DTU Vindenergi

Nacelle based lidar for performance verification

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Preface

The present summary report is the final report on the EUDP research project “Nacelle lidar for power curve measurements” with the acronym “NacelleLidar”. The project was financed by EUDP, Energiteknologisk Udviklings- og Demonstrations Program (EUDP-2009-II, J.nr. 64009-0273). The project was implemented in a cooperation consortium between DTU, Leosphere (nacelle lidar activities changed name to Avent Lidar Technology), Siemens Wind Power A/S and DONG Energy A/S.

Risø Campus, February 2013

Troels Friis Pedersen

Content

Abstract

The objectives of the project were to develop and commercialize nacelle-LIDAR technology for power performance verifications. The project included technological development of the nacelle lidar technology, development of procedures for power performance measurements in relation to IEC61400-12-1 [1], demonstration of the testing procedures that show the use of a nacelle-based LIDAR, and dissemination of the results of the project. At the start of the project a prototype nacelle lidar was used for initial experiments on a wind turbine located at the Høvsøre test site. At these tests inclinometers were mounted in the lidar, and calibrations were made. Measurements on the turbine were related to mast measurements. On the basis of the IEC61400-12-1 standard power performance measurement procedures were developed to substitute the nacelle lidar with the met mast. Procedures for traceable calibration of the wind speed measurements with the nacelle lidar against a 10m met mast were also developed. With an improved and commercialized lidar the procedures were verified on another offshore wind turbine at Avedøre, where also comparisons to a met mast were made.

1. Introduction

The objectives of the project were to develop and commercialize nacelle-LIDAR technology for power performance verifications such that the expensive and often difficult use of met masts offshore and in complex terrain is avoided. The project included technological development of the nacelle lidar technology, development of procedures for power performance measurements in relation to IEC61400-12-1 [1], demonstration of the testing procedures that show the use of a nacelle-based LIDAR, and dissemination of the results of the project.

2. Product development

At the start of the project Leosphere (Avent Lidar Technology) had developed a prototype two beam lidar for nacelle based measurements, see figure 1. This lidar was mounted at a Siemens wind turbine at Høvsøre test site for experimental work in order to develop the power performance measurement procedure. For these experiments two inclinometers for tilt and roll were built into the lidar and integrated with the lidar beam optics in order to keep control of lidar beam orientation. The experience of the experiments with the prototype lidar was used by Leosphere (Avent Lidar Technology) to develop a commercial nacelle lidar being marketed as "wind iris". This revised nacelle lidar was then used in the demonstration of the developed power performance measurement procedure, see chapter 4. At the end of the project the "wind iris" nacelle lidar had been marketed substantially by Avent Lidar Technology, and several commercial units had been sold, see web site in reference list [2]. Prototype and developed lidar are shown in figure 1.


Figure 1 Prototype Leosphere nacelle lidar to the left, and production wind iris nacelle lidar from Avent Lidar Technology on the right

3. Measurement procedure development

Inclinometers were fitted to the lidar optical heads, and they were calibrated on ground before installation of the prototype nacelle lidar on the nacelle with a fitting. The experiments on the Siemens wind turbine at Høvsøre started 9 June 2010, see figure 1, and a measurement campaign continued until 11 January 2011. The nacelle lidar measurements were related to hub height mast measurements. The results of the Høvsøre experimental were presented at the EWEA conference in 2011, see Wagner [3], and an article was submitted to Wind Energy [4]. The results were used to develop the nacelle lidar concept, see figure 1 right. The results were also used to develop the measurement procedure in relation to the IEC61400-12-1 standard, see [5]. All deviations to the standard were identified, and methods to meet the requirements despite the deviations were developed. Some of these deviations are shown in the following.

A major deviation from the IEC standard is that the mast is replaced with lidar beams at the same distance as the mast, but the lidar beams will change position as the turbine yaws. A graphical representation of the set up of a two beam nacelle based lidar for power curve measurement can be seen in Figure 2 and 3. Characteristics of the setup is that the beams must point a little bit downwards due to the installation on the nacelle, and due to the fact that the wind turbine tilts due to the thrust on the rotor during operation. The inclinometers in the nacelle lidar must keep track of these movements with an accuracy of 0.1° in order to keep the wind measurement at the right height.

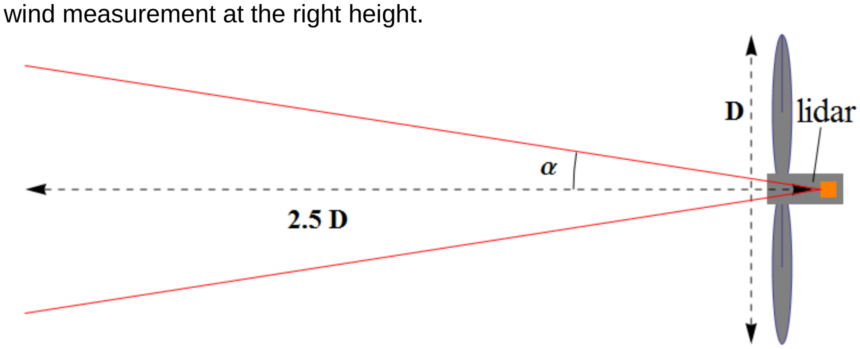

Figure 2 Top view

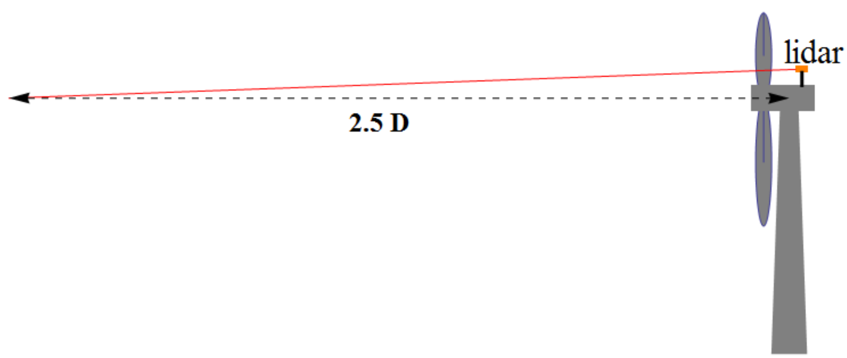

Figure 3 Side view

The wind sector to exclude due to wake of other wind turbines or obstacles, defined as in IEC 61400-12-1, will be restricted so that none of the two lidar beams are affected. This requirement has to be considered for all potential positions of the lidar beams.

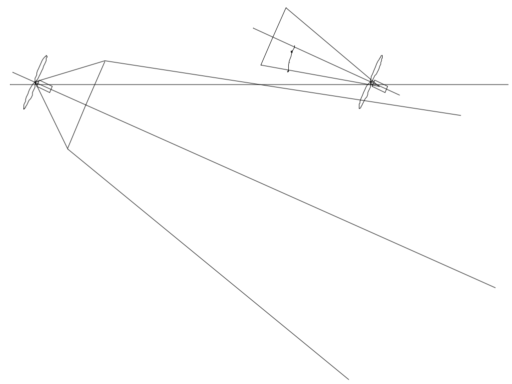

Figure 4 Example of sector exclusion from neighbouring turbine (turbine under test to the right)

As long as the total beam opening angle of the lidar is smaller than 30 degrees, the sector to be excluded is revised as.

$$\alpha L = 1.3 Arctan\left(2.5\ \frac{Dn}{Ln - Lb} + 0.15\right) + 10 \qquad (1)$$

Where D_n is the rotor diameter of the neighbouring turbine, L_n the distance to the neighbouring turbine and Lb is the lidar measurement range.

A calibration method to compare the lidar measurements with a traceable cup or sonic anemometer was developed, see Courtney [6]. The method first has to verify the positioning of the lidar beams. The geometry considered is shown in figure 5.

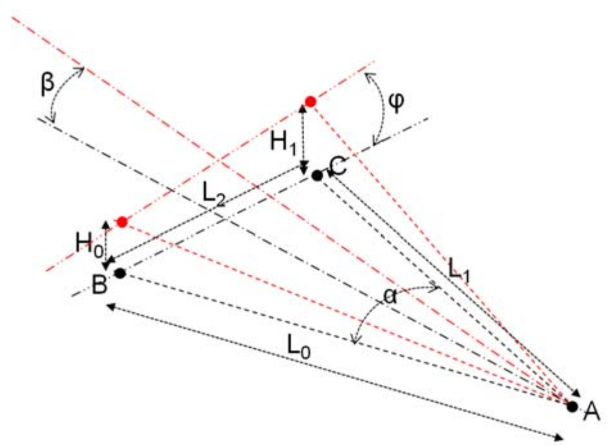

Figure 5 A tilted and rolled lidar beam (red) shown in relation to the zero position (black). Point A represents the beam origin, points B and C the detected position of beam 0 and beam 1at distances L_0 and L_0 respectively. Due to the tilting (angle β) and the rolling (angle φ), the beam 0 and beam 1 positions are lifted by heights H_0 and H_1 respectively.L2 is the distance between the detected

The setup for calibration against a sonic anemometer is shown in figure 6. The method project the sonic measurements on to the lidar beam direction for comparison.

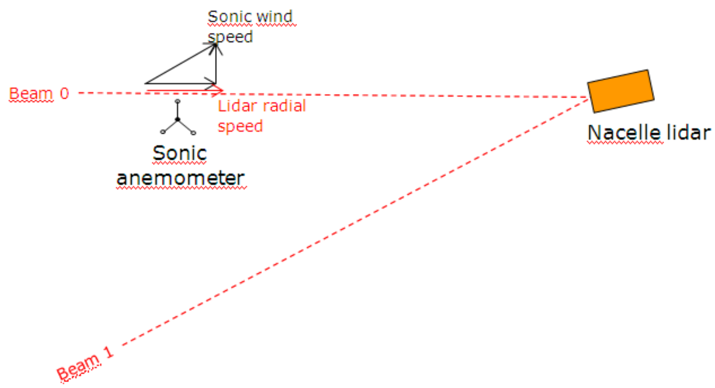

Figure 6 Line of sight calibration seen from above - first beam.

In practice the calibration was made close to the ground at about 10m height. The setup that was used in the project is shown in figure 7, where the nacelle lidar was put on a 10m platform at the Høvsøre met mast, and the sonic was mounted on a 10m mast at a distance of about 75m.

Figure 7 The 10m platform for mounting the nacelle lidar at the Høvsøre met mast to the left. The 10m mast with the top mounted sonic to the right. Met mast is shown in the background. The cross bar is used for identification of lidar beam position and is not used in calibration measurements.

4. Measurement procedure demonstration

The measurement procedure developed from the Høvsøre experiments was verified by a demonstration of the method on a similar wind turbine at Avedøre in Copenhagen, [7]. A mast was connected with the measurements, so the performance measurements could be compared with the existing IEC measurement procedure. Regarding the measurement of the wind direction, which is done by subtracting the lidar yaw error measurement from the turbine yaw direction, one should take care that the lidar yaw error measurement might be disturbed by the wake of other wind turbines. This is clearly shown in figure 8, where the wake pattern of other turbines is seen at about 80° and at about 270°.

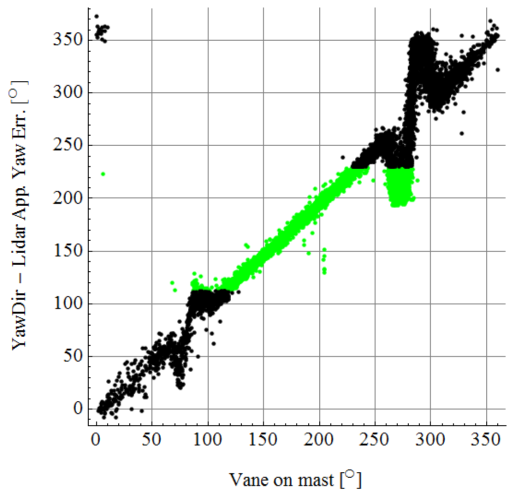

Figure 8 Comparison between the wind direction obtained by subtracting the lidar yaw error from the turbine yaw and the direction given by the vane on the met mast. The green dots are the data for which the combination of the yaw and the lidar relative angle is within 112°-230°. Care should be taken not to include green data above 250°.

Figure 9 and 10 show the measured tilt angle and the measured roll angle during operation of the wind turbine. It must be assured that the beam measurement volumes are within the specified height requirements in order to keep uncertainties low.

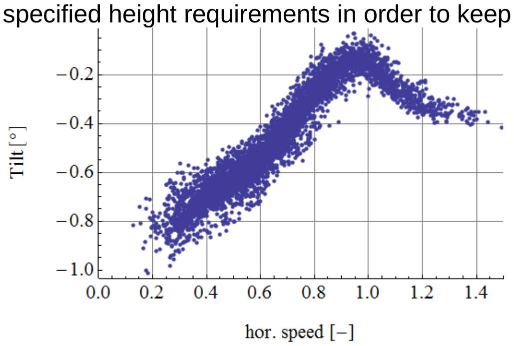

Figure 9 Lidar (10 minute mean) tilt angle vs wind speed measured by the lidar at 2D

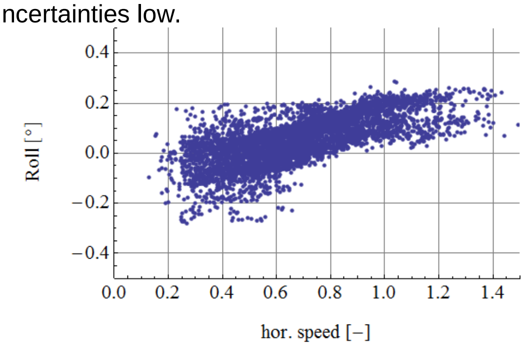

Figure 10 Lidar (10 minute mean) roll angle vs wind speed measured by the lidar at 2D

Figure 11 shows the relation between the cup measurements on the mast and the nacelle lidar measurements. The agreement of the two measurements is seen to be within 0.3%.

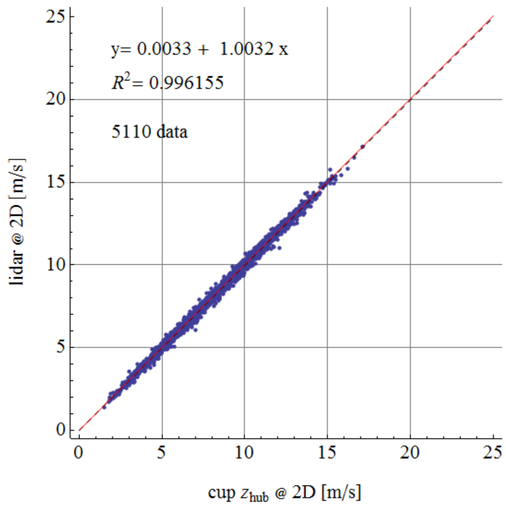

Figure 11 The measured relation between the mast mounted cup anemometer and the nacelle lidar at a distance of 2D.

Figure 12 shows the power curve measured with the cup anemometer and figure 13 shows the power curve measured with the nacelle lidar. The comparison confirms the good relation between the cup anemometer and the nacelle lidar as shown in figure 11.

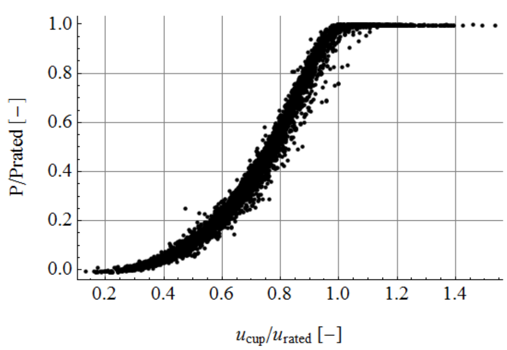

Figure 12 Power curve scatter plot obtained with the cup anemometer at hub height at 2D

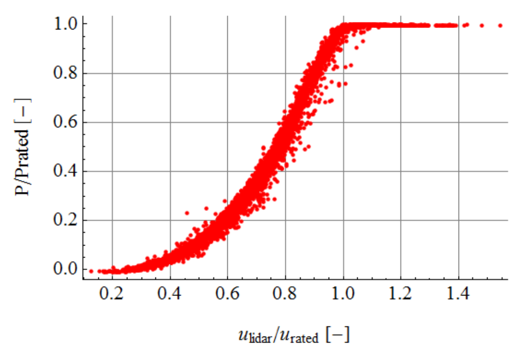

Figure 13 Power curve scatter plot obtained with the lidar at 2D

5. Workshop and dissemination of results

The results of the project were presented at a workshop at Risø 16 January 2013. There were 34 participants from the wind energy industry, including participants from lidar manufacturers, wind turbine manufacturers, energy companies, testing institutes, consulting companies, and research institutes. The workshop was quite successful, and ended in a discussion how the procedures could be put forward towards standardization. Three possibilities were mentioned: IEC, IEA and MEASNET. The measurement was forwarded to the MEASNET organization in order to promote implementation of the method within the organization.

The results have been presented at conferences during the project. For further information one should consult the reports, papers and documents listed in the following reference list.

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