Impact of Low Level Jets on Wind Turbine Fatigue

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Motivation

Wind turbine rotor diameters are increasing as manufactures strive to improve energy capture and operators seek to reduce LCOE. This has lead to turbines being built offshore and due to tip height limits rotor ground clearance reducing onshore.

Offshore turbines will experience variation of atmospheric stability which can lead to generation of the Low Level jet phenomena. This phenomena has markedly different properties to the assumed model of the wind in the IEC 61400-1 design standard.

This work seeks to analyse the fatigue contribution which arises due to low level jets offshore and better estimate lifetime fatigue on turbines. Improved understanding of fatigue can lead to reduction of risks for operators, avoidance of over engineering and ultimately LCOE reduction.

Atmospheric Stability

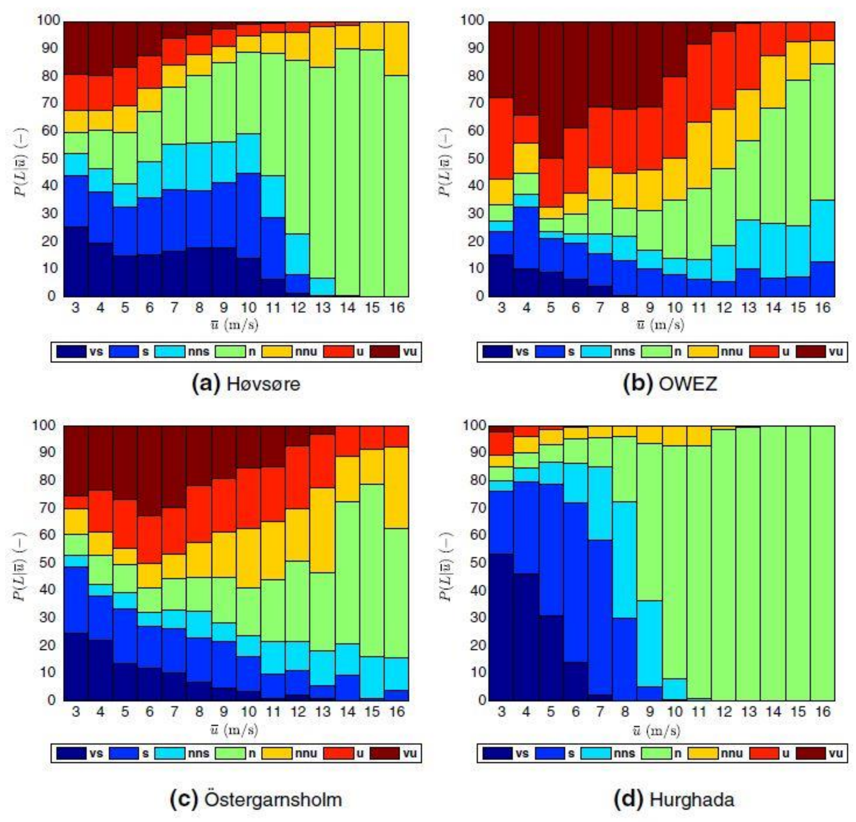

Figure 1- Histogram showing the variation of atmospheric stability against wind speed at two onshore (a and d) and offshore (b and c) windfarms [1]

Wind turbines will operate in a range of atmospheric stabilities throughout their lifetime. These can be broadly be defined as unstable, neutral and stable.

- Unstable boundary layers have high rates of turbulent mixing and have a gradient height of approximately 2km
- Neutral boundary layers
- Stable boundary layers occur when there is a temperature inversion (cold ground warmer air). This leads to buoyancy forces suppressing turbulence and a boundary layer height of approximately 200m.

Low Level Jets

In stable boundary layers the buoyant suppression of turbulence 'decouples' the sublayer from the Ekman layer and therefore the frictional force is not 'felt' higher in the boundary layer. This leads to a speed up and turning of the wind vector.

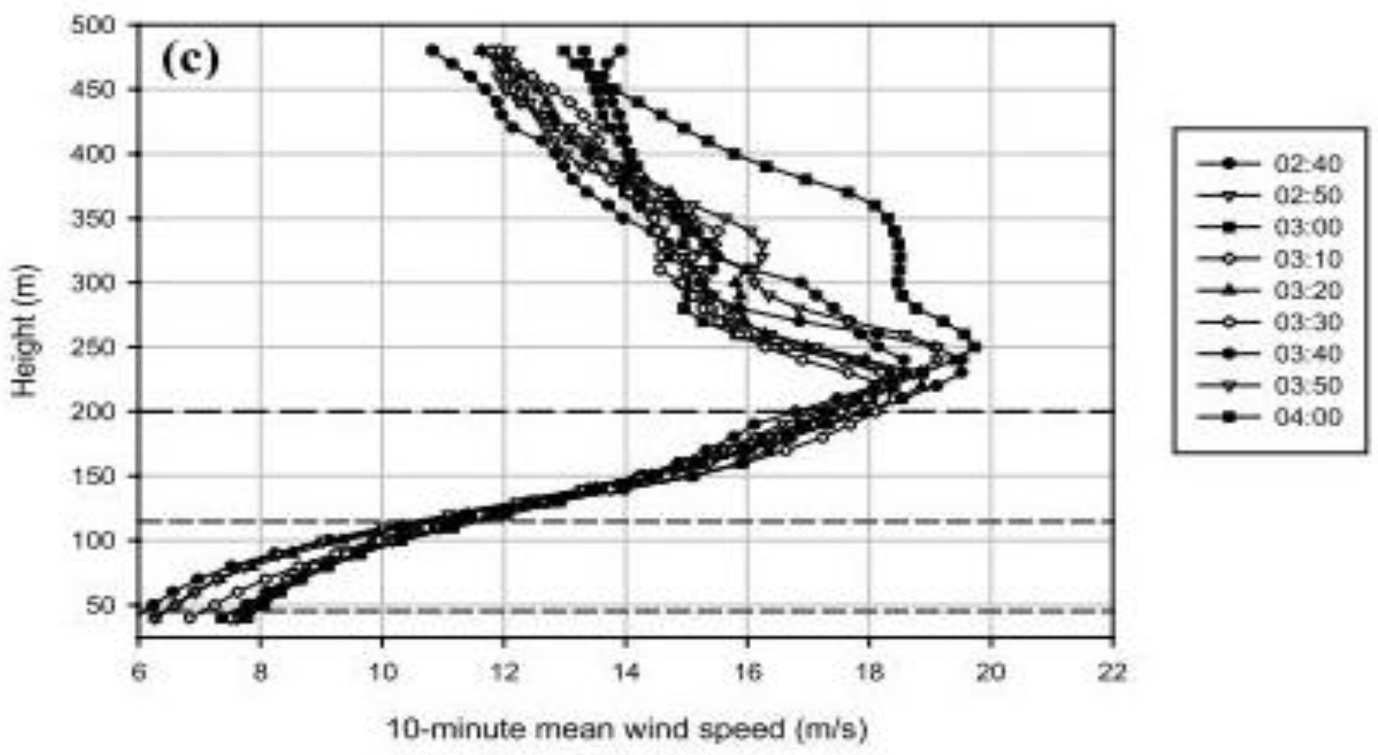

Figure 2- Low Level Jet Shear Profile [2]

Low Level Jet Properties & Implication for Fatigue

Low level jets have several key properties which are not considered by the IEC standard design load cases.

Characteristic	Impact
'Background Turbulence'	Unstable atmospheric boundary layers, with high levels of turbulence compared to stable ones, impart larger fatigue loads on the turbine tower [1].
Shear Gradient	Steep shear gradients found in low level jets impart increased fatigue loading on turbine blades. The height of the jet core also impacts blade loads with the worst case being when the jet core is at tip height.[1][3][4]
Veer	Wind directional change across the rotor is increased in a low level jet. This can impart some additional loading to the blades at 2P but there is little research into this in literature to date.
Coherent Turbulence	As opposed to background turbulence, coherent turbulent structures occur at the jet core as Kelvin Helmholtz waves build up and then burst. These structures impart high energy at high frequency into the turbine blades and can significantly increase blade loading.[2]

Research Goals

- **Offshore low level jet categorisation** – develop understanding of the behaviour of LLJs offshore. Understand their regularity, persistence, jet heights and speeds and how they relate to atmospheric stability through the Richardson number.
- **Influence of low level jet characteristics** – improve understanding of the loading impacts of each of the different characteristics of LLJs with a view to targeting mitigation techniques.
- **Lifetime Fatigue Impact** – coupling aeroelastic models of LLJ impact with the knowledge of the rate of occurrence of LLJs offshore, develop estimates of lifetime fatigue impacts for offshore turbine sites dependent on atmospheric stability variation as well as wind speed variation.

Modelling

Aeroelastic simulation of LLJs requires a precise wind inflow model, there are numerous approaches in literature:

- Spectral models (Kaimal, Mann) with defined shear profile shapes
- Measured high frequency data
- Large Eddy Simulation boundary layer models
- TurbSim stochastic inflow simulator

This work uses TurbSim and other spectral wind models coupled with low frequency averaged wind speed measurement to model low level jet behaviour. Fatigue loads for different turbine components are calculated in terms of damage equivalent load.

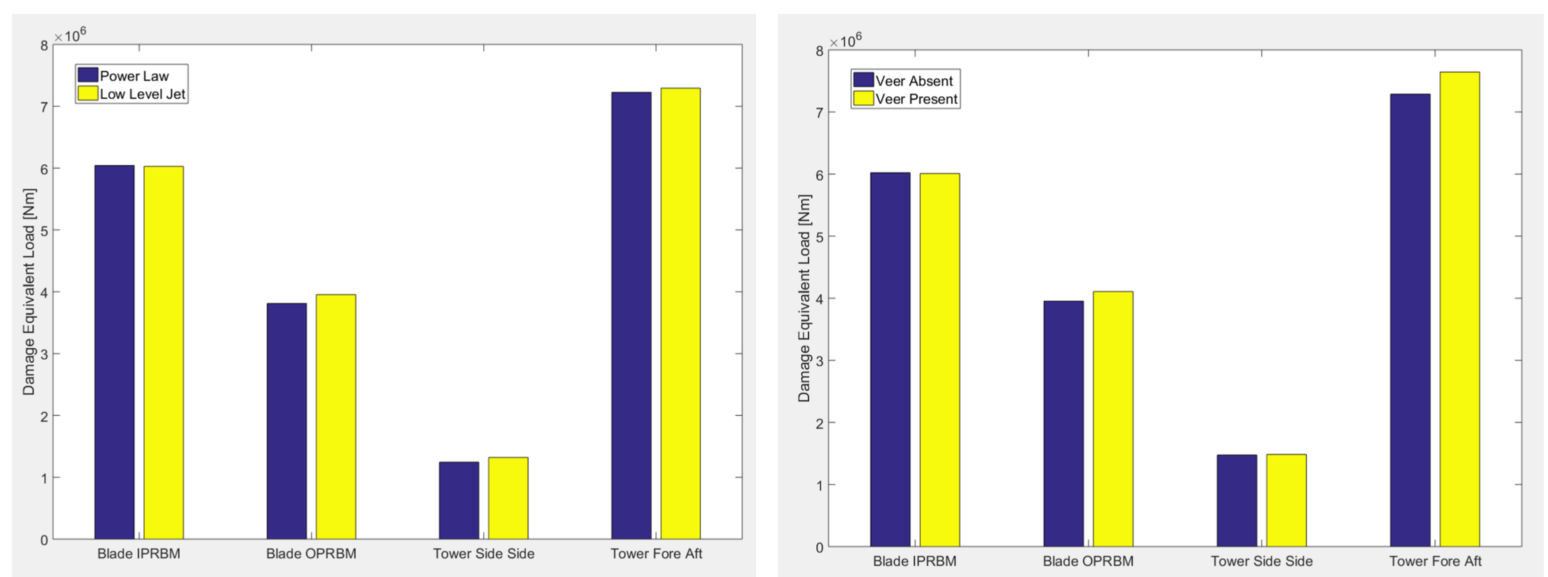

Figure 3 – DELs of turbine components when subject to (a) LLJ shear profile vs power law (b) With and without wind directional veer.

1 – A. Sathe, J. Mann, T. Barlas, W.A.A.M. Bierbooms and G. J. W. van Bussel. "Influence of Atmospheric stability on wind turbine loads". 2013. Wind Energy. 16. 1013-1032

2 – N. Kelley, M. Shirazi, D. Jager, S. Wilde, J. Adams, M. Buhl, P. Sullivan, and E. Patton, "Lamar Low-Level Jet Program Interim Report," National Renewable Energy Laboratory (NREL), Golden, CO (United States), Tech. Rep. January,2004

3 - W. Gutierrez, G. Araya, P. Kiliyanpilakkil, A. Ruiz-Columbie, M. Tutkun, and L. Castillo, "Structural impact assessment of low level jets over wind turbines," Journal of Renewable and Sustainable Energy, vol. 8, no. 2, p. 023308, mar 2016.

4 - J. Park, S. Basu, and L. Manuel, "Large-eddy simulation of stable boundary layer turbulence and estimation of associated wind turbine loads," Wind Energy , vol. 17, no. 3, pp. 359–384, mar 2014

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