NEW DEVELOPMENTS IN WAKE MODELS FOR LARGE WIND FARMS

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1 INTRODUCTION

At WINDPOWER 2008, three presentations showed that North American wind farms have not, on average, produced as much energy as expected, highlighting the necessity for greater understanding of the accuracy of long-term energy production assessments. Wake loss modeling has been cited as a possible explanation.

While the Garrad Hassan wake model has been well validated for medium-sized wind farms, recent studies of offshore wind farms have shown evidence of an under-prediction of wake losses several rows into the wind farm – the so called 'deep array effect'.

Garrad Hassan has developed a large wind farm wake model which has been validated on large offshore wind farms [1]. Within the work reported here power production data have been scrutinized to assess whether deep array effects of the magnitude observed for offshore wind farms are also observed in large onshore wind farms. These data have been used to test the application of the large wind farm wake model to onshore situations and recommendations are made regarding the use of this model for assessing onshore wind farms.

2 LARGE WIND FARM WAKE MODEL

The Large Wind Farm Model [1] is an extension to the standard wind farm wake models. The model describes additionally the disturbance of the atmospheric flow caused by the wind farm. This breaks with the assumption that the wind flow can be considered to be independent of the wind farm.

The wind turbine is treated as a disturbance analogous to a roughness element that influences the free stream flow. An internal boundary layer grows from the roughness change from ambient Z01 to increased Z02. The model is available within the GH WindFarmer wind farm design software (v4.0).

3 OFFSHORE VALIDATION

The accuracy of the wake model has been validated against production data from two large Danish offshore wind farms - Horns Rev and Nysted [1].

The turbine production has been compared to the model, illustrated in Figure 1, for selected wind speed cases with wake losses as illustrated in Figure 1. The results show the relative production as you move through the wind farm from left to right for the standard Eddy Viscosity model and the Large Wind Farm model.

While there is little difference between the two models for the first four rows of turbines deeper into the wind farm the two models diverge with the Large Wind Farm model providing close agreement with the measured data.

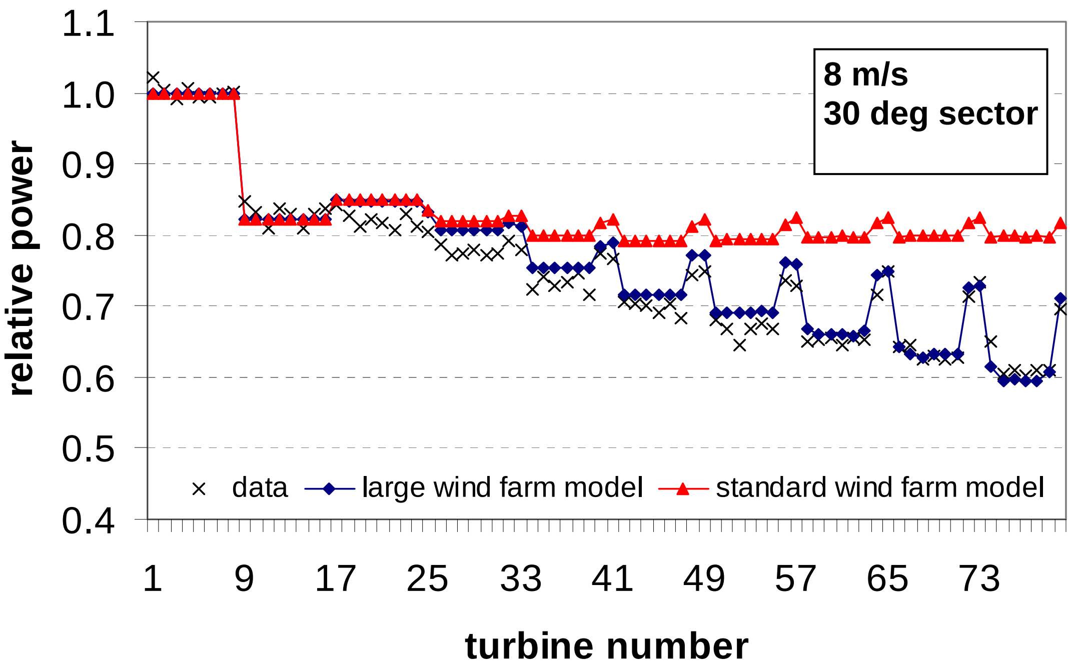

Figure 1 Model results for the Horns Rev Wind Farm

4 ONSHORE

Little work has been undertaken to date on the validation of wake models for large onshore wind farms. Considering the analogy of the wind farm as a roughness length disturbance it would be expected that any relative disturbance would be materially smaller for an onshore wind farm than for an offshore wind farm due to the higher surface roughness length at the onshore wind farm site.

In order to test this expectation production data from four large flat North American wind farms ranging in size from ~60 to ~200 MW have been analyzed. It is notoriously challenging to validate wake models for onshore wind farms as it can be difficult to reconcile whether any discrepancies observed are due to the wind flow or the wake modeling. All four of the wind farms considered gave confidence that the magnitude of deep array effect observed for the offshore wind farms, as illustrated in Figure 1, were not present at the onshore wind farms.

Having reviewed the patterns of production in the data it was concluded that despite being relatively flat the magnitude of ambient wind flow variation over three of the four sites was too great for these sites to be used for a more detailed validation exercise. For the remaining site the wind flow was considered to be sufficiently homogeneous for a detailed wake model validation to be undertaken. The fourth site provides a useful validation case as it has an irregular layout with turbines influenced by up to 13 upwind machines over a distance of 8 km. The results of this comparison are presented in Figure 2.

Initial calculations were undertaken using the standard Eddy Viscosity wake model and Large Wind Farm model with identical parameters to those used for modeling the Danish offshore projects. These are presented as red and blue lines in Figure 2. It was concluded that for the turbines towards the back of the wind farm the model with offshore settings substantially over-predicted the wake effects while the standard model marginally under-predicted the wake effects.

Using the Large Wind Farm wake model the optimum wind turbine surface roughness length was established. For the available data this was achieved with a change in surface roughness length parameter (Z02) = (Z01) + 0.03 m. This result is presented as the green line in the Figure 2.

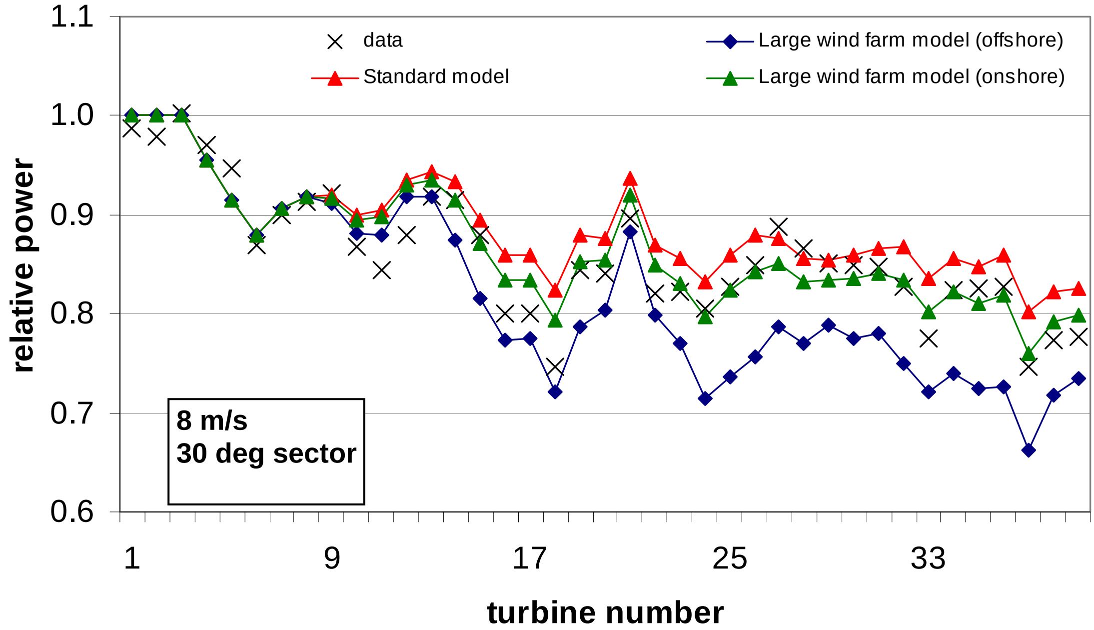

Figure 2 Model results for the onshore wind farm

5 CONCLUSIONS

From this work it is concluded that for typical current large wind farm sites deep array effects of similar magnitude to those observed at large offshore wind farms are not present. Evidence is presented to support the presence of a more modest deep array effect for large onshore wind farms.

A correction to the classic wind farm wake model has been developed that allows the disturbance of the ambient flow field caused by large wind farms to be modelled. The revised Large Wind Farm wake model is made available to the industry through the GH WindFarmer wind farm design software (v4.0) and work presented here provides guidance on suitable model surface roughness length parameters when analysing large onshore wind farms.

The model is designed to scale to different sizes and geometries of wind farm. However given the limited set of validation cases currently assessed there is considerable uncertainty in the results obtained.

6 REFERENCES

1 Schlez, W.; Neubert, A.: " New Developments in Large Wind Farm Modeling", EWEC 2009, Marseille, France.

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