Turbulence Intensity within Large Offshore Wind Farms

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Introduction

The fluctuations of the wind speed caused by turbulence cause turbine fatigue and affect turbine lifetime. For turbines within a large array, operating in wake conditions, the Frandsen model [1] for turbulence intensity (*TI*) is used as the basis for the IEC Standard 61400-1 edition 3, amendment 1 [2]. This paper summarises work carried out as part of the Carbon Trust's Offshore Wind Accelerator's project `*Validation of Frandsen Turbulence Intensity Model and Large Wind Farm Models*` [3]. The objective of this work is to assess the performance of 1) the Frandsen model and 2) a CFD code in predicting levels of turbulence intensity within a large wind farm by comparing data from the Greater Gabbard wind farm with model predictions.

Approach

SCADA data from each turbine within the Greater Gabbard wind farm alongside measurements made at two meteorological masts were made available for the project by the operator SSE. A data set representing the 'wind farm upstream' wind direction and wind speed conditions was constructed from a selection of upstream turbines. The local mean and representative *TI* from SCADA data was calculated for the masts and turbines. Note that the local wind speed for the turbines is derived from nacelle anemometry found to provide a reasonable representation of freestream conditions. The resulting data were binned by the wind farm upstream wind speed and direction. The mean and representative *TI* by direction calculated with the Frandsen model, and the mean *TI* by direction from the CFD are compared with data. Two variants of the Frandsen model were compared.

Main body of abstract

Mast and turbine data

The wind farm investigated is Greater Gabbard, situated in the North Sea, with a layout in two sections as shown in Figure 1 comprising 140 Siemens 3.6MW turbines. The site has two met masts marked in red in Figure 1, IGMMX to the south of the Northerly section, 2.5D upstream of a turbine, and IGMMZ embedded within the Northerly section. To provide a reasonable representation of the freestream wind conditions, the freestream wind direction was calculated by averaging the yaw position of the six turbines highlighted in green in Figure 1, whilst the freestream wind speed values were calculated by averaging the SCADA measurements from these turbines when they were individually considered by direction to be in the freestream flow. The data was binned by freestream wind speed, and results are shown for the 10m/s (±0.5m/s) bin. The corresponding wind rose is shown on the right of Figure 1.

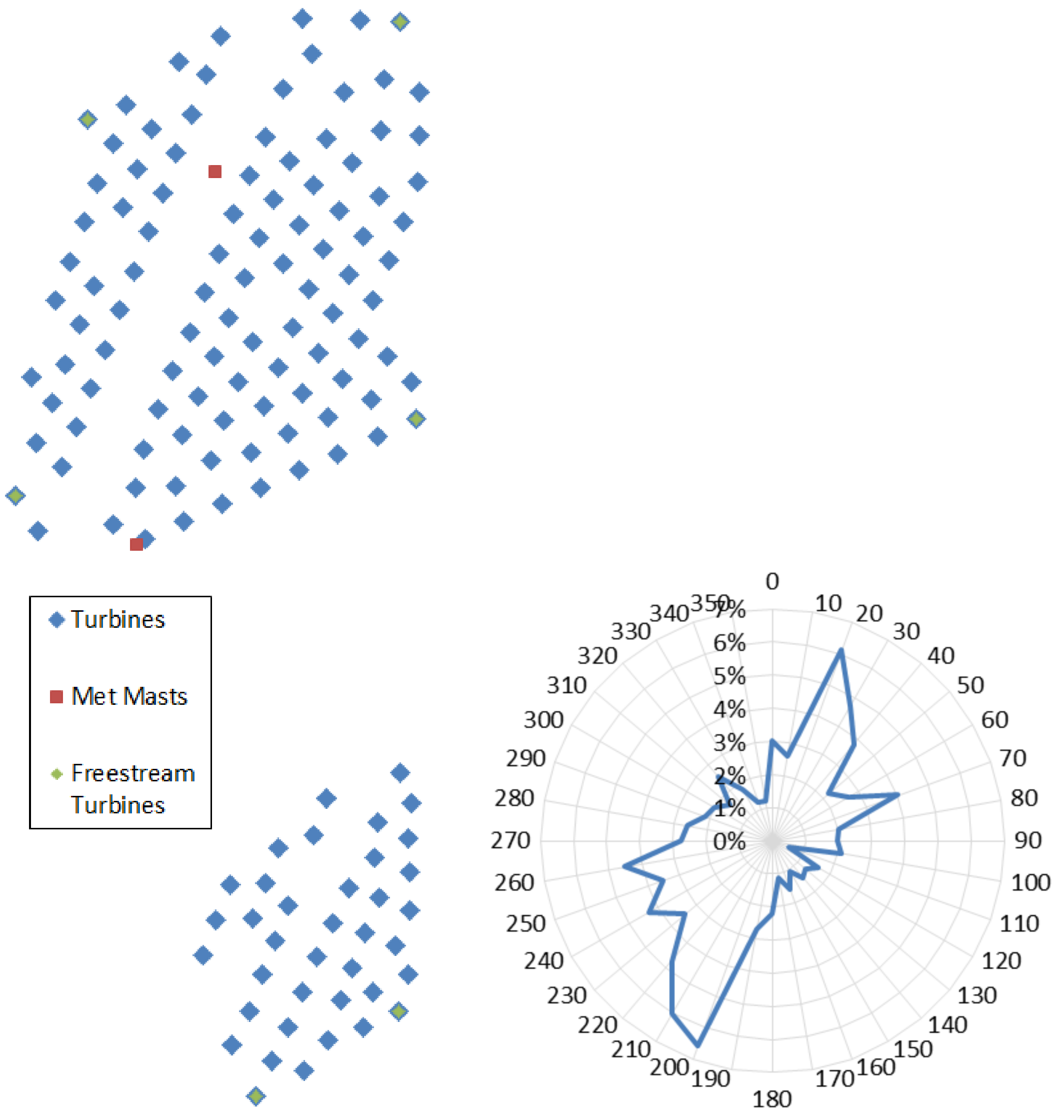

Figure 1 Layout of Greater Gabbard Wind Farm, highlighting in red the met masts and in green the six turbines used to calculate freestream conditions (left); freestream wind rose for 10m/s wind speed (right).

Frandsen TI

Frandsen describes three different methods of calculating the representative (i.e. 90th centile value of the) wind speed standard deviation, depending on the location within the wind farm with respect to wind direction, assuming a regular turbine layout. These are functions of the turbine separation, thrust coefficient, mean and standard deviation of the freestream wind speed. The first method uses ambient *TI* under freestream conditions, the second uses a wake *TI* where the location of interest is sufficiently close to a turbine (<10D) to be directly affected by its wake and the third assumes a wind farm ambient *TI* when more than 5 turbines are located upstream beyond the 10D cut-off.

The results of applying the Frandsen model are shown for the two met masts in Figure 2 and Figure 3 compared to values of *TI* measured on each mast, with freestream values also shown. The values labelled “Simplified” show *TI* calculated using either ambient *TI* for freestream directions and wake *TI* otherwise, irrespective of turbine distance (i.e. never using the wind farm ambient standard deviation).

CFD simulations

CFD simulations were carried out using ANSYS WindModeller modelling the wakes with an actuator disk method under neutral atmospheric conditions, using a *k-ε* model for turbulence. The resulting mean *TI* from the CFD is also shown in Figure 2 and Figure 3. For the results shown here, only the Northern section was modelled. Separate simulations for the entire wind farm showed that the effect of the Southern section is only minimal (increasing the TI from 5.8% to 7.1% for mast IGMMX) and only affected the sectors 130˚ to 170˚.

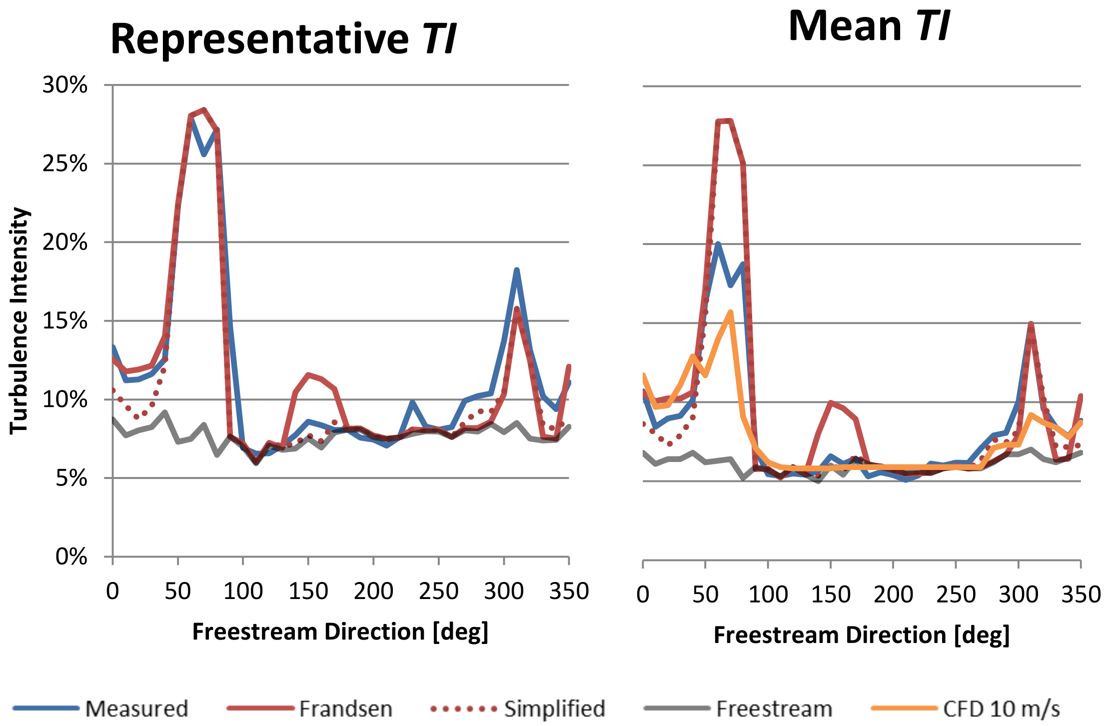

Figure 2 Representative (left) and mean (right) values of *TI* for the southern met mast IGMMX

From Figure 2, it can be seen that both the Frandsen and Simplified model provide a reasonable match to the measured turbulence values on the edge of a large farm, although they tend to overestimate the mean TI in the near wake (turbine 2.5D upstream centred on direction 60˚).

The Frandsen model over-predicts TI for directions around sector 150˚ for the wind farm ambient TI associated with the Southern section. Arguably, the wind farm ambient *TI* in the Frandsen model is not intended to cater for the effect of a separate section of the wind farm so far upstream.

The CFD model provides a reasonably good prediction of the background *TI*, which affects the majority of directions at mast IGMMX, but tends to underestimate the peak TI in the direct wake.

For directions in the direct wake of a turbine less than 10D upstream (sectors 60 and 310), the difference between the mean and representative TI from the Frandsen model is small. This may be because the calculation of the representative values in the wake only account for fluctuation of the standard deviation in the background flow and not the direct wake. The fact that the model underestimates the representative *TI* around the sector 310 (turbine 6.8D upstream) may be an indication that the representative *TI* in the direct wake should be derived in a more sophisticated way.

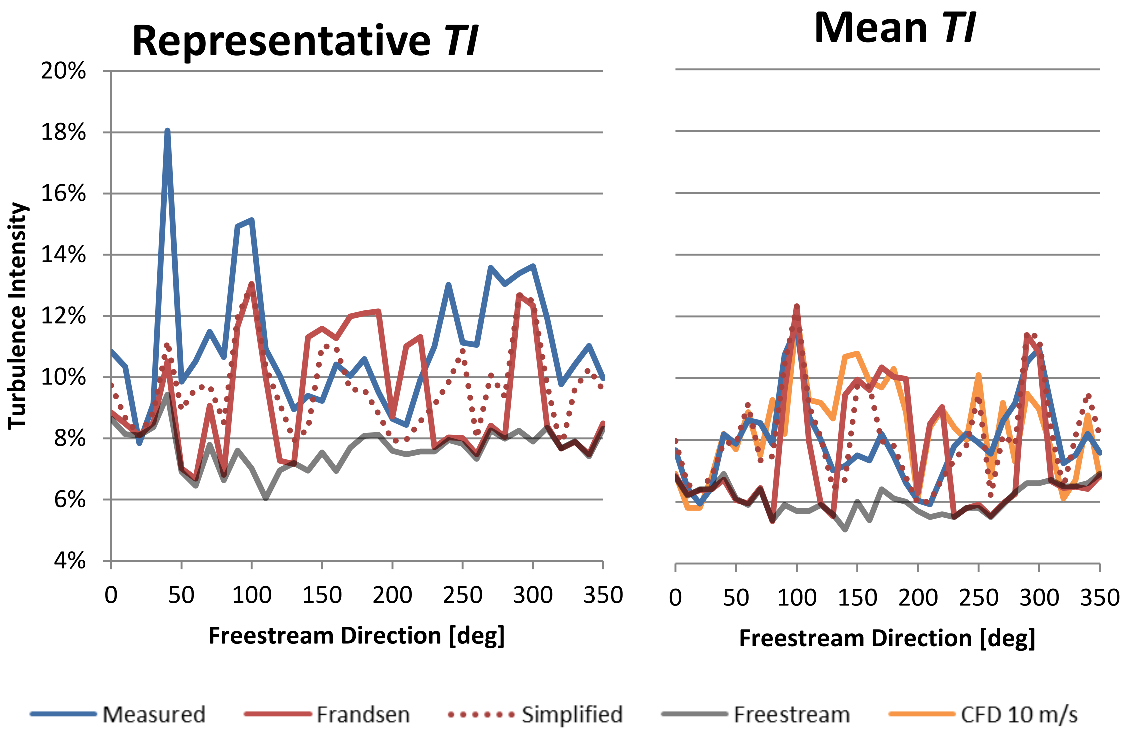

Figure 3 Representative (left) and mean (right) values of TI for the northern met mast IGMMZ

Figure 3 suggests that deep within the wind farm the simplified model predicts well the mean *TI*, except near the sector 260˚ and 330˚. The overestimation around the sector 150˚ was found to be due to reduced availability of turbine IGE06, 11.3D upstream of the mast. The Frandsen model struggles in capturing trends in mean *TI* with direction, sometimes underestimating where less than five turbines upstream are present, or overestimating for directions where the wind farm ambient *TI* overpredicts the actual *TI*.

The CFD results show a similar trend to the Simplified model, with reasonable agreement with the data, except for an underestimate of the peak at sector 300. Around sector 150˚, the CFD also produces a peak not seen in the data because of the reduced availability of turbine IGE06. Both the Frandsen and Simplified models struggle to capture the amplitude of the standard deviation of the wind speed standard deviation, underestimating the representative *TI*.

Similar comparisons will be shown in the full paper for a couple of turbines located within the wind farm. The effect of surface stability on the measured mean and representative *TI* will also be shown.

Conclusion

The Frandsen model used in the standard [2] shows reasonable prediction of the mean *TI* near the edge of a large offshore wind farm, except at short distances. Deep within the wind farm, the Simplified model appears to provide a better agreement to the mean measured values which casts doubt on the use of a wind farm level ambient turbulence intensity. Using ambient TI for directions where less than 5 turbines are located upstream beyond the 10D cut-off is also questionable as it leads to underestimated TI.

The change in values between the mean and representative *TI* seen in the data set is not captured by the Frandsen model, likely because the model only accounts for variability in the wind speed standard deviation as present in the background flow, and no variability associated with the wakes.

Acknowledgements

This work was funded by the OWA project of the Carbon Trust, and data was provided by SSE. The authors would like to thank the OWA partners and the Carbon Trust for many stimulating discussions on the work, especially Dong Energy and Paul Housley of SSE.

Learning objectives

Does the IEC standard [2] using Frandsen's work [1] accurately capture the variation in *TI* with respect to position within a large wind farm, the freestream atmospheric stability and turbine spacing. Does this model cope with non-regular wind farm layouts.

References

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