Projektinfo **12**/2016

Detailed information on energy research

Measuring wind potential in low mountain ranges

Long-term measurements on a 200-metre-high met mast near Kassel

BINE Information Service

One of the highest meteorological masts in Europe is situated on Rödeser Berg, a hill near Kassel. The research facility with its measurement devices records the wind conditions up to a height of 200 metres. The aim is to measure the impact of forest areas and low mountain ranges on the wind profile and flow characteristics. The results will help to improve the meteorological models for assessing sites, will make it possible to estimate the loads on individual system components in more detail and will help to further develop the laser-based LiDAR method.

Modern wind turbines have hub heights that extend up to 150 metres and rotor diameters that are up to 170 metres wide. The wind conditions up to 200 metres in height are therefore important for them. The meteorological mast on Rödeser Berg near Kassel extends to this height. Since 2012, it has improved the database for designing inland wind turbines by providing continuous wind measurements. The aim is to provide a solid database for modelling wind fields for forested low mountain ranges, thereby reducing previous uncertainties in the assessment of new sites. Measurements include the horizontal and vertical wind speeds and the turbulence. This makes it possible to tailor the design of critical components such as rotor blades more specifically to the site conditions. The met mast is also being used to make comparisons with the cheaper, laser-based LiDAR method. The data increases the security when the devices are used for evaluating sites. The determined site-dependent errors can be used in future to correct measurement results. The Fraunhofer Institute for Wind Energy and Energy System Technology IWES in Kassel led the research project.

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A study of the wind potential areas in Germany has shown that forested upland locations account for about half of the suitable sites in Germany. Excluded are areas that have to remain free of wind turbines for nature conservation reasons or in order to maintain minimum distances from residential buildings. The forest areas relevant for wind energy are mainly located in central and southern Germany.
In 2015, more than 30 % of all newly constructed turbines in Germany were erected in the southern part of the country, i.e. in Baden-Württemberg, Bavaria, Hesse, Rhineland-Palatinate, Saarland, Saxony and Thuringia. The wind turbines located there generate their electricity in the immediate vicinity of urban areas and industrial centres with high power requirements. This relieves the transmission lines for the electricity grid.

Aiming high and well designed

The 200-metre-high met mast is situated in a typical inland location at 380 metres above sea level. The flow conditions are influenced by the complex terrain structure in the low mountain range situation. In the main wind direction, the wind flows over an approximately two-kilometre-long forest area before it has to rise steeply on reaching the clearing with the mast. It is the only mast of this height in Germany that specialises in the requirements of wind energy.
The mast is fitted every twenty metres with outriggers and more than 40 sensors (e.g. different anemometers). These make it possible to determine the horizontal and vertical wind speeds as well as to identify high-frequency turbulence and momentum fluxes. The wind profile is measured for each air layer for a wind turbine from the tower base to the highest point of the blade tips. Other measuring devices record the global radiation, air humidity and air pressure, rain intensity, temperature, icing and cloud height. All data streams are fed into a measuring container at the foot of the installation.

Customising wind turbines to the location

The meteorological data from the met mast is used to improve and validate models for calculating the wind profile, turbulence and yields in inland situations. This data can therefore also depict forest areas and complex terrain in much more detail. For example, a wind turbine manufacturer is now using the turbulence fields determined in the project to calculate the loads on individual wind turbine components in forested uplands. These findings are helping to optimise the use of materials.
During the investigations it was demonstrated that LiDAR instruments also meet the requirements for accurate site assessments in complex inland situations. The challenge is to transfer local measurements to large areas. The experience gained from the investigations has now been incorporated into the further developed technical guidelines for wind potential determination produced by the Federation of German Windpower and other Renewable Energies (FGW).

Lasering the wind profile

The measurements comparing the conventional met mast and various LiDAR devices have shown that the margin of error is less than was originally expected. On Rödeser Berg, it generally lies between +2.5 and –4 % for the devices typically used for planning wind farms. These deviations in the laser measurements are due to the measurement principle and can be easily balanced out by the correction factors identified in the flow simulations. Surrounding the measurement site there are areas with higher and lower LiDAR error probabilities that can be depicted on an error map. Fraunhofer IWES recommends measuring from the points with low probabilities. LiDAR measurements can simplify the assessments for planned wind farm sites and reduce costs. In addition to their use for year-round measurements, laser devices can, for example, make height measurements above shorter met masts.

Fig. 1 *The Rödeser Berg met mast is 200 metres high and is equipped with more than 40 instruments.*

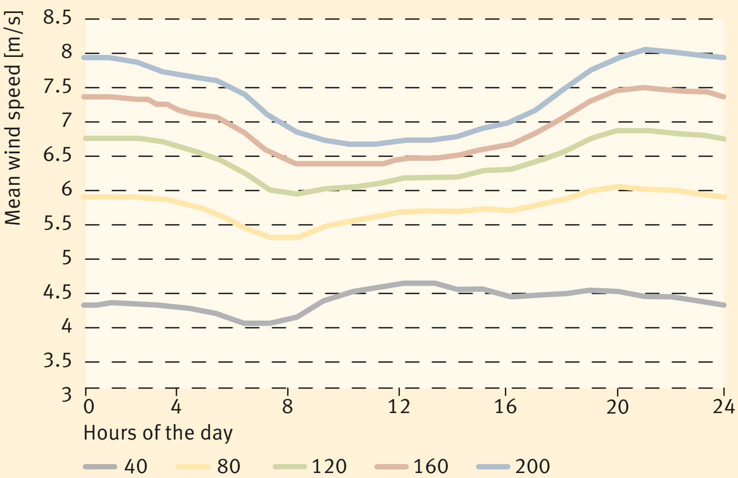

Fig. 2 *During the day, the wind conditions above 120 metres and b elow 80 metres differ significantly.*

Wind conditions in the low mountain ranges

In the southern regions of Germany and especially in low mountain ranges, the air layers with wind speeds suitable for utilising wind energy lie at higher altitudes. The average wind speed increases by roughly 25 % between

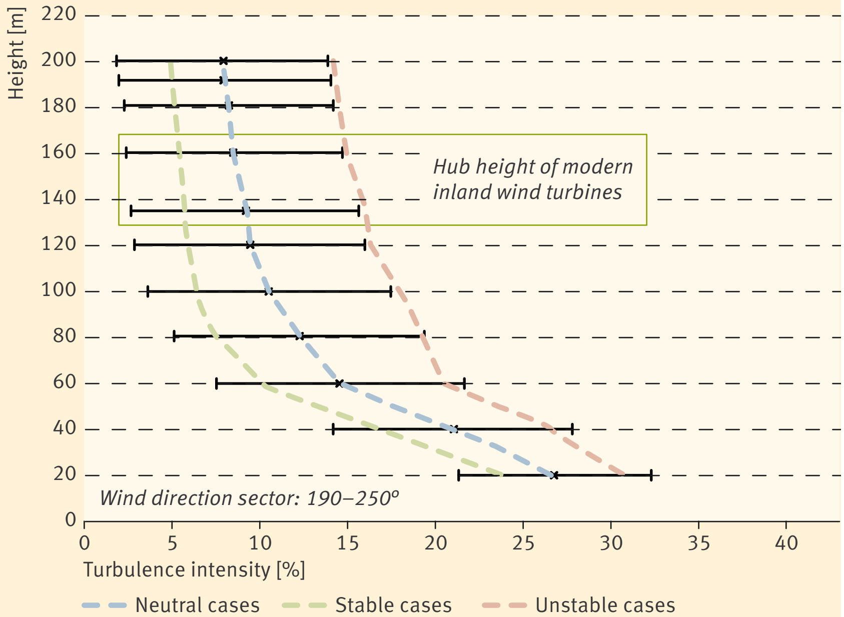

Fig. 3 *Dependence of the turbulence intensity relative to the height for the main wind direction sector on the 200-metre met mast. The turbulence increases considerably above the treetops. At the hub height of modern wind turbines, the turbulence intensity is comparable to offshore conditions with about 10 %. Depending on the state of the atmosphere (stable, neutral, unstable), the turbulence increases considerably or attenuates.*

Fig. 4 *The measurements from these LiDAR devices were compared with the backup data from the met mast. This made it possible to identify systematic measurement errors and develop correction methods.*

100 and 200 metres. The earth's surface (e.g. hills and forests) has a considerable influence on the wind speed and direction. Complex terrain with, for example, steep slopes, often causes short-term, rapid changes in the air flow especially near the ground known as turbulence. The turbulence only corresponds to unwooded regions 60 to 80 metres above the treetops.
Each rotor blade passes through air layers with higher wind speeds at the upper apex than at the lowest point. The change in wind speed with altitude, known as wind shear, varies throughout the day. The solar radiation heating the earth's surface causes vertical air streams and boundary layers to be formed. The mean wind speed at midday reaches its greatest value below a height of around 70 metres, whereby it reaches its lowest value at exactly the same time above a height of around 100 metres. At night, there is more stratification of the air layers, less vertical mixing and greater wind shear.
The wind turbine technology has to be designed to meet these stress factors, which is why manufacturers offer special inland wind turbines.

Tracking the wind with lasers

Using laser beams, LiDAR (Light Detection And Ranging) technology is used for the remote sensing of atmospheric parameters. Before constructing new wind farms, special Doppler LiDAR devices are used to measure the wind speed and direction vertically upwards from the ground. This eliminates the need to make time-consuming wind measurements with a mast. For offshore installations, LiDAR instruments can also be installed on floating buoys. Many banks and insurers recognise laser measurements for wind assessments.

Scanning LiDAR devices also make it possible to measure the wind conditions at any point within a wind farm. Scientists combined the devices to measure the flow across hills precisely.

Verified wind atlas

Another part of the project was concerned with providing long-term and spatially accurate wind data with a 3 km horizontal resolution. This data is now available as a verified wind atlas.
The new wind atlas incorporates existing measurement data from 33 met masts in Germany and anonymous data from existing wind turbines. The data was debugged, verified with the measured yield values and then included in the wind atlas. The aim is to draw on weather data and wind power yields with a spatial coverage that is as dense as possible to verify the wind atlas. The model can provide, for example, wind roses, vertical wind profiles, daily cycles and frequency distributions of wind speeds.
In the calculations, the mesoscale Weather Research and Forecasting Model (WRF) was combined with the high-resolution Meteodyn WT model, which is particularly suitable for wooded areas.
The time series for the wind speeds in the wind atlas were combined with performance characteristics for all common wind turbines and published as a production atlas. A market value atlas has also been created by additionally combining this data with current market prices.
The data can be accessed via an internet platform and is used in particular for making preliminary estimates of the wind and yield potential and for index calculations.

The European NEWA project

The mast will also be available for scientific purposes beyond the scope of the original research project. The current work is being incorporated in the New European Wind Atlas (NEWA).
For this purpose, several research institutes installed their LiDAR measurement devices and scanning LiDAR equipment on site in 2016. The flow across the entire forested area was surveyed in detail using a second, 140-metre-high met mast at the foot of the hill. More than 30 project partners from eight countries are working together in NEWA. The atlas is scheduled to be published in 2020.

Measurements in southern Germany

The Endowment Chair for Wind Energy at the University of Stuttgart is also conducting research on the uses of LiDAR for controlling wind turbines and measuring wind fields.

These devices can measure the wind not only vertically but also horizontally. For this purpose, the devices are installed on a nacelle. The scanner scans the wind field in front of the wind turbine at any point. These measurements can then be integrated into the wind turbine control system to anticipate the position of the wind and thus optimally align the rotors. This makes it possible to reduce both fatigue and extreme loads on the wind turbines.

In the LiDAR project, the Stuttgart-based scientists also conducted additional complex laser measurements in complex mountainous terrain at sites in southern Germany. These were aimed at increasing knowledge about the influence of the topography, collecting data to determine the measurement accuracy of the equipment, and developing and validating correction algorithms for them. The wind field was measured using ground- and nacelle-based LiDAR equipment as well as from aircraft and met masts. The highly varied topography was recreated as a model and measured in a wind tunnel. All data is being used to better understand and predict the operating performance of wind turbines in such terrain.

Test field in southern Germany

The establishment of a regional research test field would help wind turbines better adapt to the requirements posed by the low mountain ranges in southern Germany. Together with partners, the Karlsruhe Institute of Technology (KIT) has therefore provided the basis for this as part of the KonTest project. The aim of the project was to identify possible locations for a test field and to characterise the meteorological conditions and determine the flow conditions there. Such a test field makes it possible to test out new materials and construction methods as well as to optimise the aerodynamics of the wind turbines, the noise reduction and operation.

Project participants

- **Project management met mast and LiDAR measurements:** Fraunhofer Institute for Wind Energy and Energy System Technology IWES, Kassel, Germany, Tobias Klaas, tobias.klaas@iwes.fraunhofer.de, www.iwes.fraunhofer.de
- **Wind atlas:** anemos Gesellschaft für Umweltmeteorologie mbH, Reppenstedt, Germany, Martin Schneider, martin.schneider@anemos.de, www.anemos.de

Links and literature

- **Video:** A four-minute video about the construction of the met mast can be found on the Internet at www.youtube.com/watch?v=33KMORnzJj8
- **Literature:** Klaas, T.; Pauscher, L.; Callies, D.: LiDAR-mast deviations in complex terrain and their simulation using CFD. In: Meteorologische Zeitschrift, Vol. 24 (2015), No. 6, p. 591–603

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Hermann-von-Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen
Germany

Author
Uwe Milles

Contact · Info

Questions regarding this Projektinfo brochure? We will be pleased to help you:

+49 228 92379-44
kontakt@bine.info

BINE Information Service
Energy research for application
A service from FIZ Karlsruhe

Kaiserstraße 185-197
53113 Bonn, Germany
www.bine.info

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