Impact of Complex Wind 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 larger and larger turbines being built offshore and due to tip height limits rotor ground clearance reducing onshore.

Larger turbines will begin to encounter more complex wind conditions. Such as:

- Forestry enhanced turbulence
- Complex Terrain
- Atmospheric Boundary Layer stability – leading to Low Level Jets
- Onshore to offshore transition

Currently IEC standards assume neutral boundary layer stability with spectral representation of the wind turbulence.
This work seeks to:

- Understand in detail the complex wind conditions which occur
- Develop models of these conditions validated against measurement data
- Investigate the impact on turbine fatigue through aeroelastic modelling
- Explore mitigation techniques

Atmospheric Stability and Low Level Jets

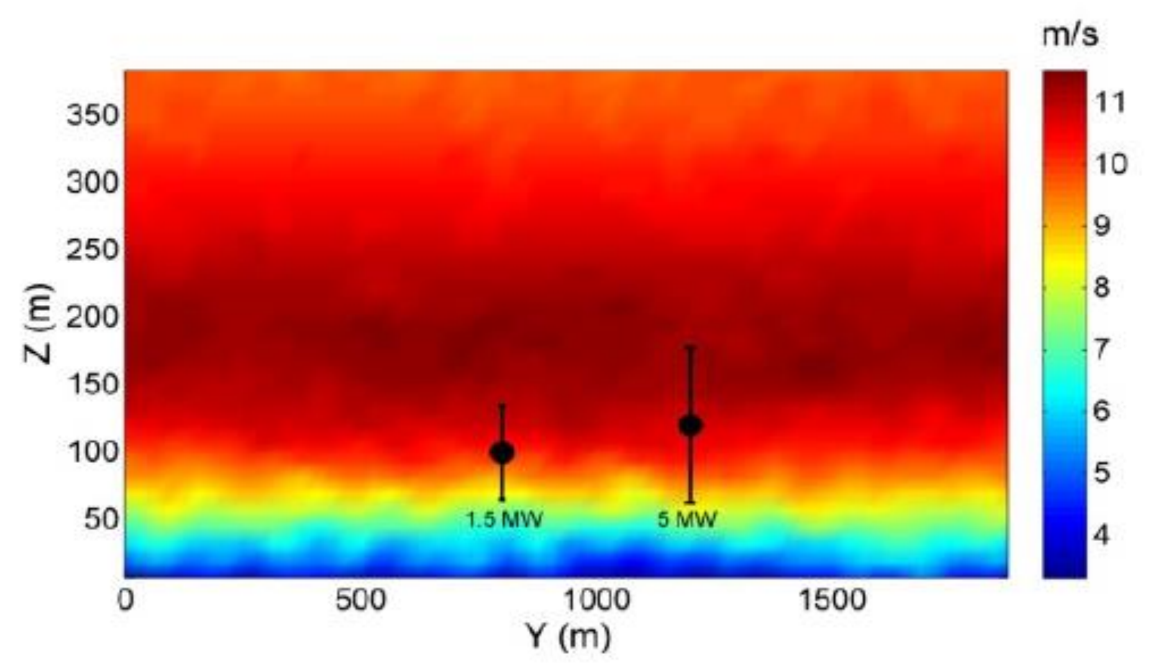

Figure 1 – Lateral cross section of a LES generated wind field with a LLJ[1]

Low level jets occur in stable atmospheric boundary layers (ABL) at heights between 100 and 1000m.[2]

- LLJs create a strong shear profile which deviates from the normal power law representation and has a negative shear gradient above the jet centre.
- Wind direction changes significantly across the rotor (wind veer).[3]
- Reduced turbulent kinetic energy (TKE) compared to neutral and unstable ABLs is also observed[4].

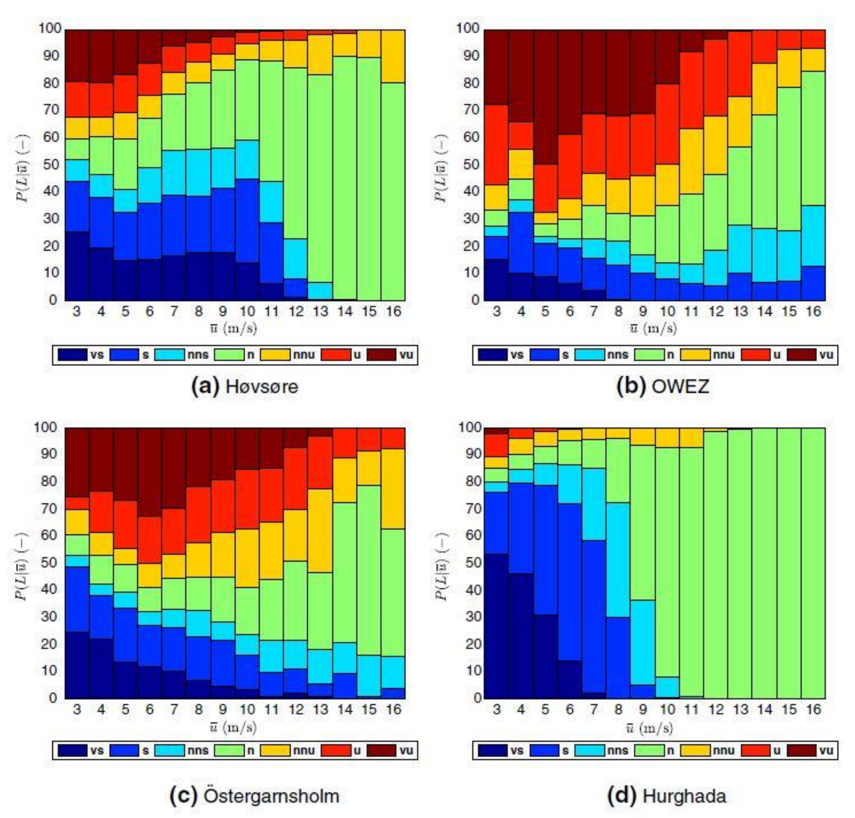

Figure 2 – Distribution of ABL Stability Across 4 different wind farm sites[5]

Load and Fatigue Implications

Blade fatigue is significantly impacted by the strong shear profile arising due to low level jets. Whereas the tower loads tend to display higher fatigue in neutral and unstable atmospheric boundary layers with higher turbulence.[3][4][5]

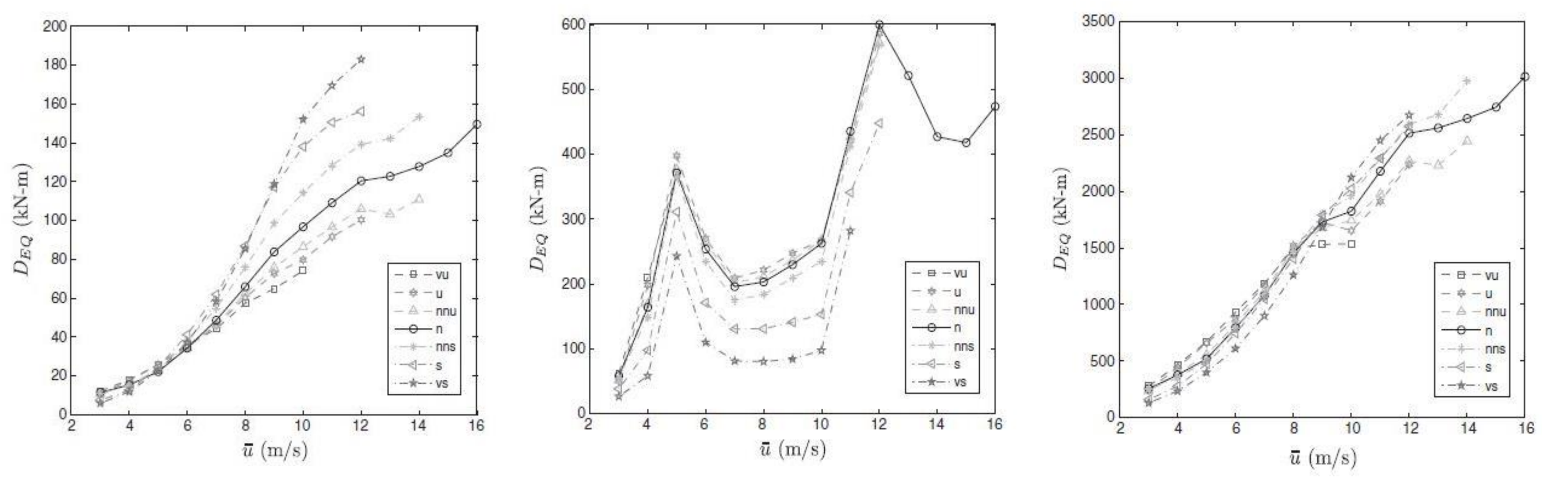

Figure 3 – Damage Equivalent Loads arising from different ABL stability conditions for a) Rotor b) Tower fore-aft c) Blade Flapwise Bending Moments[5]

Figure 3[5] shows the influence of each stability condition on Blade, Rotor and Tower loads. Demonstrating that the more turbulent unstable ABL has a large effect on tower loads while rotor loads are significantly impacted by stable ABLs – likely due to strong shear profiles arising due to LLJs.

Blade loads Seem to not be significantly influenced by stability. This could be explained due to the combination of shear and turbulence both having a loading impact. Stable atmospheres have strong shear but reduced turbulence and vice versa[3][5].

Future Work

Methods of representing non-neutral ABLs will be explored in order to model the complex wind conditions and generate inflow windfields for aeroelastic analysis.

- Chi squared fitting of Mann model to measured data[5]
- Large Eddy Simulation[3]
- TurbSim[6]

Complex terrain effects will also be investigated. Models of wind fields arising from complex terrain will be developed using measured data and CFD data from current wind farm sites where turbines are sited in locations close to trees and complex topography.
The aeroelastic response of the 5MW Supergen and 10MW DTU reference turbine, and the contribution to fatigue, of these generated wind fields will be analysed.

References

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