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Light Detectors Boost Wind Harvests

By Nikolas Angelou, Risø DTU | October 14, 2010

Research at Denmark's Risø National Laboratory for Sustainable Energy suggests light detection and ranging — or lidar — could oust MET masts and optimise wind turbines' power production.

Frederiksborgvej, Denmark An accurate knowledge of wind characteristics is essential to the development of the wind energy industry. Speed and direction data are used in fundamental wind energy applications such as wind resource assessment and power performance studies, as well as in wind turbine control.

If a wind turbine's control systems 'know' in advance the nature of the approaching wind they can optimise its operation to maximise power production. By adjusting in advance for gusts and other extreme wind events, loads on the wind turbine blades can also be reduced and the lifetime of the wind turbine increased.

Currently, in line with IEC standards, the accepted method for the acquisition of these data involves the installation of in-situ measuring devices on meteorological masts, or MET masts.

Yet as the wind sector starts to produce a greater proportion of electric power needs, and as it starts to be developed in new markets, more wind parks are likely to be either offshore or in complex terrain such as forest or mountain areas. Wind energy research is also increasing the size of wind turbine. For example, wind turbine models with a rotor diameter of more than 120 metres and hub heights of 100 metres or more are soon expected to become commercially available.

To keep pace with these developments, detailed wind measurements will be needed — and MET masts may not be the best solution. Larger wind turbines require the measuring of wind speed at greater heights and distances from the wind turbine rotor plane. The cost of installing MET masts that can monitor the wind at those heights becomes significant. Moreover, installating MET masts either offshore or in complex terrains can be expensive and technically challenging.

Today an alternative to the use of the conventional MET masts is appearing, using remote sensing techniques. Light detection and ranging (known as lidar) is increasingly being used in wind energy research and industry. Lidar instruments (wind lidar) are capable of acquiring measurements with high resolution (~0.1 ms^{-1}) at different heights. Moreover, they provide indirect distant measurements, meaning that they do not themselves affect the flow of the wind while acquiring the measurements.

Rapid progress in fibre optics and laser technology during the 1990s — which has been mainly applied in telecommunications — has also enabled the production of robust portable lidar systems. Taking advantage of this opportunity, the industry has produced wind lidar systems that are reliable and trustworthy and at the same time operate at eye-safe wavelengths (~1.5 μm).

Today various types of wind lidar systems are commercially available from four companies (Catch The Wind, Leosphere, Natural Power and SgurrEnergy). According to the technical specification of each system, they can either be ground-
based, to measuring the wind speed in different heights above the ground, or mounted on wind turbines, to measure wind speed at various distances in front or behind the wind turbine rotor.

Wind Lidars Mounted on Wind Turbines

The deployment of lidar on wind turbines offers the opportunity to investigate both the incoming wind flow approaching the rotor plane and also the wake produced by the wind turbine.

So far, wind turbine control has been based on the measurement of the direction and the speed of the wind, made by instruments (wind vanes and anemometers) installed on top of the nacelle. These instruments are subject to errors due to the effect of the rotating blades on the wind flow. Furthermore, the wind turbine's operational parameters can only react to the wind fluctuations after they have already arrived at the turbine.

A ZephIR lidar installed at the UK's Robin Rigg offshore wind farm (Sources: ZephIR, Natural Power)

A wind lidar instrument mounted on top of the nacelle — or installed in the hub of a wind turbine — and aligned with the horizontal axis of the wind turbine, can provide detailed measurements of the wind characteristics (speed and direction) of the incoming wind flow at different distances from the rotor plane. Such an application offers — in advance — an unimpeded view of the wind field that the wind turbine will experience in the future.

Integration of a lidar in a wind turbine can lead to the pro-active control of its operational parameters. Thus it enables achievement of an optimum rpm (revolutions per minute) and yaw and pitch control of the wind turbine, with the potential for subsequently increased power production. Additionally — through the advance detection of extreme wind events, such as gusts, and the adjustment of the operational parameters of the machine — it is possible to reduce the loads of the wind turbine blades, and hence to increase the wind turbine's lifetime.

Spinner-Mounted Lidar: The SpinnerEx 2009 Experiment

The feasibility of upwind observations via a spinner-mounted wind lidar was tested during the SpinnerEx 2009 experiment, held by Risø National Laboratory for Sustainable Energy at the Technical University of Denmark (DTU) in collaboration with Natural Power (UK). The experiment was conducted as part of the new Danish research infrastructure facility activities under the auspices of Windscanner.dk. The wind scanner facility at Risø DTU is intended to assist the research community and the wind industry with new and easily accessible wind speed measurement devices based on lidar remote sensing methods.

For the needs of the SpinnerEx 2009 experiment a QinetiQ (Natural Power, UK) ZephIR lidar was installed in the rotating spinner of a Vestas NM80 2.5 MW wind turbine, belonging to Dong Energy (DK). The QinetiQ

(Natural Power) ZephIR lidar is a commercially available wind lidar, capable of measuring wind speed and direction. This system is designed to acquire measurements with a fast sampling rate (50 Hz) at distances between 10 and 200 metres. A built-in optical prism deflects the laser beam to enable scanning in a conical pattern. It has been used successfully in various experimental campaigns, including resource assessment, power curve analysis and detection of the incoming wind flow.

The ZephIR wind lidar was modified and installed into the rotating spinner of the (NEG Micon) Vestas NM80 wind turbine. It was aligned with the horizontal axis of the wind turbine, so as to scan upwind. In this way it was possible to investigate the structure of the incoming wind field in front of the wind turbine. Time series of wind speed measurements from the lidar with 50 Hz sampling rate were successfully obtained for about 60 days. The measurement campaign lasted from April to August 2009.

The hub of the NM 80 wind turbine, with the optical head of QinetiQ's (Natural Power) ZephIR lidar in the tip of the wind turbine (Source: Risø)

Measurements were acquired at two distances from the wind turbine: 46 metres and 100 metres. These distances correspond respectively to multiples of 0.58 and 1.24 of the rotor diameter upwind along the shaft axis. The scanning patterns were achieved through the use of two optical prisms with a wedge-shape and deflection angles (from the zenith) of 15° and 30° respectively.

While the wind turbine was operating the lidar was scanning the incoming field in a conical pattern in front of the rotor plane. In this way it was possible to acquire real-time measurements of the radial wind speed at various heights. In terms of 10-minute average values, it was possible to reconstruct the wind profile, with a resolution of 1 metre, for an atmospheric layer ranging between ~40 and ~90 metres above the ground.

A methodology was tested for the calculation of the yaw misalignment of the wind turbine. Two cases were investigated, during which the wind turbine was operating in different wind conditions (in terms of wind shear and veer). According to the results, mean yaw misalignment angles of 9.5° and 5° were estimated for each case respectively. This data acquisition methodology, using lidar integrated in the wind turbine spinner, was evaluated by using data from an adjacent located MET mast and from the NM80 wind turbine's own control unit. In both cases the calculated values of the yaw misalignment angles were following the fluctuations of the wind direction in reference with the wind turbine yaw. Limitations to this technique appeared when the wind turbine rotor was found in the wake of another wind turbine. The presence of a wake led to variations in the radial wind speed values, which could be misinterpreted as a change of the wind direction.

The results of this experiment demonstrate that a forward-looking, spinner-mounted lidar is indeed able to measure wind components upwind at multiple sampling points distributed on a conically scanned circle in the rotor plane of a wind turbine. This knowledge is important for understanding the wind turbine's operation, the wind field conversion to electrical energy, and the optimum modifications and improvements in the design and control of a wind turbine, in order to improve its efficiency.

Future Plans: Lidars on Blade Edges

Following the SpinnerEx 2009 experiment, Risø DTU in collaboration with LM Glasfiber (DK) and NTK Photonics (DK), along with the lidar technological support of Natural Power (UK), is going one step further in the area of turbine-mounted lidar research. In April 2010 a three-year project was launched, aimed at integrating wind lidar systems into wind turbines to achieve optimum control and thereby to improve productivity and increase lifetime.

The objective is to demonstrate that lidar can mitigate blade loads and improve turbine regulation, by providing real-time upstream wind measurements. This will be studied by installing a Risø DTU patent-pending two-dimensional wind scanner head in combination with a commercially available wind lidar (ControlZephIR) in the spinner of a turbine. The ControlZephIR is capable of acquiring wind speed data at a sampling rate up to 500 Hz, and at a maximum distance of 200 metres.

A Catch the Wind nacelle-mounted lidar system (Source: Catch the Wind)

Using the two-dimensional wind scanner along with the high sampling rate of the ControlZephIR, it will be feasible to acquire fast wind speed measurements in different scanning patterns, and hence to monitor the exact wind field that is approaching the rotor plane, with a high degree of spatial and temporal resolution. The incorporation of these data into the control system will result in improved yaw and rpm control of the wind turbine.

In addition, a highly innovative concept will be applied — the mounting of optical fibres along the blades of a wind turbine. This will offer the possibility of deploying small lidars in the leading edges of the blades themselves, making it possible to measure the wind speed at a given point from a moving point of reference. This capability will provide data on the fluctuations of wind speed and turbulence that the blade experiences as it rotates. Thus it will contribute to the improvement of the wind blade's design, creating the possibility of using even longer blades.

Seeing The Future, Today

Concluding, the integration of lidar in the spinner of a wind turbine has proven its worth for investigating the incoming wind, towards the rotor plane. Furthermore, this innovative measurement concept offers the potential of active control of a wind turbine using data from a wind lidar. Incorporating remote sensing wind data into the turbine control system can improve energy yield and load reduction, through yaw, rpm and pitch control. But several parameters have to be taken into account during the lidar data processing: wake effects, terrain characteristics, and meteorological conditions such as rain, fog and clouds.

Further studies are also planned that will include the investigation and modelling of the effect on the lidar measurements of these parameters. In addition, the implementation of enhanced control algorithms utilising real-time upwind measured wind data of different wind flow conditions is envisioned.

These advances should also contribute to improving the active control of wind turbines in the near future — helping to maximise available output while minimising excessive loads on the machine. This in turn is anticipated to reduce wear and extend the operational lifespan of the turbine.

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