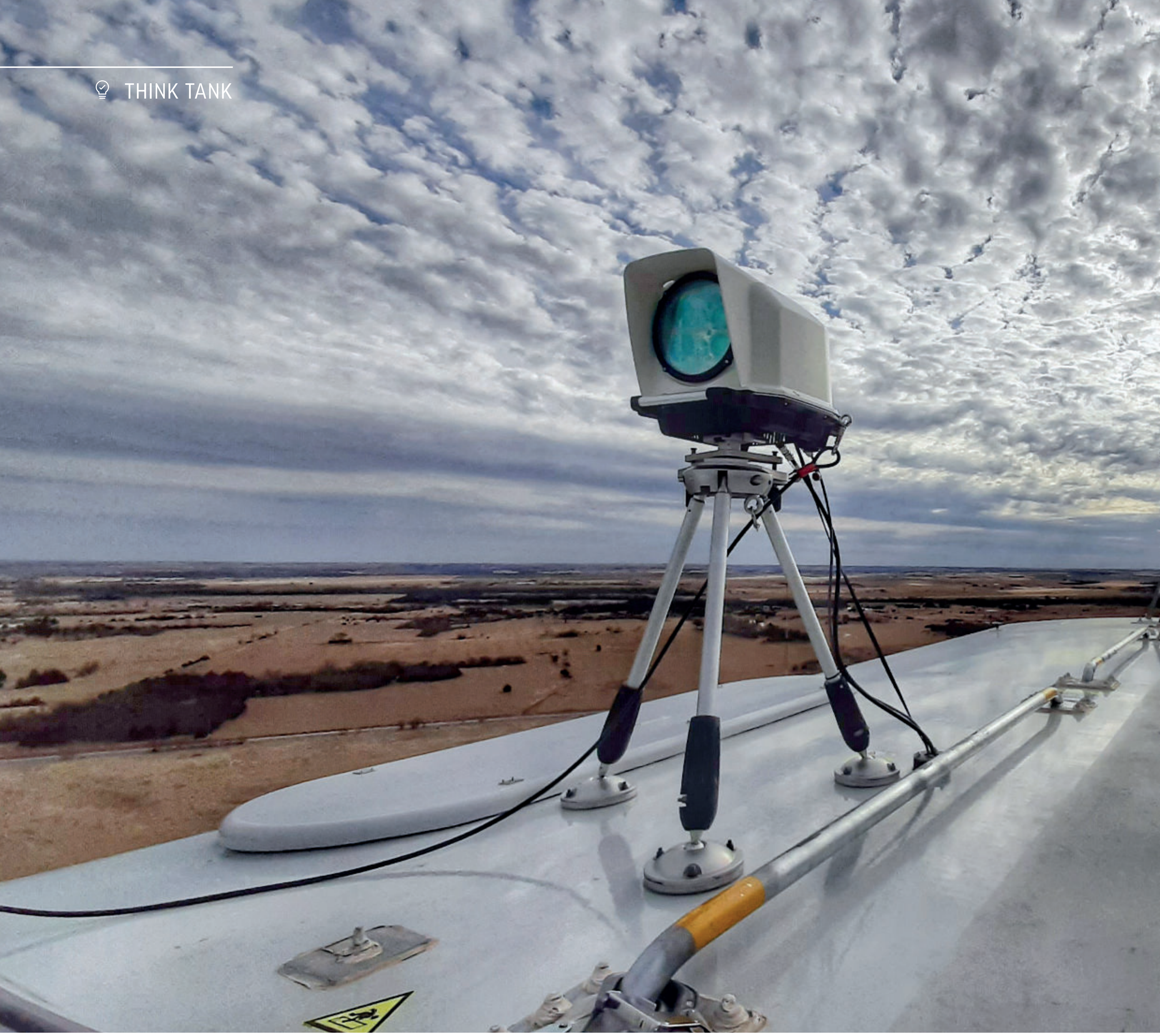
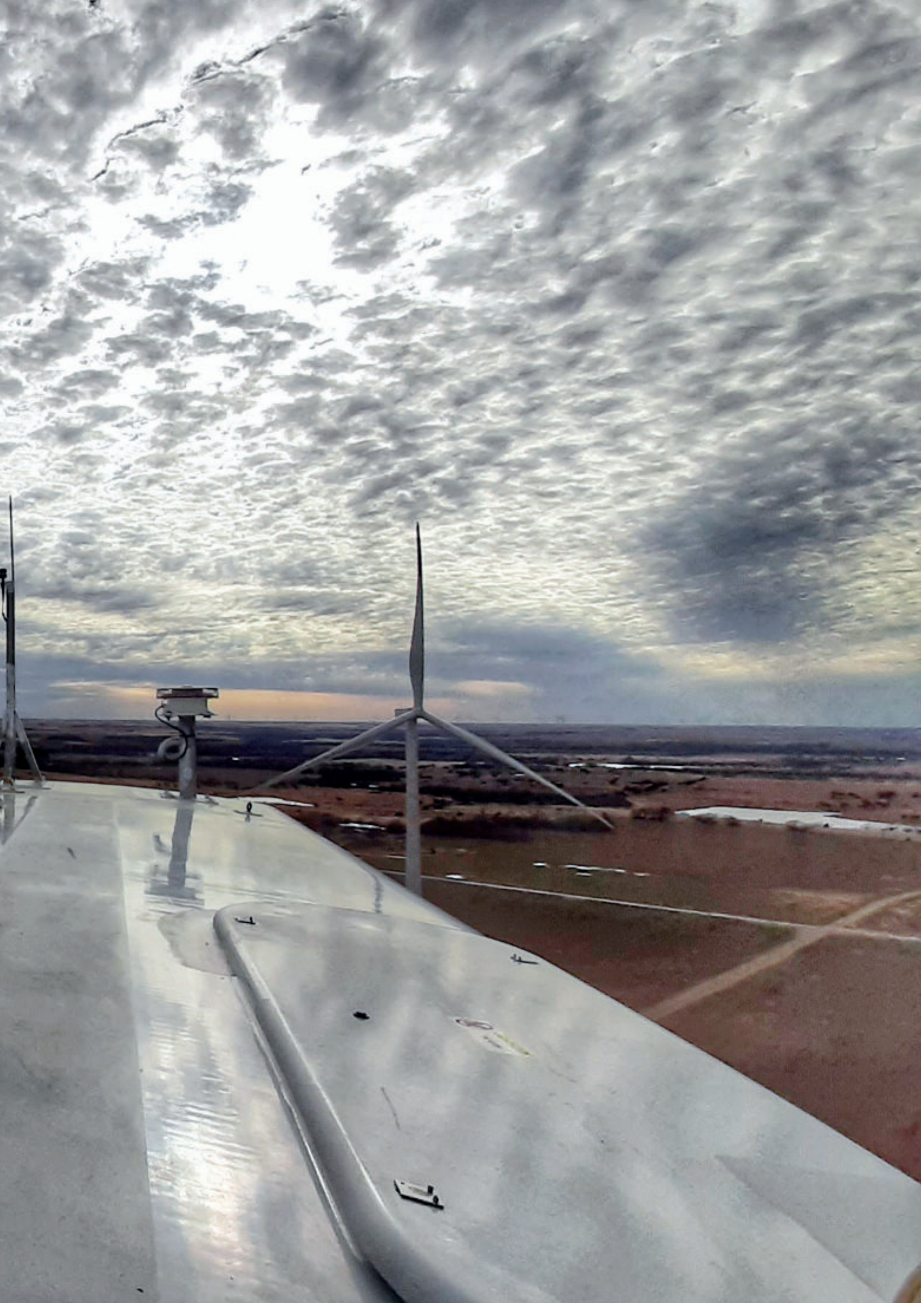


Leveraging nacelle-mounted lidar for power performance testing

As turbines grow in stature, power performance testing and verification become even more important, with underperformance equating to reduced power output and lost revenue. Can nacelle-mounted lidar, with its flexible measurement range, provide a complete testing solution?



All around the world, the demand for wind energy is growing, both onshore and offshore. Not only are mature markets continuing to invest in wind energy, but there is also interest in emerging markets.

As this industry continues its global expansion, an increasing number of projects are springing up in hard-to-access, remote areas. For offshore wind farms, that means deeper waters further from coastlines, where wind farms can cover larger areas, erect bigger turbines and generate more energy. In onshore environments, wind farms are moving to more complex terrain sites. What's more, wind turbines are constantly growing taller and more powerful in attempts to decrease the cost of producing electricity from wind.

The power of power performance testing

Combined, these trends make accurately assessing wind characteristics much more challenging. With more expansive areas and taller turbines, it is becoming increasingly important to derive the strongest performance and economic value from wind farms. To achieve that, Power Performance Testing (PPT), also known as power curve verification, is critical.

With these trends, the limitations of traditional meteorological masts are more apparent. Met masts are expensive and challenging to install, and they can no longer accurately measure up to the full height of modern turbines without mathematical extrapolation, which increases uncertainty.

As a result, wind energy organizations are embracing the accuracy, flexibility and cost-efficiency nacelle-mounted lidar delivers for PPT campaigns.

Nacelle lidar classification

Today, the current power performance standard (IEC 61400-12) is undergoing a restructuring process. The main difference with the new structure is that the wind measurement methods are being treated separately from the PPT guideline.

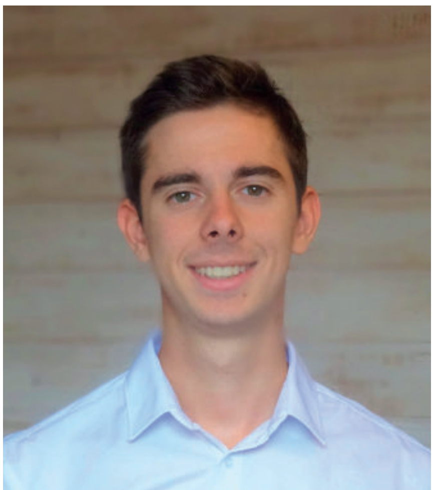
Consequently, there will be one standard for instruments mounted on a mast, one for ground-based lidars, one for nacelle lidars and another for floating lidar systems. This restructure should allow for easier maintenance of the individual standards.

Since environmental conditions during a specific measurement campaign can differ from those during calibration, the influence of environmental variables (EVs) on the measurement accuracy needs to be accommodated in uncertainty analyses. According to the soon-to-be-released IEC 61400-50-3 standard, this can be done via a nacelle lidar classification. This classification involves a two-step approach.

The first step is to study the sensitivity of the lidar intermediate values, line of sight measurements, to EVs. The EVs considered in sensitivity analysis include air temperature, pressure, relative humidity, density, cloud base height, aerosol density, turbulence intensity, linear wind speed variation within the lidar probe volume and nonlinear wind speed variation within the lidar probe volume.

The allowed methods for assessing EVs are comparison with reference measurement systems, testing in a lab, and simulations or theoretical analysis. Based on the relationships between these values and lidar intermediate values, we can determine which EVs, if any, are considered significant and taken into account during the uncertainty analyses.

The second step is to confirm, using an evidence base, the accuracy of the lidar Wind Field Reconstruction (WFR) algorithm. This evidence base is composed of several campaigns where measurements from measurement instruments, such as met mast, are compared with the nacelle lidar final outputs, such as horizontal wind speed. The evidence base requires at least five campaigns, where the lidar must be installed in an operating turbine in a minimum of two of the campaigns.



Robin Cote

The off-nacelle tests determine if the WFR model works and can provide accurate final values in a stable environment, while the on-nacelle campaigns are the ultimate test of whether the WFR can provide good final values while tilting, yawing, being blocked by the blades or dealing with any other issue associated with sitting on top of an operating turbine.

Preliminary classification results performed by DNV show that the WindCube Nacelle WFR algorithm meets the IEC-50-3 requirements. The accuracy requirements are fully satisfied for the on-nacelle evidence base, and the off-nacelle evidence base preliminary results show that the criteria are already satisfied within the majority of wind speed bins.

The outcome of the classification is that lidar manufacturer will be able to provide the end-user with:

- A list of EVs, if any, that can have a significant impact on lidar intermediate values i.e. line of sight measurements.
- An evidence base that proves the accuracy of the WFR algorithm.

When performing a measurement campaign, the end-user will assess the difference between environmental conditions obtained during the classification campaign and the specific measurement campaign.

In case the conditions observed during both campaigns are similar, no additional classification uncertainty is required in the standard uncertainty calculation method. Otherwise, the uncertainty due to changes in the significant EVs should be taken into account when calculating the final horizontal wind speed uncertainty.

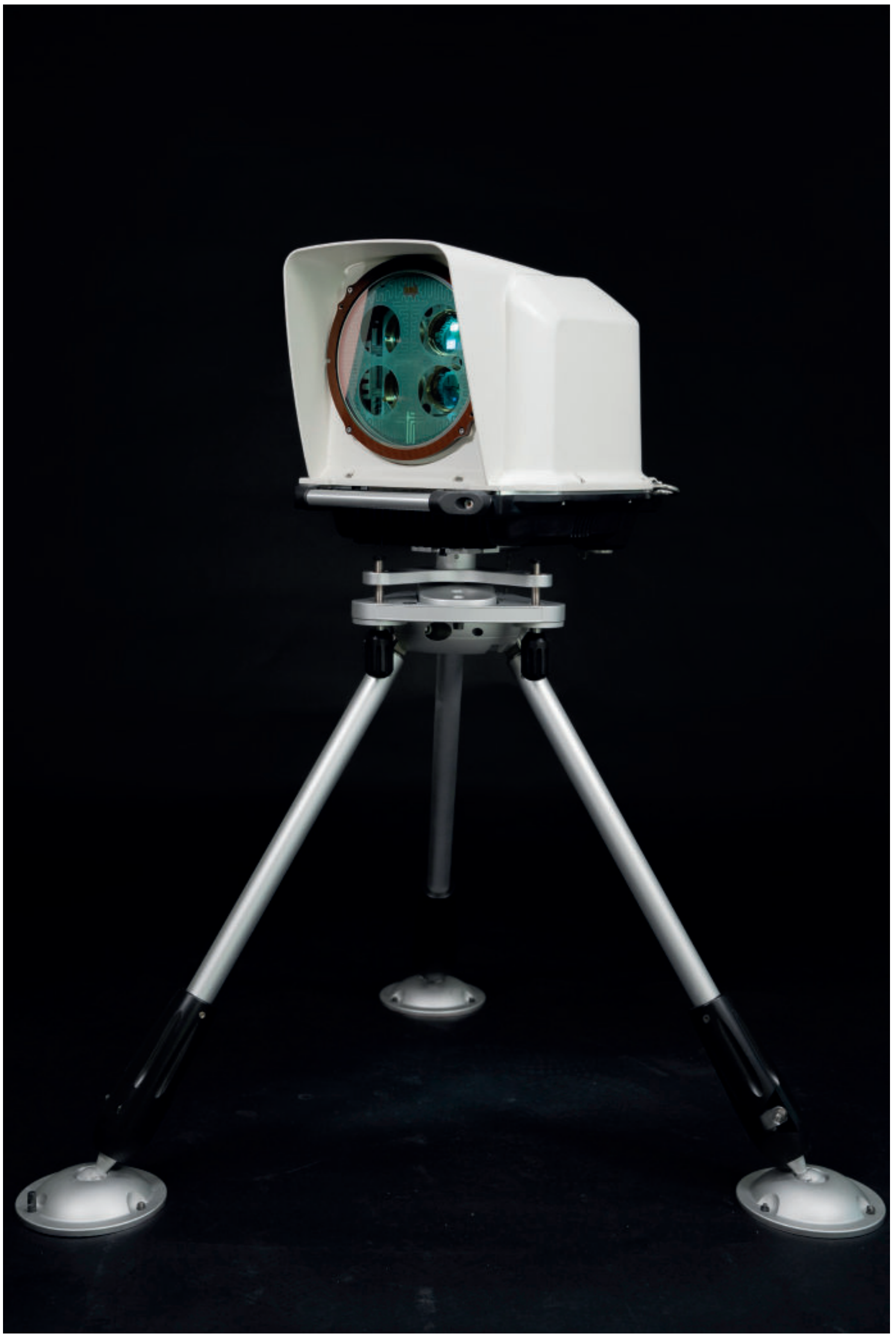
Nacelle lidar in action: preliminary findings from a joint study in Oklahoma

In anticipation of the release of the IEC-50-3 standard and to support the power performance testing program of ENGIE, a multinational utility company, a joint study between ENGIE North America, GE, Leosphere, a Vaisala company, and DNV was conducted in Oklahoma in the US.

As an owner and operator of wind projects, ENGIE aimed to optimize its power performance testing program by evaluating how the different standards, technologies and wind measurement locations could affect the results.

With the evolving power purchasing agreement vehicles in the market, nacelle transfer functions (NTFs) become important to accurately calculate the approximate generations, and ENGIE wanted to validate the NTFs used by the wind turbine original equipment manufacturers.

For this study, WindCube Nacelle lidar, an IEC-compliant hub height permanent met tower and WindCube ground-based lidar were all deployed. The three power curves constructed using the hub height wind measurements collected from each instrument were almost identical, and the differences in annual energy production values are negligible, with slightly higher uncertainty using WindCube Nacelle, by about 0.1%.



Even better, correlations between the NTFs of OEMs against those measured by the permanent met tower and the WindCube lidar are excellent. Plus, the study revealed that nacelle-mounted lidar is often the most reliable device to measure yaw alignment.

With the study clearly indicating that power performance testing results using WindCube Nacelle are comparable with those from the met tower and ground-based lidar, nacelle-mounted lidar is a useful technology to support wind project operations and a unique tool to accurately measure yaw alignment and verify nacelle transfer functions.

Nacelle Lidar installation considerations

With the increasing usage of nacelle-mounted lidar for both onshore and offshore power performance testing, there are a couple of practical points to keep in mind when planning a nacelle lidar installation. Here are key aspects to consider based on GE installation guidelines.

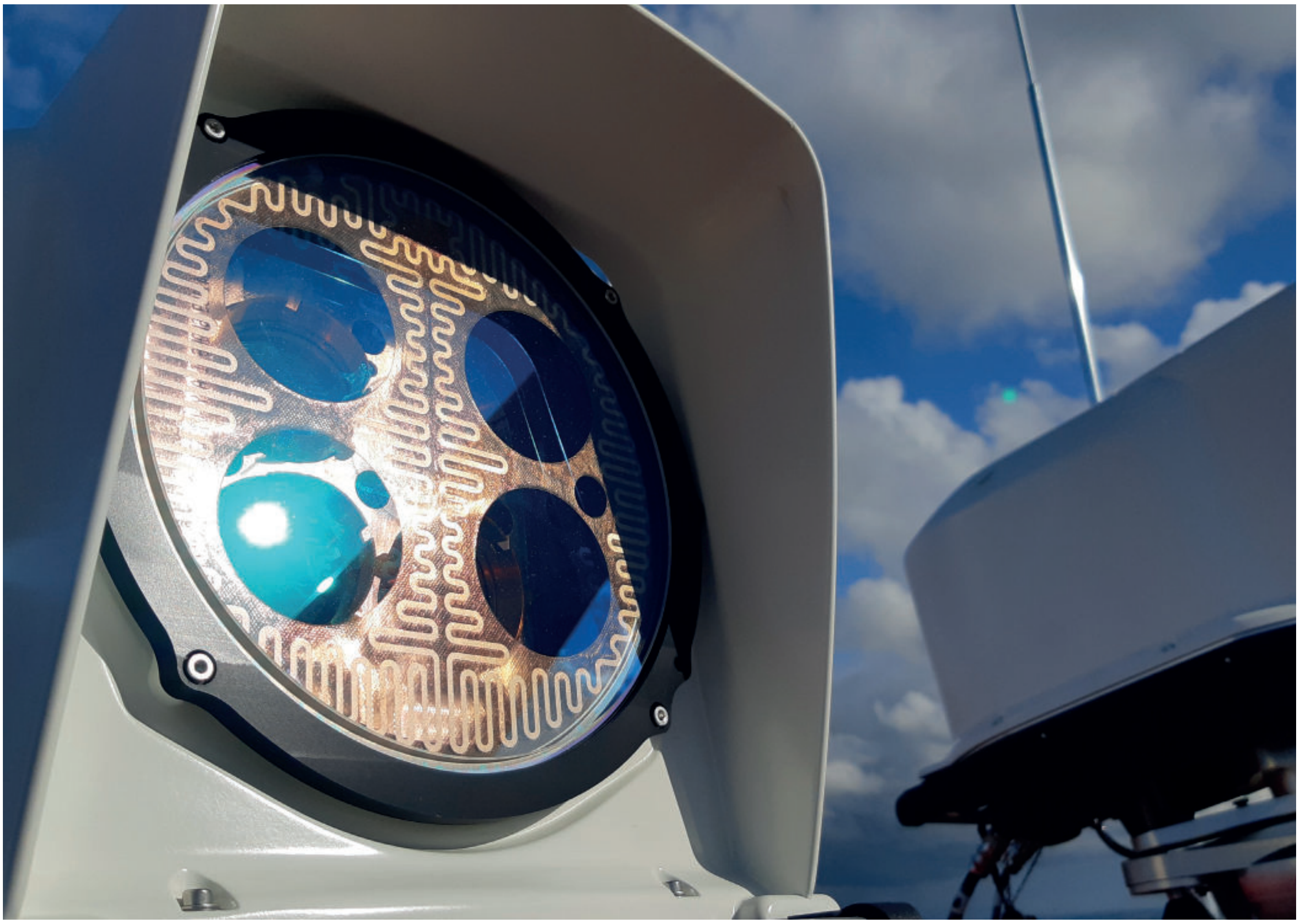
First and foremost is safety. It's vital that the nacelle lidar stays on the turbine for the intended period of time, so access to an anchor point and a lightning ground is important.

The next consideration is loading. Can the nacelle shell handle the extra loading that will be placed on it? There is a wind drag on the nacelle lidar devices, which can introduce higher fatigue and extreme loads that need to be evaluated.

Location is also important. Are there any downwind items that could be obstructed by the lidar device? Also, lidar beams need to have a line of sight out into the wind field in front of the turbine, and if there's no clearance over that nose cone, there will be some impact on the data quality.

Another crucial consideration is how the data will be retrieved. In a typical power performance testing campaign, there can be a dedicated data collection system that works via radio and cell modem, but it is also possible to integrate data into turbine SCADA systems, however, that path is much more complex and creates cybersecurity concerns.

Access to a power source is another consideration. Be sure to confirm its availability. WindCube Nacelle is installed with a processing unit that takes in the lidar data and computes the wind field, and that processor needs to be mounted in the nacelle with easy access and out of the way.



Lastly, are the environmental sensors. Are there dedicated devices on the nacelle lidar or do they need to be installed? The answer depends on your purpose, on the scope and on the target of a campaign.

The key takeaway? Engage early. While every installation is unique based on site-specific conditions and the objectives of the campaign, GE's standard guidance answers all of the aforementioned installation consideration questions for most situations.

Conclusion

As turbines continue to grow taller, power performance testing and verification become increasingly important, as underperformance equates to reduced power output and significant lost revenue. Fortunately, nacelle-mounted lidar, such as the WindCube Nacelle, with its flexible measurement range, provides a complete picture of the wind profile, with accuracy and reliability as good or better than met masts, ultimately enabling wind farm operators to maximize power output and profit.

Overall, this collaborative campaign was an opportunity for four key industry players to gain high confidence in performing power performance testing using WindCube Nacelle and ensure a cost-effective and straightforward approach throughout installation, data collections and data analysis.

The joint campaign also brought compelling evidence of the technical suitability and industry readiness for PPT using nacelle-mounted lidar according to the IEC-61400-50-3 standard.

www.vaisala.com/en/wind-lidars/wind-energy

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About the author

Robin Cote is a Product Manager at Leosphere, a Vaisala company, where he is responsible for the nacelle mounted lidars portfolio and is responsible for building and driving the WindCube Nacelle roadmap. Before joining the wind energy industry, he worked in the aerospace industry in several product management positions. Robin is currently located in Saclay, France.

Co-Authors

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Luke has been focused on power performance testing of wind turbines for 15 years. As a principal specialist at DNV he is also an active member of several IEC committees including the 61400-50-3 nacelle lidar project team. Luke has led research and innovation projects around the application of nacelle lidar, including in complex terrain, since 2013. Currently he is working on a variety of lidar measurement applications to provide the industry with the highest quality results for understanding and managing their assets.

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Hong has a PhD in Atmospheric Science and has over 20 years' experience in renewables industry supporting project development and operations in North America. Hong currently leads the Resource Assessment team and manages power performance measurements for Grid-scale Renewables at ENGIE North America.

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Alex holds a master's degree in mechanical engineering from Cornell University and has worked in the wind industry for six years. Five of those years have been with GE Onshore Wind improving performance through modeling and measurement. He has been a user of ground-based lidar data for performance measurement throughout that time and more recently taking on additional responsibility for nacelle lidar turbine integration for the GE Megawatt Constrained fleet.