Power curve measurement using nacelle lidar estimates of V_∞ and its uncertainty

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Topic: Resource assessment

I. Introduction

Nacelle-mounted nacelle lidars offer an attractive opportunity to assess a wind turbine's power performance. Their usefulness in power curve verification is twofold: cost-efficiency and enhanced representativity of wind measurements.

The procedures for the measurement of a turbine's power curve are detailed in the IEC61400-12-1, edition 2 (2017) standards. One key element is the wind speed measuring instrument. In the latest standards, it is allowed to use either mast-mounted cup or sonic anemometers, a ground-based remote sensing device (usually a lidar or sodar), or a combination of both – but not a nacelle lidar. The measurements shall be taken at a distance between two and four rotor diameters (D) upstream, usually recommended to be $2.5D$. For multi-megawatt turbines, $2.5D$ corresponds to 300-500m. At such a distance, signal decorrelation issues arise between the wind speed and power measurement signals. Moreover, the wind at $2.5D$ can still be significantly affected by the turbine(s) operation. These problems can be solved by using nacelle lidars instead.

We have developed an innovative and robust methodology challenging the need to take measurement at 2.5 rotor diameters upstream as recommended by the IEC 61400-12-1. Instead, the free stream wind speed V_∞ is estimated from nacelle lidar measurements taken close to the rotor. The method has been applied to experimental data from two different nacelle lidars (a ZephIR Dual Mode (ZDM) from *Zephir Lidar* and a 5-beam Avent Demonstrator (5B-Demo) from *Avent Lidar Technology*) mounted on a multi megawatt turbine in flat terrain. In this study, we demonstrate how nacelle lidar estimates of the free stream wind speed V_∞ can validly be used to measure a turbine's power curve.

II. Approach

With the new method we developed, free stream wind speed and direction is retrieved from lidar line-of-sight velocity (V_{los}) measurements at shorter range, i.e. 0.5 to 1.25D. The lidar measurements are combined with a simple induction model in order to reconstruct free stream wind field characteristics (speed, direction, shear and induction factor[1]). The horizontal wind speed retrieved with the new method at hub height at 2.5D upstream was on average within 0.7% of standard mast mounted cup anemometer measurements (see Fig. 1).

The lidar estimates of V_∞ are then used to measure the power curve of the tested turbine. Furthermore, we derive power curve uncertainties and the annual energy production (AEP) for the two lidars. Results are compared to those obtained with the mast-mounted cup anemometer.

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[1] Borraccino A., Schlipf D., Haizmann F. and Wagner R., Wind field reconstruction from nacelle-mounted lidar short-range measurements, *Wind Energy Science*, 2, 269-283, doi:10.5194/wes-2-269-2017, 2017.

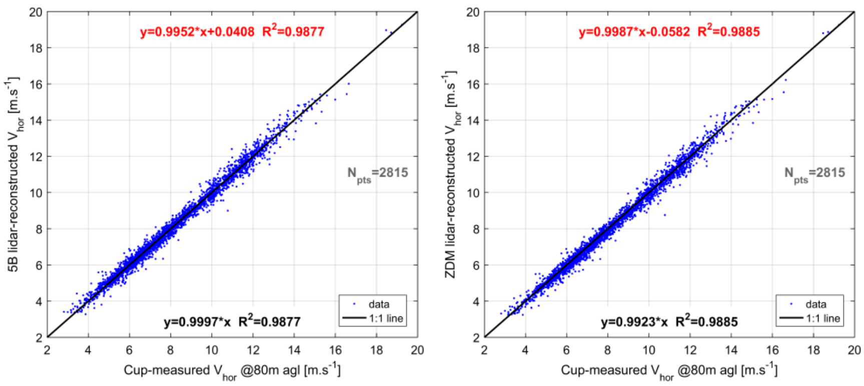

Figure 1: Comparison between mast-measured and lidar-estimated horizontal wind speed at hub height and 2.5D upstream using short-range measurements. **Left**: 5B-Demo lidar. **Right**: ZDM lidar.

III. Results

The power curves measured by the two nacelle lidars and the mast-mounted cup anemometer are presented in the form of scatter plots of the 10-minute data (Fig. 2) and using the method of bins (Fig. 3).

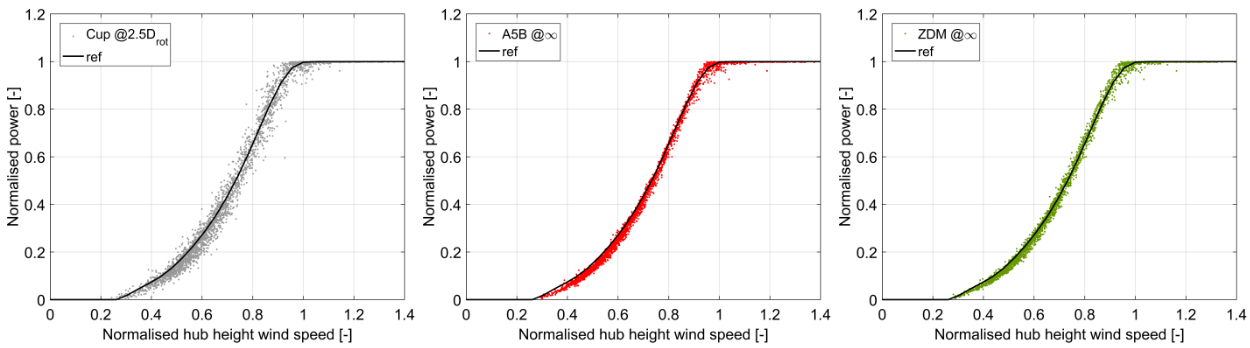

Figure 2: Measured power curves (10-min data). **Left**: mast-mounted cup. **Middle**: 5B-Demo lidar, using V_∞ estimates. **Right**: ZDM lidar, using V_∞ estimates.

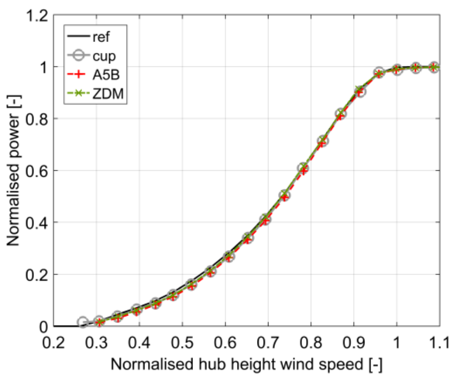

Figure 3: Measured power curves (binned data).

The measured power curves using the nacelle lidar-estimated free stream wind speed V_∞ are negligibly different from the one measured using the mast-mounted cup anemometer. Moreover, the scatter in the power curves measured by the nacelle lidar is significantly reduced, which is considered a significant benefit of using nacelle lidars.

IV. Conclusions

This study demonstrates how nacelle lidar measurements can be used for estimating the (true) free stream wind speed. In contrast, the wind speed measured by a mast or a ground-based lidar at 2.5D is only an approximation of the free stream wind speed. The power curve was accurately measured, showing the valid application of the method for power performance verification. Power curve verification no longer requires wind measurements at 2.5D upstream.

At 8 m/s mean annual speed (Rayleigh distributed), the AEP derived from the power curve measured using the nacelle lidar measurements was within 1% to the one obtained with the mast-mounted cup anemometer.

The benefits of using nacelle lidar measurements taken close to the rotor for power curve measurements are numerous. Among others, it obviates the need for horribly expensive tall masts – especially offshore, it overcomes range limitations of the nacelle lidars and increase the data availability, and it provides wind speed estimates correlating well with the turbine power output signals due to the short distance.

It is anticipated that the method can also apply in moderately complex terrain, where induction effects close to the rotor dominate over terrain ones. Further work will thus involve testing the technique in complex terrain. For this purpose, two full-scale measurement campaigns in complex terrain planned in 2017 within the UniTTe project will provide the necessary experimental data.

V. Learning objectives

During the presentation, the audience will learn:

- How to estimate free stream wind speed from profiling nacelle lidar short-range measurements
- What are the issues inherent to the standard procedures for testing the power performance of the turbine
- How to perform power curve measurements using nacelle lidars, how to assess power curve uncertainties
- How the lidar-based measured power curve compare to standard mast-mounted instrumentation
- What is the effect of measuring at 2.5D or using the free stream wind speed V_∞ in terms of AEP.