N.O. Jensen model [4]. All three wake models can be used for energy calculations, mean wind field calculations and with turbulence-calculations. The models are varying in complexity from a simple empiric engineering model to an axi-symmetric CFD-model. All the models still lack a structured validation and calibration for use on large offshore farms, just as the used wake combination model is not necessarily applicable for this purpose.

Current Progress (February 2005)
A preliminary wake study has been completed for one offshore site and a number of other wind farms are being prepared for study. Model parameters have through previous studies and literature been suggested and these are tested against this first case. The study will proceed with parameter adjustments on this first site and other wind farms in order to align these models to a correct prediction.

Expected results
The offshore measurements at the demonstration wind farms located in Danish waters contain a powerful potential for improving the existing wake models. The use of validated wake models gives a high degree of certainty for project developers running analyzes on large offshore wind farms. As the project is based on re-calibration of offshore specific parameters for existing and already validated models the results will - on a fairly short term - be able to improve the estimates and decrease the uncertainties for these models.

The project

The project has partly been funded by a grant from the Danish public service obligation (PSO) R&D program. The project runs from primo 2005 to ultimo 2006.

Test case Horns Rev.

The Horns Rev offshore wind farm was erected end 2002 and consist of 80 Vestas V80-2.0MW wind turbines. The wind farm is located 13 km from the west coast and the turbines are placed with a spacing of 7 rotor diameters. The first years of operation the turbines were suffering from poor availability, but this have been improved and for 2005 the availability was 95% according to the operator (Elsam) [5].

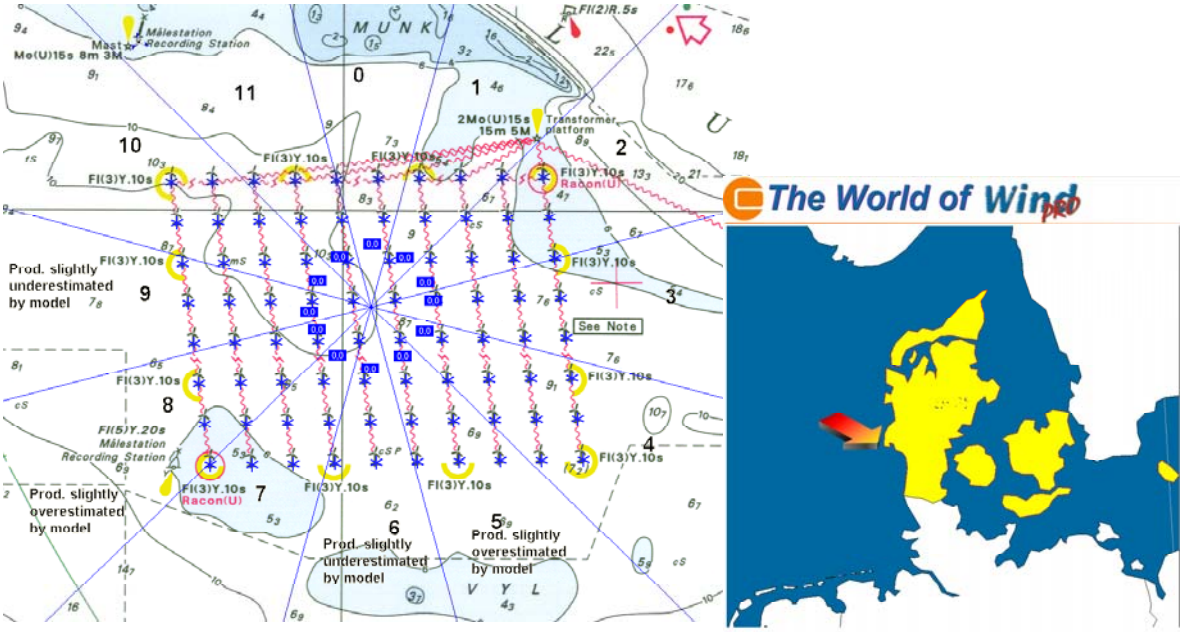


Figure 1. Map of the Horns Rev wind farm with sector numbering, showing the 12 direction sectors in whih data are grouped in the analyses.

Measured wake loss.

The operator Elsam has (through Elsam Engineering) developed a SCADAVIEW system [5] that is able to produce the deficiency in production for the wind farm compared to a free standing turbine as a function of wind speed and wind direction. The free standing turbine is the corner turbine which is most exposed to the wind direction in question. In so far as that turbine is operating correctly this system provides measurements of actual wake losses.

Test environment.

EMD has created a test system where the measured wake loss can be compared to the calculated wake loss. Park production calculations are run in WindPRO with the model and parameter settings wanted and the result is exported as a Park power curve (PPC). The PPC tells what the cumulative effective power curve has been for the wind farm as a whole. The difference from a simple multiplication of the power curve with the number of turbines and the PPC is the wake loss. In this way measured and calculated wake loss can be compared as a function of wind speed and direction. In addition by employing a representative Weibull distribution these individual wake losses can be converted to the combined wake loss. The total measured park efficiency is 87,6%, which corresponds to a wake loss of 12,4%.

Preliminary test runs

The wake models mentioned in the introduction and further described in the WindPRO manual [4] have been tested in this environment with a few tests of different parameter settings. The test settings were:

N.O. Jensen (old) [1]: This is the standard model used in previous versions of WindPRO and by WAsP's Park model. The only parameter which can be adjusted is the Wake Decay Constant (WDC), which has been tested for WDC = 0.04 and 0.075, which are recommended settings for offshore and onshore conditions respectively.

N.O. Jensen (2005): This is a modification of the old N.O. Jensen model to accommodate a new system for addition of wakes and includes optionally wake induced turbulence calculation [4]. Only WDC = 0,04 is tested.

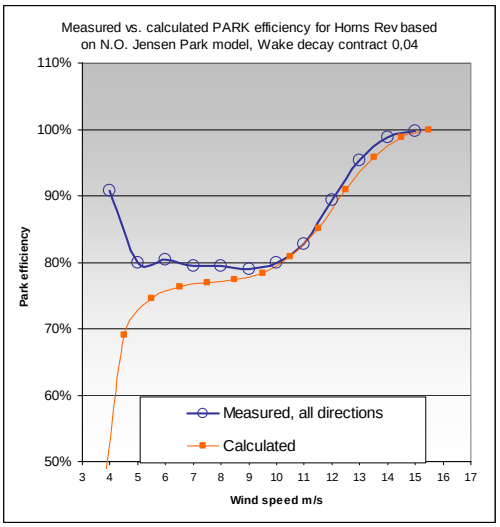
EWTS II (1999): This is a new model in WindPRO suggested by G.C.Larsen (1999) [3]. WDC = 0,04 is tested. Standard parameters as described in the WindPRO manual are used for a first order calculation.

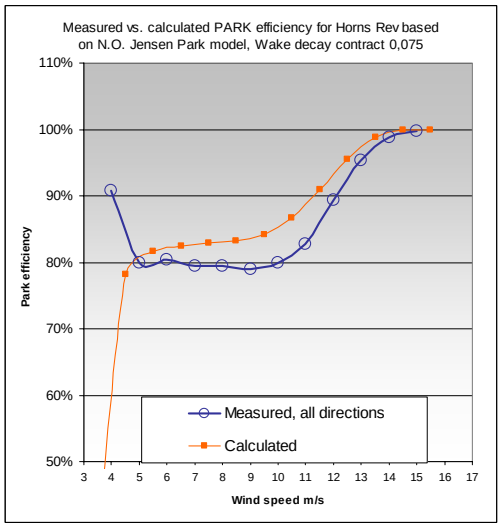
Eddy Viscosity model (1986): This model was suggested by J.F. Ainslie (1986) [2] and is new in WindPRO. This one has several parameters to adjust. In this test standard settings for WindPRO as described in the manual are used except for the constant K1, which is tested for the values 0,015 (standard) and 0,025.

As a special test suggested by some researchers the roughness inside the wind farm has been increased to z0=0,05m to reflect the roughness change induced by the wind farm itself.

Results

As the below figures show, the N.O. Jensen with offshore WDC = 0.04 is the most accurate model to predict the wake losses. The old version is slightly tighter to the measured values than the new version (N.O.Jensen 2005 as implemented in WindPRO 2.5 in addition to the old to make Wake turbulence calculation optional). Increasing the WDC to 0,075 seems to be a poor idea. Both EWTS II and the Eddy Viscosity model seem to under predict the wake loss and therefore over predict the production.





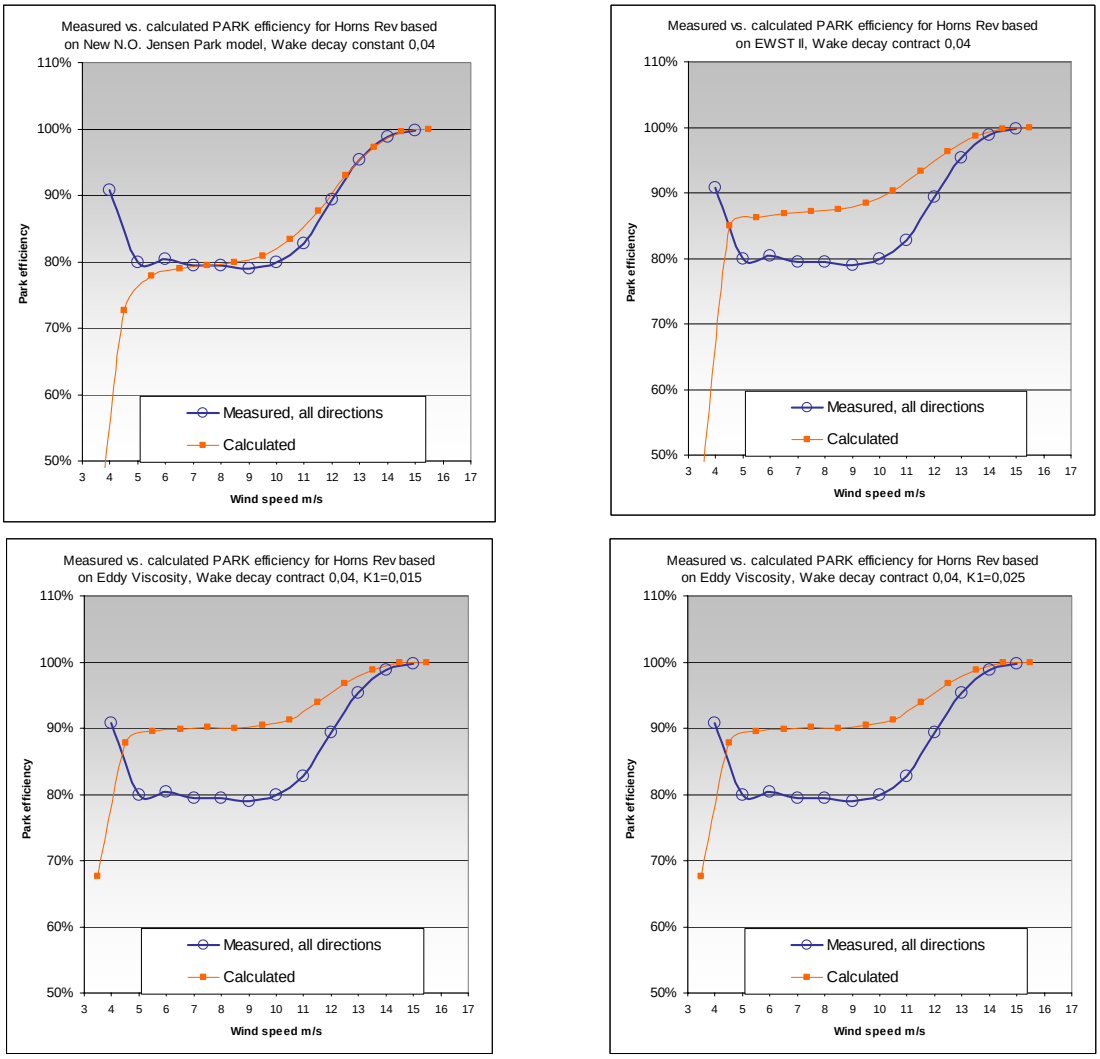


Figure 2. Preliminary tests of four available methods with standard conditions or limited parameter variation. The graphs plot the measured and calculated park efficiency for all sectors as a function of wind speed.

Even for the best predicting model there is variation as to how well each direction is predicted. Below are shown two examples of a good and less good prediction at two different sectors.

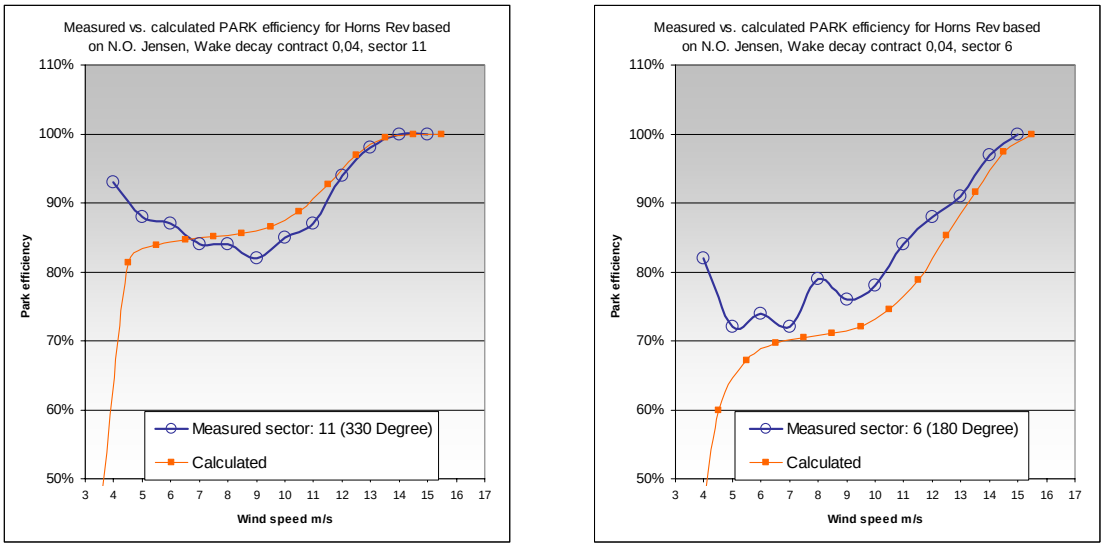


Figure 3. Even though the total fit between measured and calculated park efficiency of the old N.O. Jensen model is good, the individual sector fits can be less accurate as the two examples above illustrate.

The total difference in measured and calculated wake losses is illustrated in figure 4. Negative values are due to models that under predict the wake loss and therefore calculate too high a production. It is clear that the old N.O. Jensen for this case seems superior as long as a reasonable WDC is used.

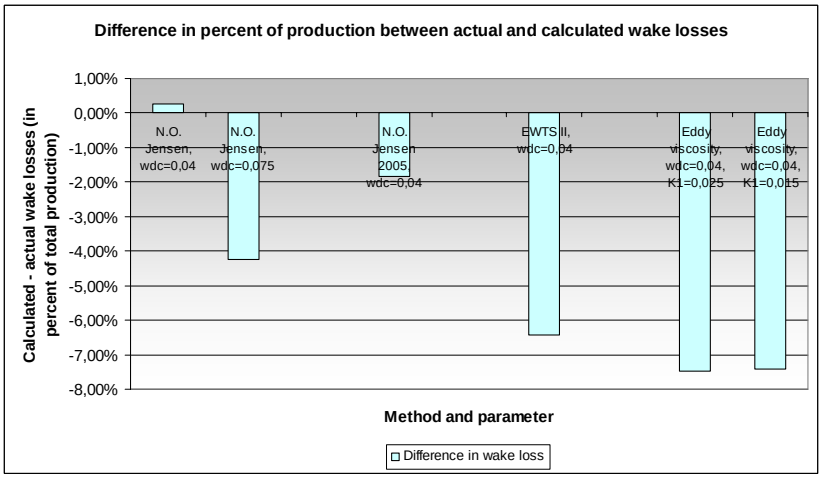


Figure 4. The ability of the models to accurately predict the measured wake loss is illustrated by this figure. A negative value of e.g. 2% means that the calculation model calculate the wake loss 2% of total production less than actually observed and therefore total production 2% higher. Most of the models under predict the wake loss, except for the old standard N.O. Jensen model that apparently is able to accurately predict the wake losses.

If an internal roughness of 0,05m is introduced inside the wind farm, the wake losses remain the same but since the base calculated production is reduced the wake loss deficit can be attenuated. This is illustrated in figure 5, which apparently

improves the performance of the poorly performing EWTS II and eddy Viscosity, but offsets the otherwise well performing N.O. Jensen model. While an internal roughness seems to be a good idea at other locations it is apparently not appropriate on this location.

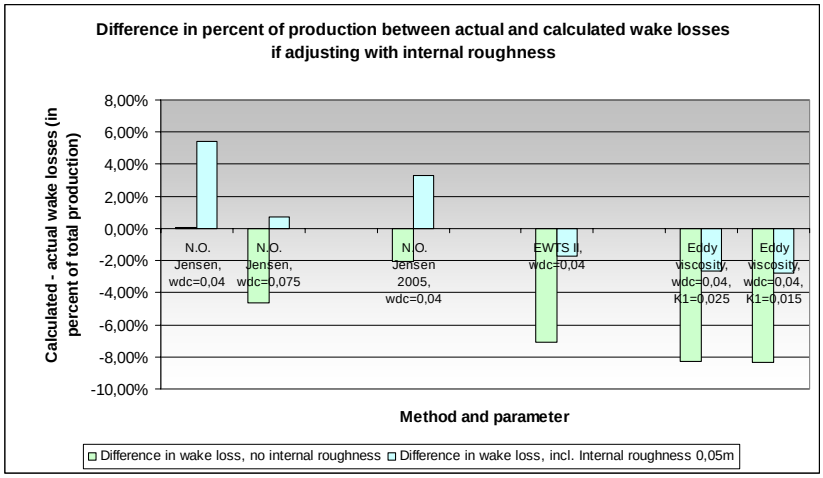


Figure 5. Introducing an internal roughness area of z0=0,05m inside the wind farm lower production and can thus compensate for the lack of predicted wake loss. However for well predicting models like N.O. Jensen this does not necessarily improve the prediction.

Conclusion

The N.O.Jensen model with WDC=0.04 seem to predict the measured array losses for the Horns Rev wind farm very accurate. Other models under predict losses typically around 6 to 8% of total production and thereby overestimate production. For other large wind farms tested, but not reported in this paper, it seems that even the most conservative of the models, the old N.O.Jensen, under predict array losses. The reason for correct prediction of Horns Rev might be the very open offshore location with high mean wind speed and real open sea stability conditions.

Future work

The plan is to set up a few other cases in order to be able to calibrate the different models and define the proper procedures and parameters choice for the models used.

References

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