LIDAR TECHNOLOGY FOR THE GERMAN OFFSHORE TEST SITE "ALPHA VENTUS"- JOINT PROJECT IN MEASUREMENT DEVELOPMENT

A. Rettenmeier [1], D. Schlipf [1], M. Wächter [2], Y. Käsler [3], H. Mellinghoff [4], B. Siegmeier [5], L. Reeder [6], M. Kühn [1]
[1] Stiftungslehrstuhl Windenergie (SWE), Universität Stuttgart, +49711/6856-8325, rettenmeier@ifb.uni-stuttgart.de
[2] ForWind, Carl von Ossietzky Universität, Oldenburg
[3] Institut für Physik der Atmosphäre, DLR, Wessling
[4] Deutsches Windenergie Institut (DEWI), Wilhelmshaven
[5] AREVA-Multibrid GmbH, Bremerhaven
[6] Fördergesellschaft Windenergie e.V. (FGW), Kiel

Summary

This paper describes the content of the joint research project "Development of LiDAR measurement techniques for the German offshore test site" and its first results. The objective is to develop reliable and standardised remote sensing techniques for various new applications in the wind energy community and to support other RAVE[1] projects at the German offshore test site "alpha ventus". The first measurement campaign dealt with the comparison of wind parameters measured by common anemometry in a height of up to 103 m and LiDAR data measured up to 220 m height. The first results show very good agreement when the two techniques are compared as to wind speed, wind direction and power curve determination at a 5 MW wind turbine. The status of the development of a wind field scanner for nacelle-based LiDAR measurements is described and an outlook to the forthcoming work is given.

1. Introduction

LiDAR, as a remote sensing technique with high spatial and temporal resolution, presents a great advantage for offshore wind energy developments [1], [2]. The measurement techniques to be developed in the LiDAR project will have direct applications for the measurement of power curve and nacelle-based inflow and wake wind fields. Moreover, research-oriented work is done with regard to wake loading simulation and loading control strategies based on inflow measurements [3]. The previously mentioned nacelle-based wind field measurements are used to verify the findings in these applications.

The project lasting from August 2007 to March 2010 is coordinated by the Endowed Chair of Wind Energy (SWE) at Universität Stuttgart, Germany, and is conducted in four work packages: the first work package "LiDAR technology" deals with the specification, acquisition, calibration and adaptation for nacelle-based measurements of a commercial LiDAR system. Work package "Power curve measurement" is dedicated to power curve assessment with ground-based LiDAR using standard statistical methods. Additionally, new methods are developed to analyze the dynamics of the power conversion process and derive a power curve from high frequency measurement data. The third work package "Wind field research" aims at the development of wake loading simulation methods for wind turbines and the exploration of loading control strategies, both assisted by nacelle-based wind field measurement techniques. Finally, dissemination of results to the industry takes place in work package 4 "Technology transfer".

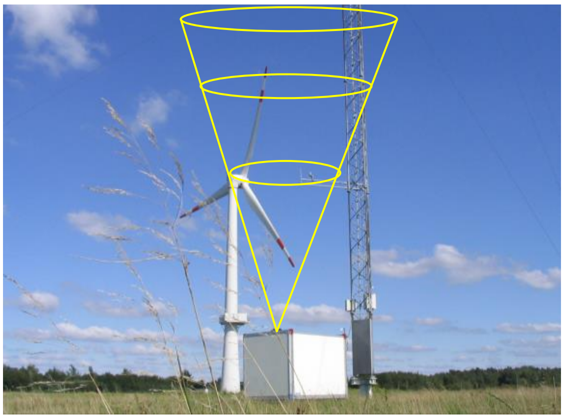

Fig. 1: Ground-based LiDAR comparison measurements with a met mast of 103 m height at the Multibrid M5000 prototype

2. LiDAR system and its technology

The first step was to describe the specification of the LiDAR system which has to fulfil the needs of the first measurement campaign: the ground-based vertical measurements had to be compared with standardized met mast signals. An additional CAN-bus interface had to be introduced to the LiDAR system which is needed for parallel data acquisition from the already existing SWE measurement infrastructure.

Together with the DLR (German Aerospace Center), which has been gaining experience in long-range LiDAR systems for several years, the requirements and comparisons were specified and the decision was made to use the pulsed LiDAR system Windcube™ of the French company

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[1] RAVE: research at alpha ventus (www.rave-offshore.de)

Leosphere^{TM}. The pulse length corresponds to a probe length of 26 m, thus measurements at heights above 40m can be done.

The LIDAR system uses the Doppler Beam Swinging (DBS) technique which is based on the following equation

$$v_r = u \cdot \cos(\theta) \cdot \cos(\varphi) + v \cdot \sin(\theta) \cdot \cos(\varphi) + w \cdot \sin(\varphi),$$

where u, v and w are the wind vector components, and θ and φ the azimuthal and zenithal angles of the wind vector. v_r is the line-of-sight or radial velocity.

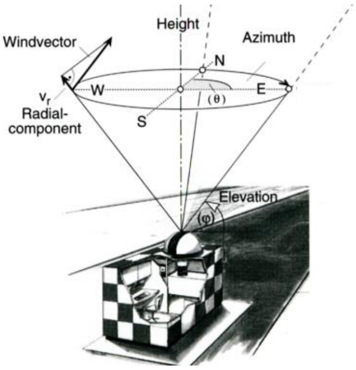

Fig. 2: Schematic of the scan technique of a Doppler LIDAR [4]

The Windcube™ system measures one radial velocity for each cardinal point, i.e. for θ=0°, θ=90°, θ=180° and θ=270°. The following equations were obtained:

$$v_{r0} = u \cdot \cos(\varphi) + w \cdot \sin(\varphi)$$
$$v_{r90} = v \cdot \cos(\varphi) + w \cdot \sin(\varphi)$$
$$v_{r180} = -u \cdot \cos(\varphi) + w \cdot \sin(\varphi)$$
$$v_{r270} = -v \cdot \cos(\varphi) + w \cdot \sin(\varphi)$$

With the first three equations, the wind vector components u, v, w can be determined. The azimuthal position is switched every 1.5 seconds; consequently a new value of the total wind vector can be obtained from the last three measurements by the above mentioned equations. The elevation angle φ is given through the prism angle which can be switched between 60° and 75° for the used LiDAR system.

3. Power curve measurements

After an initial test of the LiDAR system during several weeks of winter weather conditions and occasional winter storms, the project partners, ForWind, DEWI and SWE could gain their first experience with the LiDAR technology [5].

From May to October 2008, a comparison of the LiDAR system with a common met mast took place. At the site of the Multibrid M5000 prototype turbine (5MW rated power, 116 m rotor diameter) in Bremerhaven the SWE operates a 103 m met mast with various meteorological sensors as well as an extensive data acquisition system for load and power curve measurements.

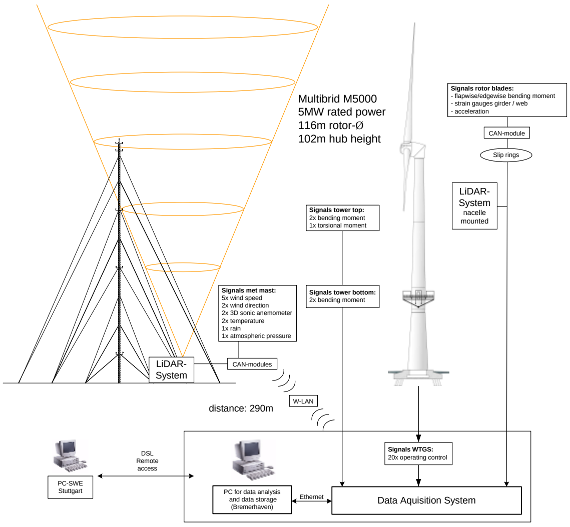

Fig. 3: Overview of the measurement system

The LiDAR system measured wind characteristics up to the rotor blade tips (160 m) and even higher (up to 220 m). These data were logged along with met mast data, nacelle anemometry and turbine loading and controller data. The measurement data of sonic and cup anemometers at three different heights (44 m, 73 m and 103 m) and wind vanes were compared with the measurement data from the LiDAR system.

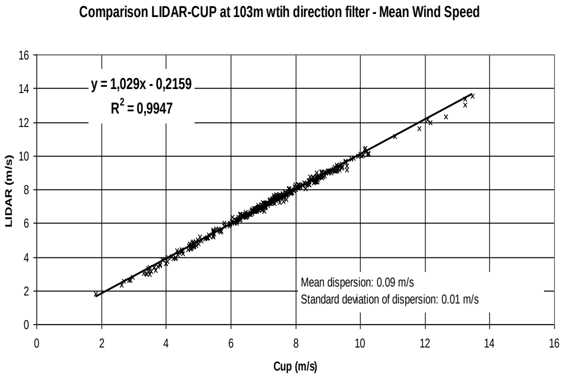

Fig. 4: Scatter plot of horizontal mean wind speed component as measured by Windcube™ against cup anemometer readings at 103 m.

An evaluation of a LiDAR wind speed measurement power curve and a comparison with the standard IEC-power curve results were conducted as a first step [6]. The wind parameters measured by the LiDAR system up to rotor blade tip height will be evaluated with regard to the effects of the wind profile and turbulence to the power curve. Both are the most interesting parameters for an extended definition of the power curve.

The power curve of the wind turbine has been evaluated based on the wind speed measurements by the LiDAR system and by the cup anemometers. The power curves agree very well (Fig. 5).

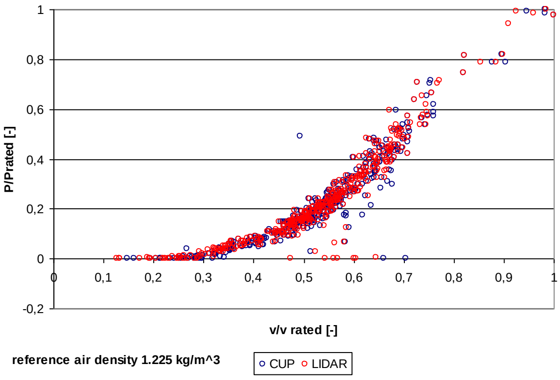

Fig. 5: Power curve raw data as evaluated by Windcube™ and cup anemometers. Each point represents a 10-minute period [7].

Further power curve evaluation methods

Another aim of the research is to investigate whether LiDAR systems can be used with a new method of dynamic power curve determination utilizing the time series information of the measured data set. The typical time increment is in the order of one second or less. For this method, sonic anemometers are installed in addition to the LiDAR system and the met mast with its standard anemometry.

At ForWind, new methods are developed to analyze the dynamics of the power conversion process and derive a power curve from high-frequency measurement data. From the LiDAR technology, with its advantageous high spatial and temporal resolution, new insights are expected on how yawed flow, turbulence and wind shear have to be taken into account in the determination of power curves of multi-megawatt wind turbines [8].

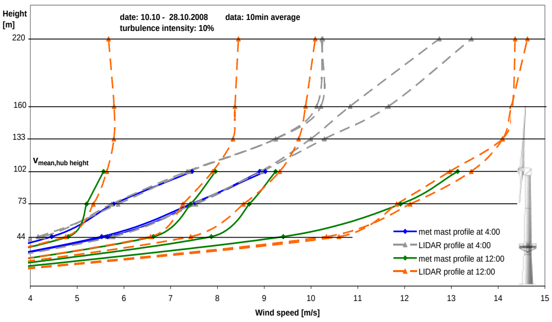

Fig. 6: 10-minutes wind profiles measured at the Bremerhaven test site at different atmospheric stratification

The LiDAR technology allows measuring the wind speed in much greater height than would be possible with the met mast. A significant difference in wind shear from day to night times due to roughness change from sea to land and thermal effects can be seen in Fig. 6. Regarding the large shear, the definition of the wind speed for power curve determination of multi-MW turbines should to be revised, e.g. by measuring the wind speed at several positions of the whole swept rotor area with a LiDAR device and average it to an equivalent wind speed [9]. Measuring the wind speed from the nacelle would allow carrying out load and power curve measurements without an expensive met mast on- and offshore. A wider free and undisturbed sector would reduce the duration of the measurement campaign.

4. Wind field research

The LiDAR technology offers great prospects for wind field analysis. The idea to measure horizontally from the nacelle could give lots of different information on the incoming wind field as well as the wake of the turbine. This information is used for the development of predictive control strategies and for the development of a physical model for the simulation of dynamic wake loading. This model aims at the development of wind field simulation tools which allow for the complex inflow conditions of huge onshore and offshore wind farms [10], [11].

So far, different horizontal scanning modes are simulated to look for the most promising shape to scan the wind field with the LiDAR technology in the most accurate way. The software WITLIS[2] simulates the scan of a modelled wind field by a LiDAR system. Afterwards the scanned points are interpolated to a wind field which can be compared with the original one. Figure 7 shows the scanning shape (lower part) and the error between the modelled wind field and the interpolated wind field of the scan simulation (upper part).

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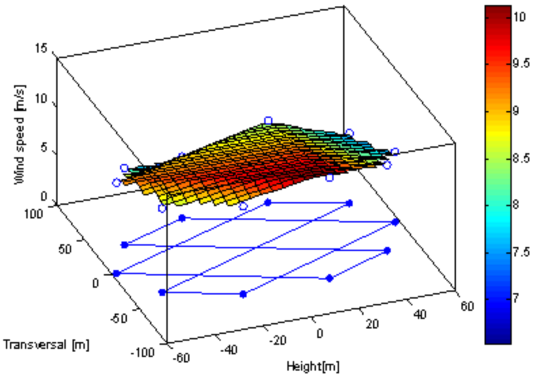

Fig. 7: Snapshot of turbulent wind field interpolated from a LiDAR scan at various positions.

The standard Windcube^{TM} system has to be upgraded with a scanning device to fulfil the specification of the scanning shape. Either a galvanometer scanner with two mirrors or a pair of rotating Risley prisms will be used.

The project participant DLR does research in connection with turbulence of aircraft wake vortices supported by airborne coherent Doppler LiDAR. DLR will assist measurements in Bremerhaven with a long-range LiDAR system [12]. Their instrument is going to be used for measurements of the far-wake of the Multibrid M5000 which will then be used for

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[2] WITLIS: WInd Turbine LIdar Simulator from SWE

the validation of wake models describing the stationary and dynamic characteristics of the flow behind wind turbines. For near-wake determination, the horizontally scanning Windcube^{TM} LiDAR will be used.

5. Technology transfer

The establishment of LiDAR wind measurements for onshore and offshore purposes critically depends on the development of new guidelines. In the field of power curve measurements with common anemometry the Federation of German Windpower (FGW) possesses a huge know-how due to the number of members from accredited measurement institutes. This knowledge will be used to evaluate the results of the project and will eventually lead to a revision of FGW's "Technical Guideline for Wind Turbines Part 2: Determining the Power Performance and Standardised Energy Yields". Moreover FGW will facilitate the scientific exchange with the national and international wind energy community through publications and contributions to trade fairs and conferences.

6. Conclusions

The objective of the LiDAR project is to further develop this novel remote sensing technique for wind energy applications in the German offshore test site “alpha ventus” and other onshore and offshore sites. First results on the application of a ground-based pulsed LiDAR device for wind speed measurements up to 220m height and power curve measurements at a 5MW onshore wind turbine show good agreement with standard cup anemometry mounted at a 103 m met mast.

A scanner device for nacelle-based LiDAR measurements is under development and will be used for wind field analyses required for improved simulation of wake loading and advanced control strategies assisted by inflow measurements. Moreover, LiDAR measurements will be used for the development of a new method for fast power curve measurements using high-frequency unsteady wind speed measurements.

Acknowledgements

The LiDAR project is carried out in the RAVE framework program and is funded under contract No. 0327642 by the German Federal Environment Ministry (BMU).

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