Nacelle-mounted lidar: New advances in Power Performance Testing, optimization, and financial outcomes in wind energy
Today, even a minor difference between estimated and actual energy output creates substantial financial impacts. While developers and operators expect to get the energy output promised by manufacturers, they can’t know if they are succeeding without accurate Power Performance Testing (PPT) data. They are also unable to identify and take corrective actions that can extend the life of the turbine and reduce annualized cost of energy.

Enter nacelle-mounted lidar. With its exceptional accuracy and range, economical design and small footprint, nacelle-mounted lidar is one of the most reliable and affordable ways to assess a turbine and enable IEC-compliant PPT. Recent advances in the lidar itself and the software that interprets its data are revolutionizing wind farm operations.

This eBook explains how nacelle-mounted lidar works, how it is changing PPT, and why it is such a powerful solution for today’s ever-growing wind turbines and farms.

$500,000

Revenue loss from a 1% decrease in annual production (100 two-megawatt turbines)\(^1\).
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How does nacelle-mounted lidar work?

Wind speed measurement and the Doppler effect

Lidar emits light pulses at a very high frequency, and these light pulses are reflected back by aerosols in the atmosphere. The Doppler effect allows the lidar to accurately compute the speed of those particles — and, thus, the speed of the wind carrying them through the atmosphere. Today, wind lidar is used for a wide range of applications in wind energy, aviation, and meteorology.

Notably, WindCube© Nacelle operates on a pulsed lidar principle, which provides several important advantages over other lidar types. Pulsed lidar maintains constant accuracy over the entire measurement range, and it offers the highest accuracy, data availability, and sample rates regardless of weather conditions.

Nacelle-mounted lidar has evolved substantially in recent years. For example, earlier generations of WindCube Nacelle (formerly called Wind Iris) measured up to 450 meters at 10 measurement distances. This was extremely useful, but today's version covers a measurement range from 50 to 700 meters at 20 separate distances, dramatically increasing PPT quality and making it suitable for even the largest turbines likely to be deployed now or in the future.

**WindCube Nacelle measures from 50 to 700 meters at 20 separate distances, dramatically increasing PPT quality and making it suitable for even the largest turbines likely to be deployed now or in the future.**
The best technology for the job

Once a wind turbine is deployed, its operators depend on its performance to match manufacturer expectations. Underperformance can be extremely costly — and without good wind data, it can go unobserved for months or years.

Back when turbines were smaller, this was less of a problem. But now that the scale of wind turbines has increased so much, so has the scale of the financial losses when they aren’t operating at maximum capacity. Even slight underperformances are no longer acceptable.

Traditionally, the way to assess power performance was to use a met mast. But because of their costs and logistical challenges, many wind operators simply skipped using them. One reason why is that you need to have both the met mast and the turbine aligned with the wind direction — meaning that frequent changes in wind direction can invalidate the measurements. Another is that the costs and logistical constraints are often too high for such a short measurement period. Nacelle-mounted anemometers are cheaper to use, but they are not accurate enough for reliable PPT.

Nacelle-mounted lidar, on the other hand, is much quicker and easier to deploy, and it collects data much faster. It is always aligned with the wind turbine because it moves with it, and it is typically half the cost (or less) of using a met mast, particularly for taller and offshore wind turbines. Lidar also uses multiple laser beams to cover the whole rotor area, creating more representative wind data that accounts for shear values and other influences acting in three dimensions. (This data, while not mandatory, can now be included in PPT for improved accuracy and higher certainty following IEC rules.)

Expert groups from IEC and independent consultants are also preparing guidelines for using nacelle-mounted lidar in complex terrain for the next revision of IEC standards.

The bottom line is that nacelle-mounted lidar is here to stay. It is the best solution for PPT — both onshore and offshore — and its continual improvements are making wind farms more profitable, reliable, and efficient.
Power Performance Testing in detail

PPT is the most critical application for nacelle lidar, since it provides operators and other stakeholders the power curve data they need to verify the performance of a wind farm project. Enormous financial resources are at stake in any PPT project.

Critical factors in PPT include:

- Ability to accurately verify turbine power performance
- Comparison of actual power curves with warranted power curves
- Reduced logistics for setting-up and operating the measurement system
- Optimized OPEX
- Rapid data completion
- Presentation and analysis of power curve data in an IEC-compliant format
- Ensuring measurement traceability
Power Performance Testing planning and key steps

Four steps to success
A correctly managed PPT campaign is broken down into four stages.

1. Design
Plan the campaign as much as possible in advance

- Check the quality of the system for every device used in the campaign

2. Verification

3. Operation
Install, operate, and monitor throughout the campaign duration

- Extract data and act on it

4. Analysis

Step 1: Design

The first decision in campaign planning is choosing which turbine(s) to measure. Operators can typically help minimize the length of the PPT campaign by selecting the one with the biggest opening sector.

Process

- Decide on the needed applications: contractual or operational PPT, checking production increases after turbine upgrades, yaw alignment and nacelle-transfer function verification, research and turbine prototyping. (One data set can be used for multiple applications.)
- Select the wind turbine to test: Maximize open sector following various rules
- Anticipate installation steps including OEM authorizations and network access
- Key documents:
  - IEC - 61400-12-1
  - IEC - 61400-50-3 – CDV (available as draft, and expected to be released from mid 2021)
  - Lidar manufacturer installation and safety guidelines
  - Various precursor project report – EUDP procedure (established by DTU, Orsted, Siemens-Gamesa and Leosphere)
Step 2: Verification and calibration

Verification ensures performance of the lidar. Much of the verification process can be done in parallel with design, and usually takes about two months at a certification site.

Process

- Verification at Leosphere: Leosphere calibrates lidar units throughout the manufacturing process, then verifies it against a calibrated lidar of the same type.
- Third-party calibration: This is a contractual step for PPT, conducted at an independent test site. The analyst uses this data to calculate the uncertainty on the power curve. Key documents for the verification process:
  - EUDP and UniTTe reports
  - IEC: IEC 61400-50-3 – CDV (expected to be published in 2021)

Leosphere certification and verification standards

Leosphere products meet the latest and most rigorous international verification standards, including ISO9001. All WindCube products are compliant to the latest IEC standards (when applicable), and they are recognized and verified by the world’s leading independent certifying bodies, including DNV GL, DTU Wind Energy, UL, and Deutsche WindGuard.
Step 3: Operation

Operation is a busy and important phase. It requires training, foresight, and effective project management.

Process

• Installation: Training is provided. Documentation includes checklist and health/safety precautions. Complete alignment on nacelle roof.
• Time synchronization: Use either NTP or GPS. All sensors should be synchronized, or the offset should be reported.
• Monitoring: Conduct daily or weekly checks on all related equipment and sensors along with any automatic alerts.
• Data collection: Choose automatic, FTP, or manual. Regularly check if data set is completed (see step 4).

Step 4: Analysis

After a few weeks of operation, there will be enough information in the dataset to extract and analyze. This can overlap the monitoring phase.

• Synchronization: This is a crucial, sometimes difficult, step in preparing for data extraction. (WindCube Insights—Analytics includes a simple-to-use synchronization function).
• Filtering: Isolate a time period when everything was working nominally and proper data was being returned.

• Data completion: The IEC provides guidance that will help you determine whether your dataset is complete. Key indicators include:
  ◦ 180h of valid measurement
  ◦ At least three measurements per bin (0.5 m/s)
  ◦ Range of wind speed according to turbine nominal power

• Complete analyses according to IEC procedures.
  ◦ PC, Cp, AEP
  ◦ And associated uncertainty
  ◦ Terrain assessment
  ◦ Obstacles & topo
WindCube Nacelle:
The industry's most trusted and deployed nacelle-mounted lidar

WindCube Nacelle is one of the most accepted and widely deployed nacelle-mounted lidar systems in the world.

It is the only long range nacelle-mounted lidar that enables PPT on any wind turbine — onshore or offshore. Its accuracy and versatility have made Leosphere a contributing expert to industry guidelines and standards for PPT.

Key benefits

- Enables quick, accurate, compliant PPT
  - Rapid data completion with continuous wind direction alignment
  - Reliable contractual and operational PPT
  - Based on industry best practices and upcoming IEC standards

- Accurate data from 50 to 700 meters
  - Captures wind data simultaneously at 20 measurement distances
  - Extremely high correlation with IEC met mast measurements
  - Gives wind industry stakeholders the reliable data needed to make better decisions

- Universal compatibility and ease of use
  - Compatible with all current and future turbine types
  - Simple installation and system integration and configuration
  - Outstanding reliability under even the most demanding conditions
  - Permits a 3-year warranty period and limited maintenance
WindCube Insights — Analytics: Revolutionary software enabling IEC-compliant PPT

No other lidar provider offers a solution like it.

WindCube Insights — Analytics software completes the PPT process by analyzing, interpreting, and displaying the data obtained from WindCube Nacelle.

Operators can perform quick, simple, and transparent PPT with IEC-compliant filtering, AEP calculation, and uncertainties reporting. Simplifying data handling activities frees users to focus on the most essential performance analysis and optimization work.

Since PPT is a very strict process, this tool provides transparent validations and even lists which IEC standards are relevant while in use. It allows for the upload of WindCube Nacelle and SCADA data with a simplified data synchronization process, and provides a variety of standardized lidar and turbine data filters that are available and fully configurable to prepare the data set.

Key benefits

Easy-to-use, fully compliant, affordable PPT analytics
- Eliminates time-consuming and expensive processes developed in-house
- Provides powerful performance calculations and data integrations

Adheres to accepted industry best practices
- Backed by rigorous, transparent validations
- Proactively displays which IEC paragraph/standard it is referring to while in use

Improved data visibility and value for the whole wind farm
- Gives users outstanding awareness of their systems
- Simple interface, efficient analyses, and easy report table exporting
- Enables data-driven decision-making and better-functioning wind farms
Siemens Gamesa Renewable Energy, one of the world’s largest wind turbine manufacturers, provides offshore and onshore wind services and is well-known as a renewable energy industry leader.

The company has been using nacelle-mounted lidar in place of met masts for several years because many of the limitations of using met masts are compounded offshore. Met masts offshore are prohibitively expensive and, between permitting and the building process itself, can take years to implement.

Siemens Gamesa has adopted nacelle-mounted lidar in offshore applications for several primary reasons:

- Reduced cost
- Wider measurement sector in most cases
- Faster power curve calculations due to the wider measurement sector
- Ability to collect both short-range (inside the induction zone) and long-range data simultaneously
- WindCube Nacelle measures up to 700m to cover their largest offshore wind turbines

As an early adopter of nacelle-mounted lidar for offshore applications, Siemens Gamesa is leading its field and routinely proving the value of WindCube Nacelle.
Further applications for nacelle-mounted lidar

Although nacelle-mounted lidar’s primary purpose is PPT, it is a multi-use tool that creates impressive efficiencies and cost savings throughout a wind farm’s lifespan. Any of these secondary applications can be compelling enough on their own to deploy nacelle-mounted lidar. They include:

- **Research Project**
  
  Many agencies and companies rely on highly detailed wind field data for studies and product development. Nacelle-mounted lidar can provide previously unavailable detail and precision, leading to accelerated innovation and new insights.

- **Turbine yaw misalignment**
  
  Nacelle-mounted lidar allows operators to identify and correct any misalignment between the turbine and wind direction — maximizing performance and reducing structural loads. Nacelle-mounted lidar is the only proven technology for this cost-saving assessment.

- **Nacelle transfer function**
  
  Nacelle transfer function, which describes how the turbine and nacelle structures influence wind speed, is an important assessment to improve turbine performance monitoring. Nacelle-mounted lidar assesses this accurately even after a wind campaign is complete.

- **Lidar assisted control**
  
  Lidar-assisted control (LAC) allows for anticipatory adjustments to blade and turbine alignment to better handle incoming weather or storms. LAC can substantially reduce turbine cost, reduce loads on the turbine and nacelle, improve longevity, and reduce risk. It can also increase energy capture and lower the levelized cost of energy (LCOE). WindCube Nacelle for Turbine Control is the ideal, custom-made solution for this purpose. Learn more about it at windcubelidar.com.
Why Leosphere, a Vaisala company?

We are modern innovators, scientists, and discoverers who enable our customers to harness the power of wind energy in new ways. We are driven by passion, relentless curiosity, and the desire to create a better world, as evidenced in our commitment to four guiding principles:

- **Trustworthy, superior metrology**
  Our solutions are backed by the best science and metrology, and validated by the most demanding testing and certifications in the industry. Our contributions make wind energy smarter.

- **Unrivaled thought leadership**
  Our years of experience, impressive global client roster, and plethora of industry breakthroughs demonstrate that we are the iconic gold standard in wind energy.

As a result, Leosphere, a Vaisala company, is the iconic and trusted gold standard in wind lidar. Our turnkey WindCube product suite offers innovative, reliable, and highly accurate solutions for thousands of customers across the globe. All of this has enabled us to be catalysts for change and ambassadors for wind energy, always advancing the field and those we serve.

Our innovation story, like the wind energy story, continues.

windcubelidar.com