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Evaluation of wind flow with a nacelle-mounted continuous-wave lidar

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Introduction

Nacelle-mounted lidar is becoming widely recognized as a tool with potential for assessing power curves, understanding wind flow characteristics, and controlling turbines.

As rotor diameters continue to increase, and the deployment of turbines in complex terrain becomes more widespread, knowledge of the incident wind field beyond the hub height mean speed and direction become essential. This is reflected in the development of the concept of rotor-equivalent power curves. A circularly-scanned, continuous wave lidar can provide a wealth of such information.

It is believed that the experiment described here represents the first time that a commercially available turbine-mounted lidar has been used to derive rotor equivalent power curves.

ZephIR DM

The "dual-mode" ZephIR DM is capable of both vertical, ground-based, and horizontal, turbine-mounted operation. In turbine-mounted mode it measures 50 line-of-sight velocities around each 1-second circular scan, at user-selected measurement ranges. Real-time sensors in the ZephIR record inclination, roll and velocity to allow measurement correction for nacelle movement.

This wealth of lidar data enables different processing methods to be applied and optimised. Measurements at different heights allow wind shear and veer to be assessed and enable rotor-equivalent wind speeds to be derived for generation of more representative power curves.

Experiment description

A ZephIR DM lidar was installed on the nacelle of a Nordtank 550 kW turbine with a 41 m diameter rotor (Figure 1) on the Risø campus of the Technical University of Denmark (DTU) from December 2012 until April 2013.

A well-instrumented met mast was situated 92 m (approximately 2.2 rotor diameters) from the turbine base (Figure 2). The ZephIR was configured to measure at a range of 90 m to facilitate comparison with the cup anemometers on the mast.

SCADA data from the turbine was recorded, along with wind measurements from the mast instruments and the ZephIR, to enable calculation of power curves.

Figure 1: ZephIR DM mounted on nacelle of turbine at DTU Risø Campus

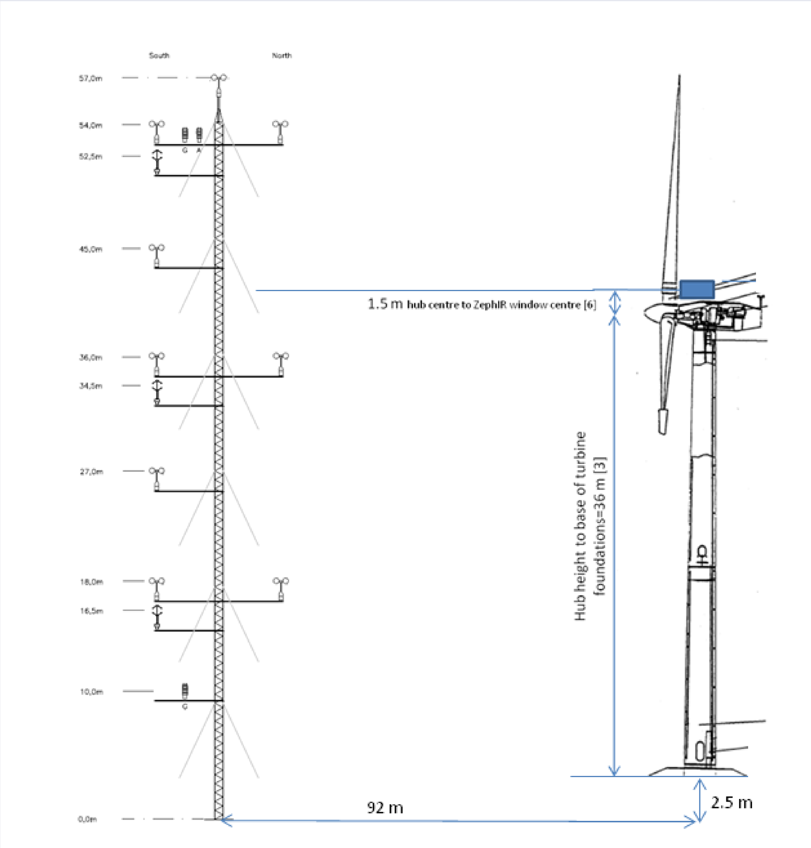

Figure 2: Turbine and mast layout

Wind shear and veer

Figures 3 and 4 show ZephIR-measured wind profiles across the rotor from a typical day in the deployment. Five measurement heights were considered: 19.6 m, 27.8 m, 36 m, 44.2 m and 52.4 m, although the ZephIR data can be processed to give results at any required number of heights.

The figures show that there was a relatively small level of shear and veer across the rotor during the trial, which is to be expected with such a small rotor.

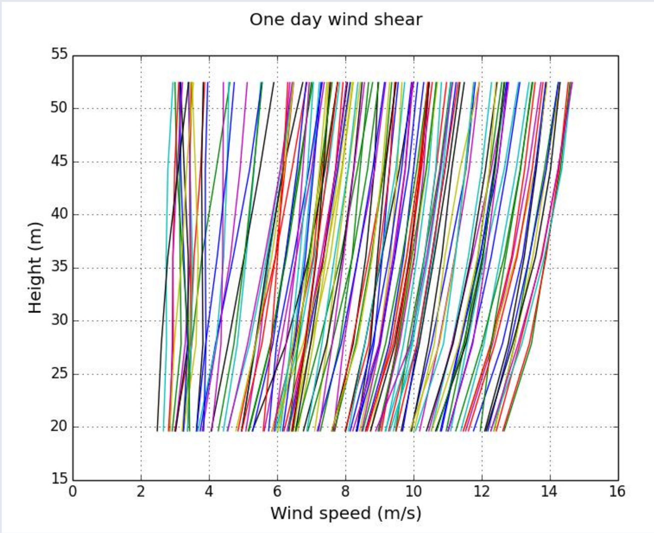

Figure 3: One day's wind shear

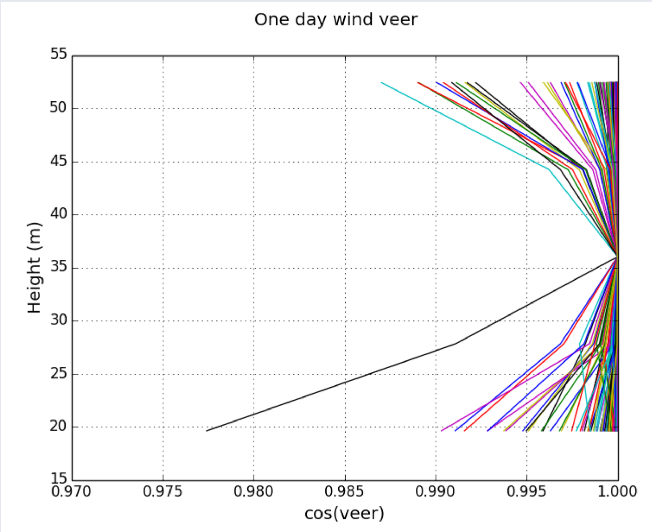

Figure 4: One day's wind veer (relative to hub height)

Correlation against mast

Figure 5 shows that the hub height wind speeds measured by the ZephIR were in very close agreement with those measured by the cup anemometer at 36 m on the mast, with a regression slope within 0.5 % of unity.

The concept of a rotor-equivalent (RE) wind speed has been proposed as a tool for calculating power curves that are more robust to variations in shear and veer than those based purely on hub height wind speeds [2]. RE wind speeds were calculated from the ZephIR measurements at the above 5 heights, taking account of wind veer. A plot of the correlation of these RE speeds against the mast hub height speed is shown in Figure 6. In this case the regression statistics were very close to those for the hub height ZephIR measurements, which is consistent with the low levels of shear and veer seen in Figures 3 and 4.

It is well known that a lidar measures turbulence intensity (TI) on a different scale to a cup anemometer, primarily due to volume-averaging effects. Figure 7 compares the TI of the horizontal wind component measured by the ZephIR at hub height with the TI of the wind speed measured by the anemometer on the mast. The regression slope of 0.917 shows how ZephIR's volume-averaging reduces the measured TI.

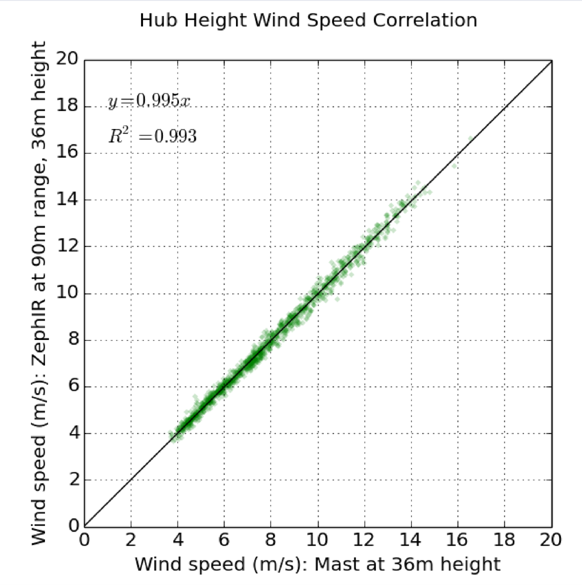

Figure 5: Hub height speed correlation:

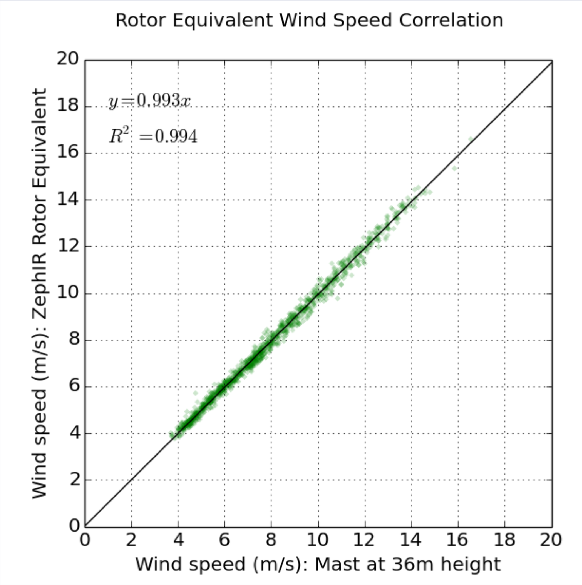

Figure 6: RE speed correlation:

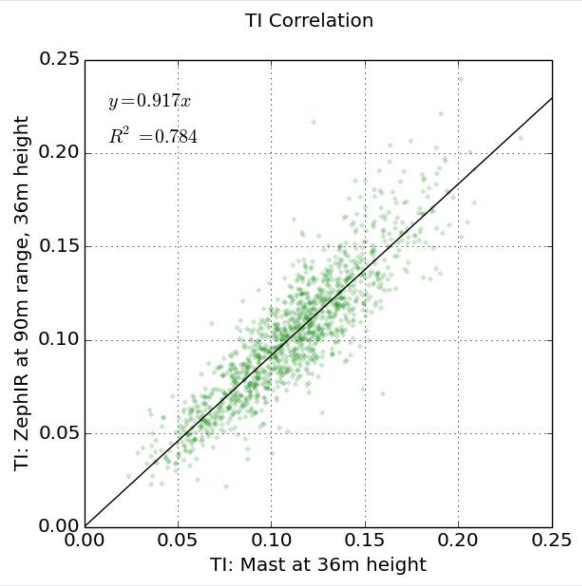

Figure 7: TI correlation:

Power curves

RE wind speeds derived from the ZephIR measurements were combined with SCADA data from the turbine to produce the power curve shown in Figure 8. The red line and markers show the bin-averaged powers while the green diamonds show the scatter in the 10-min averaged power measurements.

The bin-averaged RE power curve is compared with a standard power curve derived from the hub height cup anemometer measurements in Figure 9. They are very close, with the ZephIR's power curve shifted slightly to the left, consistent with the regression slope of less than unity in Figure 6.

The hub height mast and ZephIR TIs were used to normalise the respective power curves to a reference zero TI condition following the procedure described in [1]. Figure 10 shows that these normalised power curves are in close agreement, suggesting that it is appropriate to use the ZephIR TI to normalise ZephIR data. This zero TI power curve can then be corrected to any required reference TI.

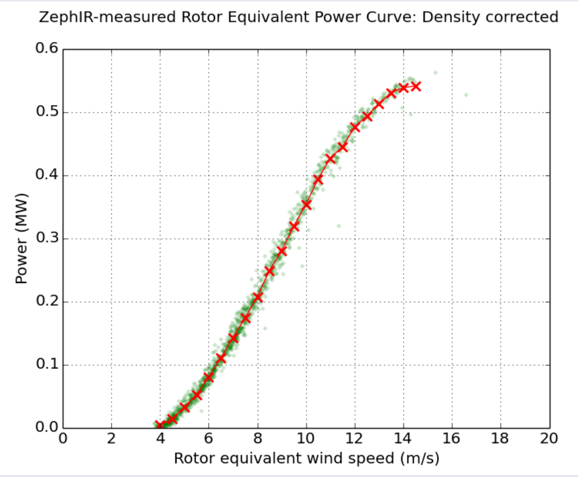

Figure 8: Power curve: ZephIR RE

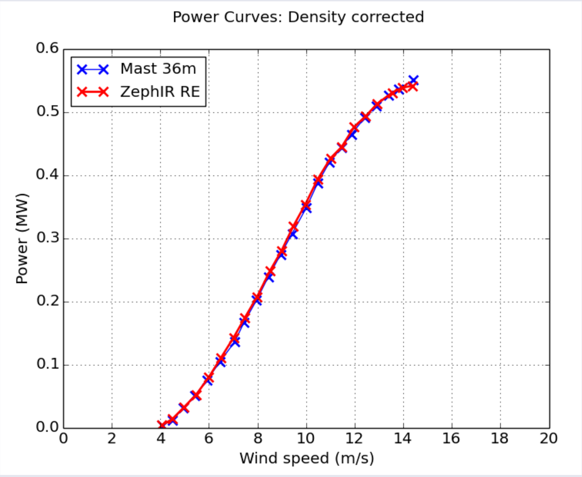

Figure 9: Power curves: ZephIR RE and Mast

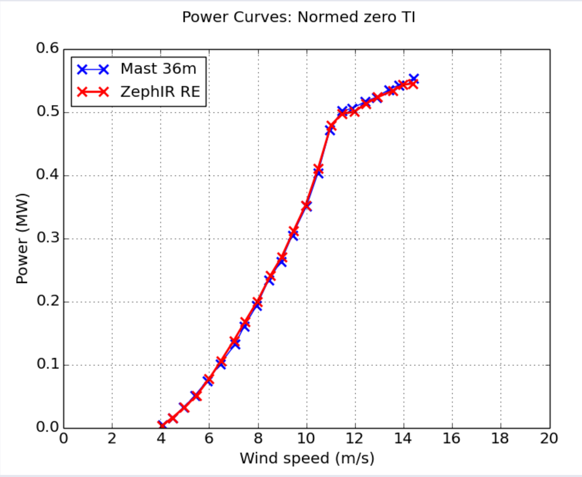

Figure 10: Power curve: ZephIR zero TI

Conclusions

The results presented indicate that high fidelity turbine-mounted measurements of several characteristics of the wind flow can be obtained with a scanned, continuous wave wind lidar. The technique for evaluating power curves that account for wind shear, veer and turbulence has been shown to be suitable, at least in the prevailing conditions during the period of the trial.

The reliability of the measurement data and the full coverage of the wind turbine rotor area improve confidence in the application of this technique for other critical tasks, such as turbine control for fatigue load reduction and power output enhancement.

References

1. **Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines, Draft IEC guidelines: IEC 61400-12-1 CDV, February 2013.**
2. **Wagner R, Courtney M, Gottschall J, Lindelö-Marsden P. Accounting for the speed shear in wind turbine power performance measurement. Wind Energy 2011; 14; 993-1004.**

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