Proactive monitoring of an onshore wind farm through LiDAR measurements, SCADA data and a data-driven RANS solver

G. Valerio Iungo, Said El-Asha, Stefano Letizia, Vignesh Santhanagopalan and Lu Zhan
The University of Texas at Dallas, Wind Fluids and Experiments (WindFluX) Laboratory, Richardson, TX 75080
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Power production of a wind farm and durability of wind turbines are strongly dependent on complex wake interactions occurring within a turbine array. The intra-wind farm wind filed, in turn, is highly affected by the specific site conditions, such as topography, wind farm layout and local atmospheric conditions. Furthermore, contingencies throughout the life of a wind farm, such as turbine ageing and off-design operations, make predictions of wake interactions and power performance a great challenge in wind energy.

In this work, operations of an onshore wind farm are monitored through LiDAR measurements, SCADA and met-tower data. Characteristics of the incoming atmospheric boundary layer are probed through anemometers and thermistors installed at three different heights of a met-tower, which is located in proximity of the wind farm. A scanning Doppler wind LiDAR is deployed at a central location of the turbine array to measure the wind velocity field around and within the wind farm, and more specifically wind turbine wakes [1-4]. A typical velocity field measured through the wind LiDAR performing the Plan Position Indicator (PPI) scan over a conical surface with elevation angle of 3° is reported in Figure 1. A significant variability in wind turbulence and evolution of wind turbine wakes is clearly observed under different atmospheric stability regimes. Under convective conditions, higher turbulence intensity promotes mixing and flow entrainment leading to a faster wake recovery. Finally, operational conditions and power production of the wind turbines are monitored with the SCADA data.

First, we show that an efficient indicator for detection of wake interactions is the added wind turbulence at the turbine location, which is obtained as difference between the atmospheric wind turbulence at hub height and the wind turbulence measured by the nacelle-mounted anemometers. This parameter allows quantifying the significance of wake interactions on power production for each turbine, different wind velocity and direction, and atmospheric stability regime [4].

The potential wind power, which is the ideal maximum power available from the atmospheric wind field as a function of time, is estimated through five different methods and by using synergistically the available experimental data. Difference between the potential wind power and the actual power production measured through the SCADA data represents the power loss due to wake interactions. For this specific array, power losses are estimated to be 4% and 2.4% of the total power production for stable and convective atmospheric regimes, respectively. However, occurrence of power losses as high as 80% of the potential wind power are observed for specific wind turbines and wind directions.

The entire experimental dataset is then leveraged for the calibration of a data-driven RANS (DDRANS) solver for prediction of wind turbine wakes [5]. The DDRANS is based on a parabolic formulation of the Reynolds-averaged Navier-Stokes equations with boundary layer approximation, which allows achieving very low computational costs, comparable to these of wake engineering models. Accuracy in prediction of wind turbine wakes is achieved through an optimal tuning of the turbulence closure model. The latter is based on Boussinesq hypothesis and is formulated as an eddy-viscosity model, both uniform or varying in the stream- wise direction, or through a mixing length model. The optimal tuning of the turbulence model is carried out through an adjoint formulation of the RANS solver and using as objective function the minimization between the LiDAR measurements and the wake velocity field predicted through DDRANS. Results of the optimal tuning of the turbulence closure model show a strong correlation between the incoming turbulence intensity and the turbulent eddy-viscosity for wind turbines not affected by wake interactions. Furthermore, a clear dependence on the operational conditions of the turbine is also noticed, such as if turbines operate below or above rated wind speed.

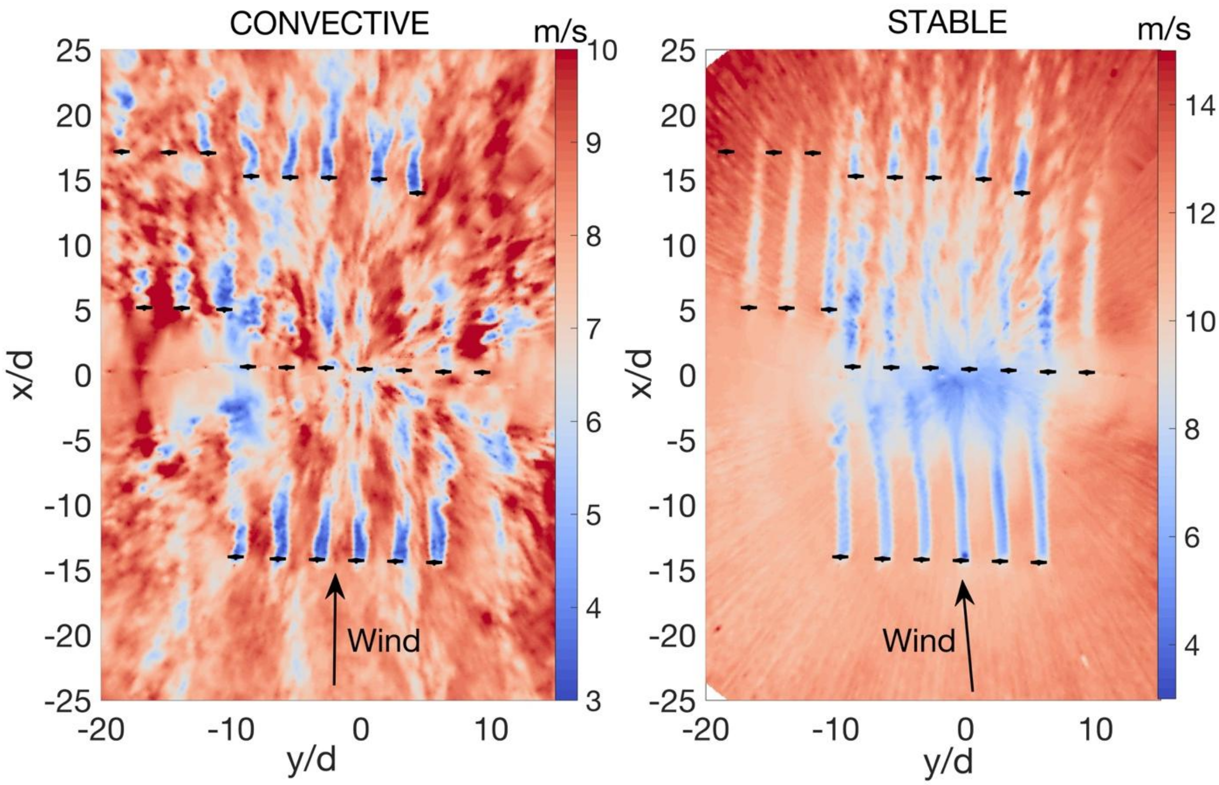

Figure 1: Horizontal equivalent velocity measured with a scanning LiDAR with the PPI technique over a conical surface with elevation angle of 3°. Measurements are carried out under different atmospheric stability regimes: (lhs) convective; (rhs) stable.

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