Technology Review

Scanning Doppler wind lidar for wind field measurements

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Scanning Doppler wind lidar allow remote wind measurements for wind resource assessment, power performance measurements, and other wind field diagnostics.

This document provides a short perspective on the state of the art in scanning wind lidar for wind energy applications. For more information, or to have this customised to your needs, please contact us.

Figure 1: Scanning wind lidars allow wind speed and direction to be measured from up to 10 km away. Image courtesy of Stuttgart Wind Energy, University of Stuttgart.

Contents

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1 What is it?

Scanning wind lidar allow wind speed and direction to be measured remotely (Figure 1).

Some devices are able to measure at distances of 10 or 15 km. This allows wind resource measurements across large areas using a single device rather than multiple masts, power performance measurements for multiple turbines at the same time, and is an enabling technology for wind farm control as it can measure wind fields (and wakes) across a wind farm in close to real time.

Also, because scanning wind lidar can measure wind data hundreds of meters above ground, they can be used to measure wind speeds at the tip of modern wind turbines, which is very difficult and expensive with a meteorological mast (Figure 2).

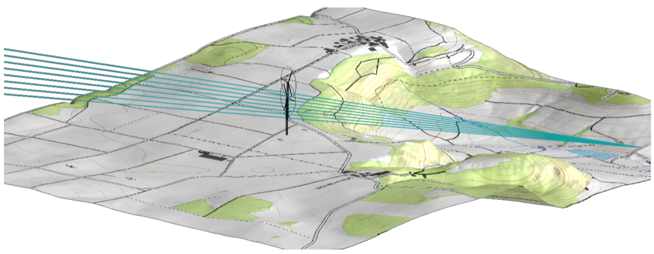

Figure 2: Here a scanning lidar is used to measure the wind field near a wind turbine from several kilometers away.

2 How does it work?

A scanning wind lidar allows wind speed and direction to be measured remotely using laser light. The measurement path can be set arbitrarily by the user in a hemisphere around the lidar.

The laser light is emitted by the device and then reflected back to the source by dust or water particles. These particles move in the wind. The wind speed in the line of sight is established from the Doppler shift of the reflected light, compared to the emitted light.

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A wind field can be calculated by probing different points in a volume (e.g., the corners of a box), recording the azimuth and elevation of the line-of-sight and the wind speed in the line of sight, and then fitting the data assuming e.g. the same wind direction at all points (Figure 3). This process is called *wind field reconstruction*.

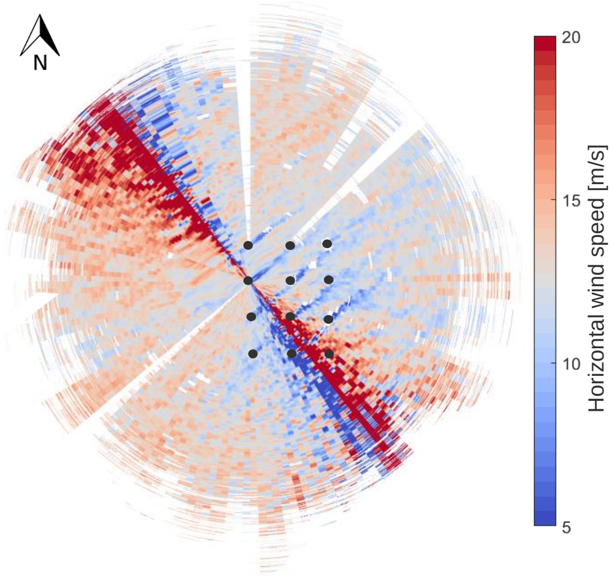

Figure 3: Wind field at the offshore wind farm alpha ventus obtained from a scanning lidar [1]. Perpendicular to the wind direction, the scanning lidar (and all other lidars) measure very small line-of-sight wind speeds and the wind field reconstruction fails.

If a single scanning lidar is used to measure the wind, it is necessary to apply assumptions e.g. that the flow is uniform at all the measurement points to allow the wind vector to be estimated. This assumption can be violated in some flow conditions, for example in complex terrain, in a wake, or around a wind turbine or wind farm.

It is possible to coordinate two wind lidar so that they measure at the same point – from different directions – simultaneously. This approach is sometimes known as *dual Doppler* measurement. It allows the wind vector to be calculated at that point if some assumptions are made [see e.g., 2]. If three lidar are used, no assumptions are required; this is often described as *Multilidar* measurement [see e.g., 3]. These approaches offer the ability to create virtual met masts in almost any location within range of the devices. They also offer increased accuracy in areas of hilly terrain. Because of cost and complexity, dual Doppler and multilidar systems are almost only used in research applications.

3 How is it used?

The major use cases for scanning wind lidar for wind energy are for applications where met masts would usually be used, but their deployment would be too difficult or expensive. These include pre-construction wind resource assessment on land or offshore; monitoring winds and wakes in large wind farms; and power performance measurements. The main applications are summarised in Table 1.

It is not known if data from a scanning wind lidar have ever been used as part of a financing package, or as part of a contractual power performance test.

Scanning wind lidar are also often used as research tools to help measure and visualise wind fields. Researchers value their flexibility and ability to adjust many of the operating parameters of the device.

4 How mature is the technology?

The technology is mature and has been available as an off-the-shelf product for over a decade. The technology readiness level (TRL) of the equipment itself is thus 8-9. The surrounding ecosystem for deployment, monitoring, and data evaluation is concentrated in a few specialist consultants. As a result independent engineers are not always confident in assessing data obtained from scanning lidar (TRL 7).

The majority of current users in the wind energy sector are researchers, early adopters, or have no other way to obtain the data they require. Most measurements use single scanning lidar, but a few multilidar are in use in research. Different applications of scanning lidars have reached different stages in adoption (see Figure 4).

5 What standards exist?

Scanning wind lidar can be mounted on a turbine nacelle and configured to measure the wind upwind of the turbine. This application was standardised in 2022 in the IEC 61400-50-3 standard.

There are no IEC standards for the use of scanning wind lidar for wind resource assessment or wind field measurements in the wind energy sector. We are not aware of plans to standardize these applications by the IEC.

Some community guidelines exist. In 2015, participants in IEA Wind Task 32 published an overview of the use of scanning wind lidar and gave some preliminary recommendations [8]. We expect IEA Wind Task 52 on the large-scale deployment of wind lidar (the follow-on from IEA Wind Task 32) to initiate guidelines for the use of scanning wind lidar for wind resource assessment and other wind field measurements in 2022, with publication in 2023.

Table 1: Applications for scanning wind lidar during the development and operation of a wind farm

Application	Benefits of using scanning wind lidar
Resource assessment	
• Wide-area wind fields	Measure wind vectors over large areas at distances up to 10 km; possibility to retrieve turbulence information using multilidar configurations [2]
• Virtual met mast	Retrieve wind data and wind profile information at multiple locations at significant heights above ground [e.g., up to 600 m in 3]
Construction	
• Wind monitoring during lifting operations	Can be used as an flexible anemometer to ensure safety and avoid heavy lifting during wind gusts
Operation	
• Power performance measurements from a turbine nacelle	Standardized [4]; can be done on land or offshore; easy access offshore by helicopter
• Power performance measurements from an offshore wind turbine's transition piece	Can be tested on land; easy access by boat (compared to the nacelle) [5]
• Wind & wind power forecasting	Potential for >10-minute warning of wind ramps [6]
• Wake monitoring	Can trace the wake of a single turbine and a whole wind farm to check the impact of the wake deficit or for wake model validation [7]

6 What are the challenges with it?

The major challenges in using scanning wind lidar are:

- A scanning wind lidar can be several times the cost of an 80- or 100-m met mast on land.
- Setting up a measurement campaign requires considerable expertise.
- Setting up a scanning lidar data processing pipeline can be challenging. There is no standard method for data processing.
- The uncertainty of a windfield reconstruction is difficult to estimate. Although there are tools to estimate this [e.g., MOCALUM 9], there is insufficient benchmarking of their accuracy.
- Difficulty in retrieving turbulence intensity.

More details about the opportunities and barriers to the adoption of scanning wind lidar are in [10].

7 What's coming next?

We expect to see continued product development and cost reductions, as well as pre-normative guidelines or best practices for some applications. We also expect improved data processing tools, likely leveraging community efforts.

8 How do I get started with it?

Because of the great flexibility of scanning wind lidar, there is no one way to use a scanning wind lidar. However, the process can be generalised, and an overview of how to design and execute a measurement campaign using scanning wind lidar can be found in [11].

Training on the specific device(s) being used is strongly recommended. New users may also benefit from support by a third party who has specialist scanning lidar experience during early campaigns. This can help overcome the barriers noted above and increase end-users' confidence in the data.

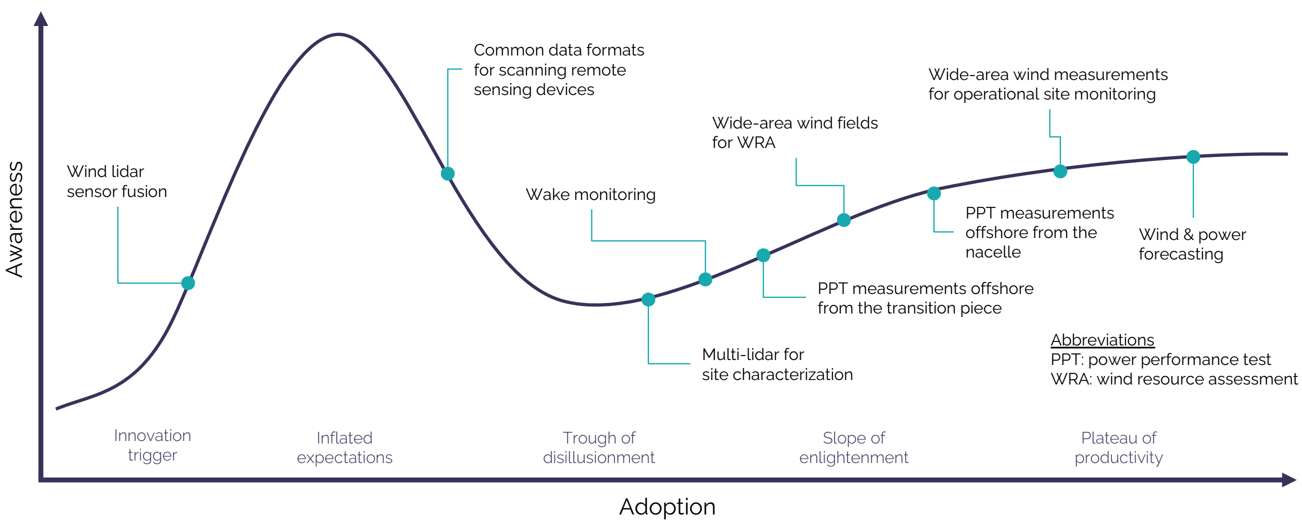

Figure 4: The hype cycle for several common applications of scanning wind lidar in wind energy.

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9 Suppliers

Scanning wind lidar models are differentiated on characteristics such as scanning range, weight, power requirements, or flexibility of use. Many organisations offer scanning Dopppler wind lidar. For example:

- **Vaisala** offer several WindCube Scan models.
- **HALO Photonics** offer the StreamLine series.
- **LEICE** (QINGDAO Leice Transient Technology Co. LTD.) offer several scanning wind lidar
- **Lockheed Martin** offer the WindTracer system.
- **Raymetrics** offer a range of atmospheric lidar systems, including Doppler wind lidar.

Inclusion in this list is not an endorsement. It is not complete, and we welcome suggestions.

10 User groups

Several groups exist to help users. These cover a range of applications and TRL:

- **The Consortium for the Advancement of Remote Sensing (CFARS)** is a broad wind energy industry consortium on a mission to accelerate adoption of remote widn sensing devices for wind energy applications.
- **IEA Wind Task 32, "Wind Lidar"** Operating from 2011 to 2021, this international group coordinated wind lidar R&D and published several Recommended Practices for the use of wind lidar.
- **IEA Wind Task 52, "Large Scale deployment of Wind Lidar"** started operating in 2022 and will explore the issues associated with the scale-up of wind lidar use in the wind energy industry.
- The **PROBE COST Action** is funded by the European Cooperation in Science and Technology (COST). PROBE bridges between user needs and the expertise residing in industry and academia, and will strengthen and harmonize methods to get higher quality boundary layer observations.

11 Our experience

At enviConnect, we have used scanning lidars for different applications. We've set them up in complex terrain to measure wind profiles over mountain ridges. And we've put them on top of wind turbine nacelles to use the preview wind speed information for minute-scale forecasting.

Our take away for this technology:

- The wind field visualisations that can be achieved with this technology are spectacular and insightful.
- Scanning wind lidar can be used to replace fixed met masts in many situations.
- The configuration of scanning lidars is very dependent on the application. This also means that the data processing needs to be adapted to your needs. As there is no toolbox available (so far – we are working on it), this takes expertise and time.
- Scanning lidars can be quite heavy and big. Depending on the application, it is crucial to choose a device that you can still move flexibly (for example, when we put it on top of the nacelle).
- The measurement range of a scanning lidar depends on many factors. Environmental conditions are important; in rainy or foggy conditions, the range decreases significantly. This is actually true for all Doppler lidars, but more pronounced for the long-range scanning lidars. You may not always be able to measure at a target distance.

We are happy to help you figure out how to use scanning wind lidar in your business. Get in touch.

Feedback and updates

Please send any feedback to info@enviconnect.de. Check for new versions of this document here.

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