Influence of ABL characteristics on wind turbine wakes: surface roughness and stratification

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Abstract

Extracting energy from the wind, the wind turbine wake is generally characterised by reduced wind speeds and increased levels of turbulence. Within a wind farm array, the effects of several wakes interact resulting in reduced power generation and increased fatigue loads . Two primary mechanisms determine the decrease of momentum deficit in the wake of a wind turbine: mechanical turbulence generated by the turbine itself, which is controlled by the turbine design and performance and usually is of a relatively high frequency and small scale, and the turbulence level in the ambient atmospheric boundary layer (ABL) flow. With the latter being controlled by terrain roughness, topography, stratification, etc., the characteristic length scales as well as spectral characteristics of these two interacting mechanisms are quite different.

Wake characteristics, development and interactions are studied in the large EnFlo wind tunnel ($L \times W \times H$: $20 \times 3.5 \times 1.5$ m) at a model scale of 1:300 for a 5 MW machine with a rotor diameter of 126 m and a hub height of 90 m. Completed case studies comprise the comparison of wake development in off-shore and rural ABLs for neutral conditions (Figure 1) as well as wake interactions for small farm arrays (maximal 3 turbines) in neutral off-shore conditions.

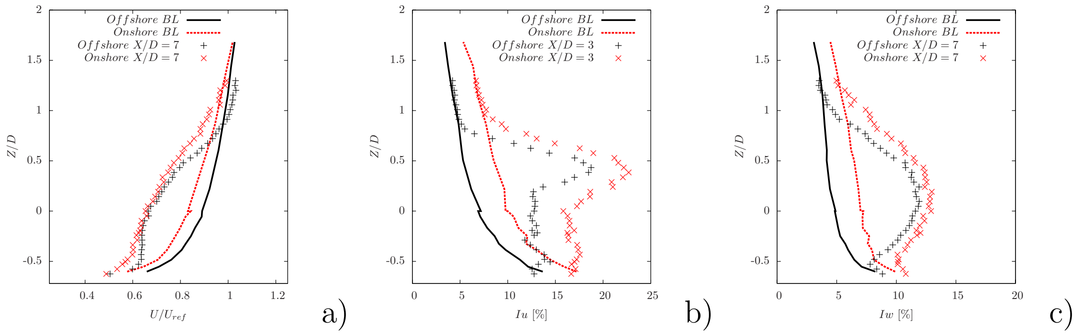

Figure 1: Comparison of wake development in off-shore and rural neutral stratified ABLs. Vertical profiles of a) mean wind, b) longitudinal and c) vertical turbulence intensities.

Neutral stability is usually considered to be the most important situation for wind energy applications, particularly with respect to turbulent wind loads on the turbine in strong winds. Nevertheless, in unstable conditions large convection cells (thermals and plumes) develop and may cause sudden gusts at low levels. While strong wind shear is found in the surface layer, changes of mean wind speed with height are small above heights of 100m due to increased vertical mixing and transfer of momentum. In stable conditions, turbulence is suppressed affecting the wind speed recovery in a turbine wake. Furthermore, the increase of wind speed with height can be large. Wind turbines are thus subject to significant asymmetric loading due to high wind shear. Non-neutral ABL conditions play a role in both on- and off-shore wind farming. Over land stability variations shoe a daily cycle while off-shore conditions tend towards a season cycle with unstable conditions in fall-winter and stable conditions in spring-summer. However, the average stratification in mid-latitudes is slightly stable. Wind tunnel studies on the influence of stratification on the wake development will commence soon and preliminary results will be presented in addition to the roughness case studies.