UTILISATION OF INLAND WIND POWER –
First results of 200 m mast measurements in comparison
to lidar measurements at a complex terrain site

Tobias Klaas, Doron Callies, Saskia Hagemann, Paul Kühn, Bernhard Lange
Fraunhofer Institute for Wind Energy and Energy System Technology (IWES)
Königstor 59, 34119 Kassel, Germany

E-Mail: tobias.klaas@iwes.fraunhofer.de, Tel: +49(0)561 9274-447, www.iwes.fraunhofer.de

Abstract

At the end of the first half of 2011 a capacity of almost 27 GW of onshore wind power was installed in Germany. However, wind power onshore has still a huge potential for further growth. To assess this potential, especially in forested and complex terrain, new measurement techniques have to be established. With current tower technologies allowing the installation of turbines with hub heights up to 150 m, extrapolation methods for traditional mast based measurements are becoming increasingly unreliable – particularly under consideration of today’s large rotor diameters. Furthermore building measurement masts up to hub height tends to be uneconomic.

Nowadays ground based remote sensing using lidar technique is a new option to complement or eventually even replace mast mounted measurements. Lidar measurements have shown a high accuracy in even, homogeneous terrain i.e. offshore or in flat lands. In contrast to that, applying these techniques in hilly or mountainous terrain results in considerable bias, due to the principle of the 3D wind vector reconstruction.

Within the two years of project "Utilization of Inland Wind Power", ending in December 2011, a 200 m high met mast has been installed at a hilly, forested site in central Germany to survey the profiles, the wind resource and the design parameters relevant for the design of wind turbines, e.g. turbulence, extreme winds, etc. The met mast is equipped with up-to-date meteorological sensors observing a wide range of different meteorological parameters.

In addition to that diverse lidar measurements are carried out, to analyze uncertainties and limits of those devices in this terrain.

For this purpose the measured wind profiles will be compared to mast mounted measurements in several heights between 40 and 200 m. This allows to survey the dependency of the accuracy of the measurement on the height of the measurement. Additionally measurement results are to be evaluated under consideration of different atmospheric conditions, weather situations and time of day. Wind speed and direction sensors at least every 20 m up to 200 m height and multiple temperature difference, pressure and humidity sensors give detailed information about wind profiles for different atmospheric stabilities.

As a first approach to correct the lidar measurements the method developed by Ferhat Bingöl was applied to check if it improves the quality of the measurement. First calculation results show that (depending on wind direction) lidar measurement bias reaches values in the order of 10 %. Due to the fact that for this site the highest errors occur at the main wind direction, the resulting impact on the energy yield assessment on basis of lidar technique will be considerably high.

As expected there is a significant deviation between lidar and mast at all heights [1]. Neglecting the few outliers, the maximum absolute difference is about 2 m/s. Most values are located within an interval of -1 m/s to 1 m/s.
Objectives

To further increase the utilization of inland wind power, the long term goal is to find suitable technical solutions especially for application in inland wind power. In future, cost-efficient alternatives for mast based wind measurement, such as lidar, must be applied to analyze the wind characteristics in great heights to use these techniques for resource assessments. The wind characteristics in complex terrain and in great heights must be understood in detail to model and evaluate the wind potential at the precise site and on a large-scale. Adequate knowledge of the prevailing wind conditions at complex inland sites is further more essential to reach the long time goal of optimized wind turbines for such wind regimes.

Within the two years of project "Utilization of Inland Wind Power", ending in December 2011, a 200 m high met mast has been installed at a hilly, forested site in central Germany near the city of Kassel.

Its purpose is to survey the wind speed, direction and turbulence profiles as well as the wind resource and the design parameters relevant for the design of wind turbines, e.g. turbulence, extreme winds, etc.

The met mast is equipped with up-to-date meteorological sensors observing a wide range of different meteorological parameters.

In addition to that diverse lidar measurements are carried out, to analyze uncertainties and limits of those devices in this terrain.

Objectives of the research activities described in this paper are in detail:

- A comparison of lidar measurements to mast mounted measurements for great heights at a complex terrain site.
- A first examination of the difference between cup anemometers and lidars depending on wind direction and atmospheric stability
- The identification of periods of icing and their influence on mast and lidar based measurements

Methods

The comparison of pulsed doppler lidars and the 200 m met mast with its unique measurement system gives detailed insight to the behavior of lidars at forested complex terrain sites.

Measurement Site

Fig. 1 gives an overview of the measurement site. The meteorological mast is located on the lee side of a hill, close to the highest point at about 390 m altitude.

It is further more located in a clearance which can be seen in Fig. 2. In low heights high turbulence can be considered due to forest and orography effects on the wind.

In the estimated main wind direction the wind passes a forest for about two kilometers. Winds coming from that direction sector are strongly influenced by the roughness of the forest, which gives detailed insight to the effects of forestry on wind characteristic up to great heights.

The site orography is quite complex but typical for a inland wind energy site in central Germany. The mast is located at a hill range that runs from south east to north west. Highest slope is located in main wind direction and exceeds 30 %. Further, even higher hills, are located within 20 km around the site but cannot be seen in the figure.

A small wind park with four turbines is planned by the local energy supplier along the hill range.

Fig. 1: Measurement site in complex terrain
The 200 m measurement mast is equipped with about 40 sensors at more than 10 heights.

First class cup anemometers are mounted at least every 20 m from 10 m to 200 m height. Multiple wind vanes are available on different heights. Additionally six 3D ultrasonic anemometers are mounted at the mast.

Meteorological sensors measuring temperature, pressure, relative humidity, global radiation and rainfall complete the sensor equipment.

At all heights the sensors are mounted at opposed booms with a length of 5.40 m according to IEC 61400-12.

Measurement data is available with a resolution of one second for cup anemometers, wind vanes and other meteorological sensors. 20 Hz and 50 Hz data is recorded for ultrasonic anemometers revealing high resolution deviations in 3D wind speed components.
The lidars used by Fraunhofer IWES are pulsed doppler lidars following the velocity azimuth display (VAD) measurement geometry. Radial wind speeds along the line-of-sight of the laser are measured in four directions, every 90°. Wind speeds in up to 10 heights are measured simultaneously by using the time-of-flight method to identify measurement data from different heights.

The 3D wind vector reconstruction from at least three radial wind speeds assumes horizontally homogeneous flow.

Lidar measurements are compared to the mast at all heights from 40 to 200 m.

Atmospheric stability is taken into account by using data from several temperature and pressure sensors at different heights and calculating stability via the gradient Richardson number.

Results
The measurement data has been recorded from 25 Jan. to 22-Feb. 2012. Predominant wind directions were North-East and South-West. Wind speed statistics are illustrated in Fig. 6.

The lidar was located next to the measurement mast at the same altitude.
Scatter plots for cup and lidar

Fig. 7 and Fig. 8 show scatter plots of mast versus lidar measured wind speed for 60 m and 180 m height.

Low availability values as well as rain and icing have been filtered out. The latter is highlighted in blue, illustrating the high influence of icing.

At 180 m lidar measurements are compared to measurement of a unheated Thies first class cup anemometer. Only values in the main wind direction sector are used for the comparison, so tower shading effects can be neglected.

As the cup anemometer is unheated a considerable amount of icing events occurred during the measurement campaign. By using temperature and humidity measurements as well as data from a close by heated anemometer, icing events could have been identified very precisely.

In periods of icing the wind speed values measured by the cup anemometer do heavily decrease. Due to its measurement principle lidar measurements are not influenced by low temperature and high humidity and are therefore more reliable during those times.

General correlation between cup anemometer and lidar is very good, when icing events are filtered.

A direct comparison between lidar and a fully heated Vaisala cup anemometer at 60 m height is shown in Fig. 8.

There are no significant icing events during the measurement period on that anemometer. At high wind speeds correlation between lidar and cup anemometer is very good. Strong differences occur at low wind speeds. One explanation for that could be high turbulence at low levels above canopy height. This must be analyzed more detailed in future.
Difference between cup and lidar

As expected there is a significant deviation between the two at all heights [1]. Neglecting the few outliers, the maximum absolute difference is about 2 m/s. Most values are located within an interval of -1 m/s to 1 m/s.

As difference occurs in a positive and negative way comparably, the influence on mean wind speed statistics is neglectable. In contrast to that energy yield calculation are sensitive to those deviations.

Fig. 9 shows the comparison results in detail for 40 m, 100 m and 200 m height. The difference between cup anemometer and lidar wind speed is plotted against the wind direction.

During the measurement campaign the prevailing wind directions were south-west and north-east.

As expected for winter season the most common stability class is 'neutral'. Only a few 'stable' and 'unstable' cases appear.

Sectors with tower shading have been filtered from the data and are therefore not shown.

Lidar data with low availability during a ten-minute-period is filtered and not compared to mast based measurements.

Positive values indicate periods where the lidar has underestimated the wind speed compared to a cup anemometer. Negative values indicate an overestimation.

At 40 m height the highest positive difference is close to 4 m/s, while most values do not exceed a difference of 2 m/s. Highest negative deviations do not exceed -2 m/s for this height.

At 100 m height difference does not decrease. Highest values can still be found close to 4 m/s, most measured values lie below 2 m/s difference.

Even at 200 m height high deviations comparable to those on lower heights occur. No decrease of difference by height can be found for this measurement campaign.

At the north east sector the lidar tends to overestimate the wind speed stronger, than in other sectors, which must be analyzed in more detail.

In general approximately the same amount of measurement value pairs can be found below and above the x-axis. Due to that, the mean value of wind speed measured by lidar is very close to the one measured by cup anemometers.

The influence of the shown differences on wind resource assessment must be analyzed more detailed.
Conclusion

First comparison results show significant deviations between lidar and mast. The difference between cup anemometers and lidar measurements stays at a considerable values - even for 200 m measurements.

Further investigations must include longer time series covering all relevant direction sectors and atmospheric stability situations. More detailed investigations of lidar and mast measurements are needed to analyze the influence of height, direction, atmospheric stability and wind speed on the deviations between the two.

In addition to that Fraunhofer IWES will test and develop different correction algorithms for lidar measurements at diverse complex terrain sites [1] [2] [4].

References


