Detection of Wake Impingement in Support of Wind Plant Control

C.L. Bottasso[1,2], S. Cacciola[1], J. Schreiber[1]

[1]Technische Universität München, München, Germany

[2]Politecnico di Milano, Milano, Italy

ABSTRACT

Objectives

Wind turbines operating in a wind plant may be affected by the wake of neighboring wind turbines. When this happens, the affected machine experiences reduced power output and increased fatigue loading. The implementation of any control strategy to address this problem, requires the ability to detect such an interference condition. For example, Fig. 1 depicts the case of wind plant control by wake deflection; in such a case, the detection of a wake interference condition may be used to yaw the affecting wind turbine until a clean condition on the affected machine is achieved.

This paper describes a methodology to detect on a wind turbine wake impingement by an upstream machine. The detection is based on the use of rotor loads. As rotor load sensors are becoming routinely available on modern wind turbines, for example to enable individual blade pitch control, no additional sensors or equipment is necessary for the implementation of the present method. The use of rotor loads for the detection of wind conditions is a technology that has been proposed and demonstrated in [1-5]. The present work extends the technology to the estimation of the wake state.

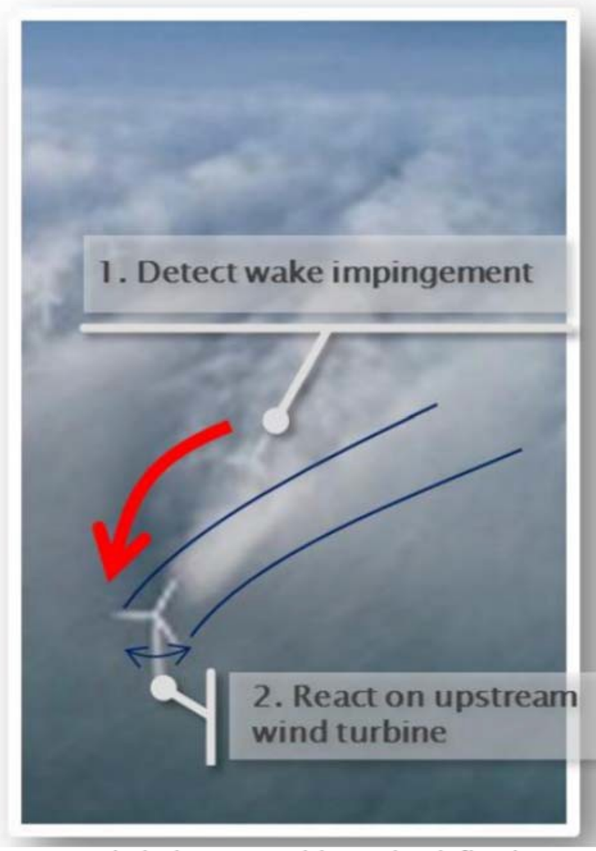

Figure 1. Wind plant control by wake deflection, supported by the detection of wake impingement.

Methods

At first, a new rotor-effective wind speed estimator is developed, based on the out-of-plane cone (i.e. averaged over the number of blades) bending rotor loads. From the cone loads measured at each time instant, an estimate of the rotor-effective wind speed may be obtained by the use of a Kalman filtering approach. Such a method delivers estimates of the wind speed and turbulence intensity of good accuracy and robustness with respect to the tuning parameters of the filter, as shown in Fig. 2.

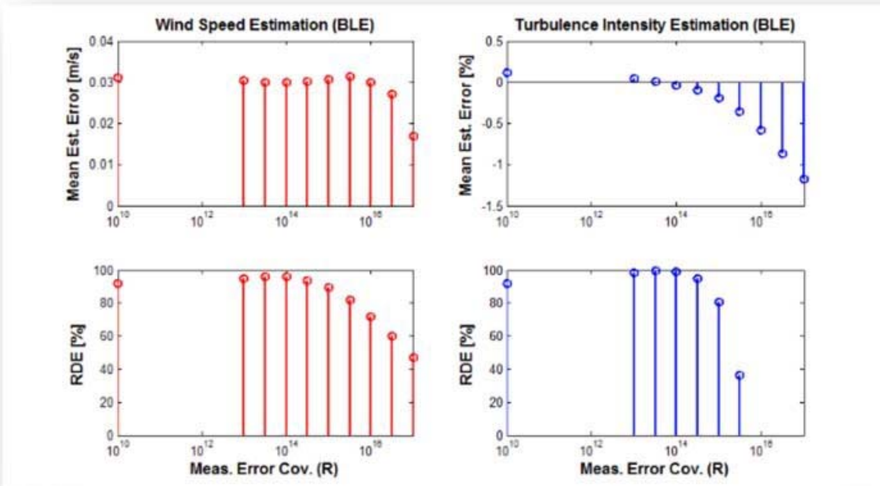

Figure 2. Estimation of rotor-effective wind speed (left) and turbulence intensity (right): mean estimation error (top), and relative degree of explanation (RDE) [6] (bottom).

Next, the method is specialized to the estimation of wind speed on sectors of the rotor disk. The concept is illustrated in Fig. 3, which shows how the passage of a blade over a disk sector can be used for estimating a sector-effective wind speed and turbulence intensity.

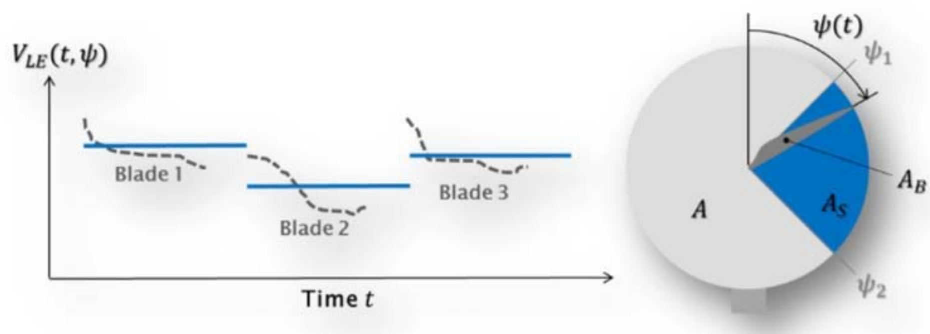

Figure 3. Estimation of local-effective wind speed and turbulence intensity, from the loads of a blade passing through a rotor disk sector.

Results

At first, the new method was tested using field test data on the NREL CART 3 wind turbine [7]. As no known wake interference condition of that machine with other wind turbines was available for this study, the local wind estimation method was used to estimate the different velocities in the top and bottom quadrants of the rotor, which gives an idea of the vertical wind shear. The comparison between estimated and measured values can only be qualitative, because only the values of the top and bottom met-mast anemometers is available, which are hardly comparable to the sector-effective wind speed estimates. Nonetheless, as shown in Fig. 4, the method follows reasonably well the trend of the met- mast anemometers and it is capable of consistently detecting a higher wind speed on the top than in the bottom quadrants.

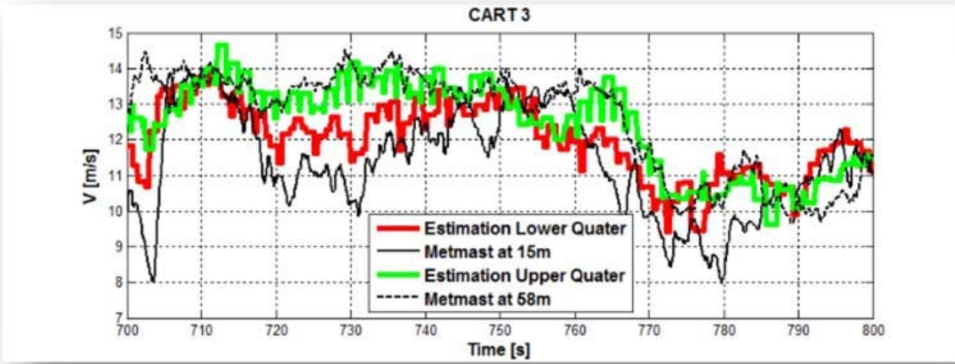

Figure 4. Estimation of top and bottom quadrant effective wind speeds, and comparison with met-mast data for the NREL CART 3 wind turbine.

Finally, the new method was used for estimating the local wind speed separately on the left and right parts of the rotor, thereby detecting the possible presence of an area of reduced speed and increased turbulence intensity, which may indicate the presence of a wake. As no experimental data was available for this case, a simulation study was conducted, by using a high-fidelity aeroservoelastic model [8] of a multi-MW wind turbine operating in different partial and full wake conditions. The results are summarized by Fig. 5, which shows the actual and estimated local wind speeds in two lateral quadrants of the rotor. Each subplot refers to a different overlap indicated by the lateral distance between the rotor and the wake center.

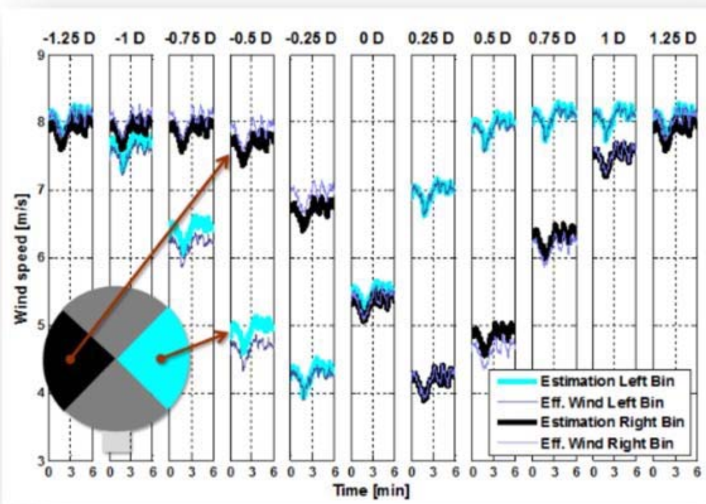

Figure 5. Estimation of local wind speed on two lateral rotor quadrants.

Conclusions

As well illustrated by the results shown here, the proposed method is capable of estimating with good accuracy the local wind speed and turbulence intensity, and in particular it is able to detect variations of these quantities on the two sides of the rotor that may be indicative of a wake interference condition. Similar results can be derived for various wind conditions, demonstrating the robustness of the local wind speed estimator. The new wake detector is currently being used for driving wake deflection strategies by active wind turbine yaw.

References

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