ZephIR Dual Mode

WINDTECH INTERNATIONAL

June 2013 | Volume 9 | No. 4

Siteur Publications

March 2013 saw the tenth anniversary of the first commercial lidar deployment for wind energy applications – and while it is now commonplace to see wind lidars (such as ZephIR 300 and those that followed) in wind energy resource assessments, it was actually a turbine-mounted application for which the ZephIR technology was first deployed. Ten years on, and ZephIR's continuous-wave (CW) lidar technology continues to be developed and is now gaining increasing acceptance in its original application of optimising wind turbine generator performance. This acceptance is founded on a body of evidence from ground-based operation spanning some 650+ deployments, 3.5 million operating hours and recent comprehensive comparative trials of 79 ZephIR 300s against an IEC-compliant met mast as part of an industry accepted validation process with banks' engineers such as Natural Power and GL Garrad Hassan.

By Alex Woodward, Head of Marketing, and Michael Harris, Chief Scientist, ZephIR Ltd, UK

ZephIR Dual Mode

The Dual Mode Solution to Wind Resource Assessment and Turbine Performance Optimisation

The principle by which lidar measures wind velocity (see Figure 1) was first described in several early trade-publication articles (including ones in Windtech International in November 2004 and July 2007) and in a number of technical journals (see www.zephirlidar.com/resources/publications). An infrared beam of coherent radiation illuminates natural aerosols (particles of dust, pollen, droplets, etc.) in the atmosphere, and a small fraction of the light is backscattered into a receiver. Motion of the target particles along the beam direction leads to a change in the light's frequency through the Doppler effect. This frequency shift is accurately measured by mixing the return signal with a portion of the original beam, and sensing the resulting beats at the different frequency on a photodetector. Since a single lidar measurement only provides the component of wind speed along the beam direction, it is necessary for the direction of the beam to be altered in a scanning pattern in order to generate a measurement of the wind speed vector. ZephIR uses a conical scan pattern; as the beam moves, it intercepts the wind at different angles, thereby building up a series of measurements around a disc of air from which the wind speed vector can be derived.

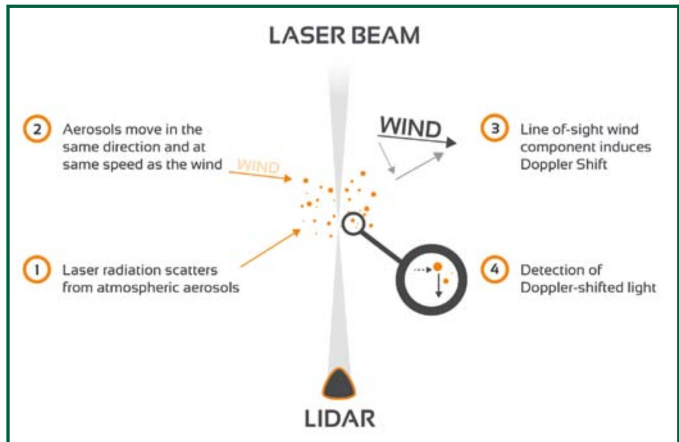

Figure 1. Principles of wind lidar

Figure 2. ZephIR installed with Nordex, under previous R&D company QinetiQ

Combined results from 79 ZephIR300 trials				
Height (m)	Gradient		R-Sq	
	Mean	StDev	Mean	StDev
91	1.002	0.006	0.987	0.006
70	1.002	0.005	0.991	0.004
45	1.001	0.004	0.991	0.005
20	0.999	0.004	0.991	0.005

Figure 3. Trials from 79 ZephIR 300 systems compared to IEC-compliant met mast at the UK's Lidar & Sodar Test Site

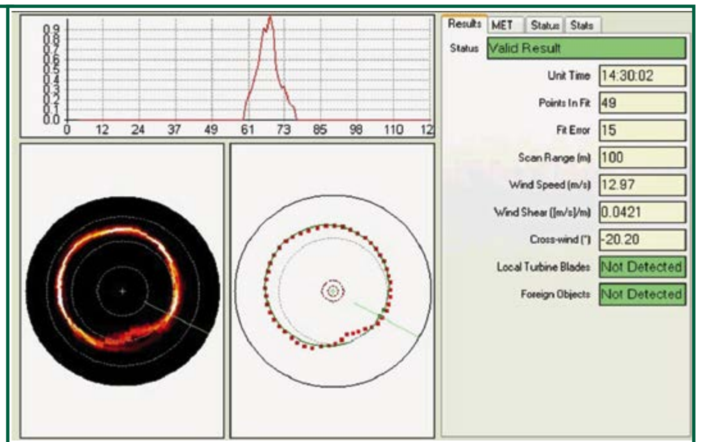

Figure 4. ZephIR Dual Mode screen capture identifying wind speed measurement around a 360-degree scan disc. This permits the calculation of wind parameters including hub height speed, shear and yaw error

The very first practical use of wind lidar by ZephIR occurred in 2003, with the system deployed on a Nordex turbine (Figure 2) performing measurements upwind from the nacelle – a world first. In order to verify its performance claims, ZephIR Lidar embarked on a ten-year research programme to illustrate the performance attributes when compared to more traditional techniques, such as tall meteorological (met) masts and even wind tunnels used to calibrate cup anemometers themselves – another world first.

Verifying Wind Lidar in Ground-Based and Offshore Applications

Over this period of ten years, many performance verifications have been accumulated by ZephIR Lidar. These include:

- Measurements in a high-specification wind tunnel. These confirmed very close agreement over a very wide velocity range ('HTF number 049-2009-3 – Integration of wind LIDAR's in wind turbines for improved productivity and control').
- A Danish National Advanced Technology Foundation (DNATF) project. This project was conducted in close collaboration with LM Windpower, NKT Photoniks and Risø DTU.
- An independent evaluation test of ZephIR 300 wind lidar by Risø DTU, who carried out an investigation on their test site over a five-week period in 2011.
- Comparison of ZephIR measurements against cup anemometry and power curve assessment in collaboration with EDF Energies Nouvelles.
- Performance of ZephIR at greater heights against a 200-metre mast in Iowa, USA.
- Exploring lidar remote sensing technology for offshore wind resource monitoring applications by GL Garrad Hassan.
- 'Best practices in financing wind parks', a white paper by Ecofys, utilising ZephIR 300 and presented by Triodos Bank.
- 'Lidar Calibration and Performance Consistency' presented at the Windpower Monthly Wind Resource Assessment Forum based on a set of 79 trials of ZephIR 300 systems against an IEC-compliant met mast (Figure 3).

The above-mentioned verification studies are supported by some 650+ deployments and 3.5 million operating hours across more than 30 countries where a range of topographies and climatic conditions have been encountered – from Australian summers and Canadian winters to urban environments and complex sites.

With this unique body of evidence, ZephIR Lidar has become widely accepted as a leading provider of wind lidar technology for wind energy applications in ground-based and offshore applications and ZephIR data is regularly accepted as quantitative input for the financing of wind farms by leading banks' engineers. Some relevant quotations are noted below:

- GL Garrad Hassan has engaged with stakeholders in the industry over the last six years to review the development of remote sensing technology and recommend successful deployment strategies. As part of this effort, GL Garrad Hassan defined three stages of development for remote sensing devices to act as a benchmark which is widely recognised.
- Stage 3 has been defined as: 'A device is considered proven for use in the assessment of wind farm sites. The data may be used quantitatively within formal wind speed and energy assessments with only limited or no site-specific validation against conventional anemometry.' The largest body of data available from ZephIR deployments has been characterised by predominance of neutrally stable atmospheric conditions, and simple terrain. GL Garrad Hassan considers that for these conditions, referred to here as 'benign', and subject to appropriate deployment and data analysis techniques, that the ZephIR 300 may be considered to be one of the devices in Stage 3.
- [Natural Power considers that] ZephIR can be recommended as a primary wind measurement system for offshore wind farms. There is

Reprinted from Windtech International June 2013

a significant and consistent body of evidence to support the use of ZephIR in offshore conditions as the sole data capture system.

- Industry acceptance of Lidar measurements, as well as our experience with the flexibility of Lidar deployments, leads Ecofys to recommend Lidar in the following configurations:
  1. Lidar stand-alone on-site. In simple terrain (flat, few obstacles), a Lidar can entirely replace a met mast for the wind resource assessment. This is typically recommended if the erection of a met mast is impossible. A stand-alone Lidar can also be used to characterise a site, for instance evaluating the wind shear around forests.
  2. Lidar next to a relatively short on-site met mast. This can be a cost-effective solution to quantify the wind shear and extrapolate wind speeds to hub height.

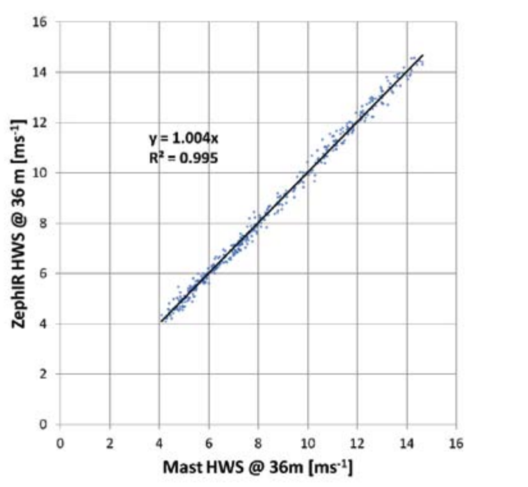

Figure 5. ZephIR Dual Mode measurement of ten-minute averaged wind speed at 90 metre range, compared to corresponding met mast data

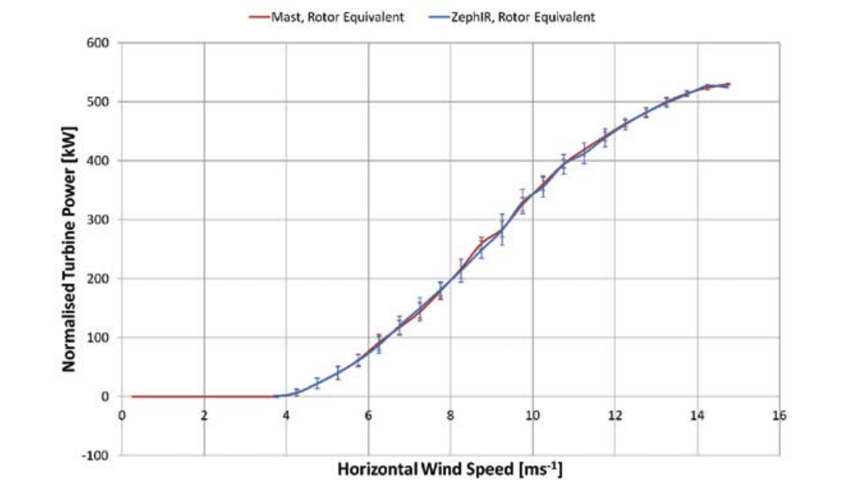

Figure 6. Wind turbine power performance curves, based on equivalent wind speed calculated from ZephIR Dual Mode data (blue curve), and from corresponding met mast data (red curve)

Figure 7. ZephIR Dual Mode

Back to the Roots

Moving forward to 2013 and ZephIR Lidar has released yet another world first – a true dual mode system which is grounded on the validations described above, centred on the same core robust internal components and chassis, yet capable of being deployed in both a ground-based/offshore application and also in a turbine-mounted application. In effect, two for the price of one!

ZephIR Dual Mode (DM) was officially launched earlier this year at EWEA 2013 in Austria, and satisfies the emerging needs of many developers, turbine manufacturers and wind energy consultancies progressing both onshore and offshore developments for power curve measurements (both relative and absolute), condition monitoring, yaw calibration and performance optimisation. These applications can only be delivered due to a key set of technical capabilities including:

- full rotor disc measurements, because of ZephIR's conical scan pattern (Figure 4);
- standard, verified measurements (see above) of horizontal wind speed, turbulence and yaw alignment/misalignment;
- vertical wind shear measurements, unique to ZephIR's 50 measurements taken around the scanning perimeter;
- measurements at ±2.5% of hub height (requirement of Power Performance Testing IEC Standard 61400-12-1) and ±1% in new draft standard (IEC 61400-12-1 CD).

These capabilities permit the measurement of 'rotor equivalent' wind speeds, which account correctly for flow complexities, such as shear, on the actual turbine performance. Conventional measurements based on hub height speed alone are incapable of providing this information, which is being considered for inclusion in future power curve standards.

Although a new product in the market place, ZephIR Dual Mode has already been fully tested and delivered commercially in its intended application. While it is not possible to report many of the projects that have been undertaken because of commercial restrictions, a couple of case studies are summarised below, with further studies available on request:

- A demonstration and quantification of turbine performance improvements after turbine tuning was undertaken on a 2MW NEG-Micon turbine with a 72-metre rotor diameter situated in flat terrain in Eastern Jutland, Denmark, featuring a nacelle roof mounted, dual mode, ZephIR 300 lidar. Yaw errors of 14 to 16° that became evident from ZephIR yaw alignment measurements were remedied by nacelle wind vane recalibration part way through the campaign. Effects were clearly visible in the ZephIR measured power curves pre- and post- yaw recalibration with an estimated improved AEP of approximately 5% after yaw recalibration.
- A ZephIR Dual Mode unit has been installed on the nacelle of a test turbine at Risø DTU since December 2012. The deployment has allowed the lidar data to be compared against high-quality met masts at two ranges in front of the rotor plane. Shear, veer and turbulence have all been investigated along with the standard parameters such as hub height speed and direction. According to Professor Torben Mikkelsen of DTU Wind Energy during the final presentation to project stakeholders: 'The Nacelle mounted ZephIR installed at DTU Risø Campus as part of a Danish Advanced Technology Foundation Wind Lidar project apparently provided results as accurate as a calibrated met mast'. Results from this trial will be published shortly but an initial set of mast comparisons demonstrating the excellent agreement is shown in Figures 5 and 6.

A further study, 'Quantifying Lidar Benefits for Turbine Control', A collaborative study with GL Garrad Hassan, September 2011 to July 2012, notes that: 'Both pulsed and continuous-wave Lidar types are suitable, as long as they can sample something like 10 points distributed around the swept area every second or so and provide a few seconds of look-ahead time.' ZephIR is the only production lidar in existence that meets these requirements.

Data is Only One Part of the Jigsaw

With a lot of experience in wind energy deployments, ZephIR Lidar has not only delivered the requirements of data performance verification but also addressed the key practical concerns listed below gathered from a number of focus user groups:

- A compact design able to fit through turbine hatches and turbine internal spaces with a low enough mass for easy two-person deployment.
- A mounting system that is safe to use, and capable of deployment on a variety of nacelle roofs.
- On-lidar aids for alignment with the turbine axis, essential if the lidar is to be used for turbine yaw optimisation.
- A robust, integral and sealed design to avoid issues with sensitive connection cables.
- A core system design with associated factory quality assurance calibration processes in place to ensure pre- and post-deployment measurements at an IEC-compliant mast show no deviation.

A ten year chronology of wind lidar evidence, with ZephIR Lidar

At the heart of ZephIR Lidar technology is a core innovation team based in the UK, fed by the requirements of an evolving industry and close collaboration with key partners and clients. However, an industry founded on reducing the risk associated with substantial financial investments is driven only by equally substantial bodies of evidence on new technologies. After a decade of experience, some of which is referenced here, ZephIR Lidar has a demonstrable track record across the full range of applications – ground based, offshore (both floating and fixed) and now turbine mounted in this latest product variation, ZephIR Dual Mode (figure 7). ■

Biographies of the Authors

Michael Harris received a First Class degree in Physics from Oxford University in 1980. Following his PhD in Atomic Physics from the University of Newcastle, he worked at the Joint Institute for Laboratory Astrophysics (JILA), Boulder, Colorado, and at the University of Essex. He joined DRA (now QinetiQ) Malvern in 1993, and became a Fellow of the Institute of Physics in 2001. He has contributed to the invention and design of a variety of lidar systems including ZephIR Lidar. Until 2008 he was Technical/Team Leader for Remote Sensing at QinetiQ Malvern, and is currently Chief Scientist at ZephIR Ltd, where he continues to develop and promote laser anemometry for use in the wind energy industry.

Alex Woodward studied Product Design & Development at university, being awarded a First Class Honours degree, and subsequently received awards from Dyson for his innovative approach to developing new products in addition to a place in the Top 15 UK Graduate Designers listing. He joined DERA (now QinetiQ) Malvern in 2002, and became marketing lead for the company's airport technology stream. Moving to a Fred. Olsen related company in 2007 following the acquisition of ZephIR Lidar by the same company, Alex is now Head of Marketing for many of these related organisations including ZephIR Ltd, driving forward the adoption of wind lidar technology within the renewables industry. He also project managed the development of ZephIR 300 in 2010, which forms the core of the company's latest innovation – ZephIR Dual Mode.

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