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Using LIDAR To Turbocharge Power Production

Many are finding that the remote sensing tool has applications beyond pre-construction wind measurement.

By Brogan Morton

Wind farm profitability is strongly impacted by an operator's ability to optimize a turbine fleet by assessing the performance of individual turbines. Increasingly, nacelle-mounted LIDAR technology is being used for this critical purpose. Because many nacelle-mounted LIDARs are highly mobile, easy to install and suitable for a variety of applications, they are earning a reputation as a general diagnostic tool for turbine performance characterization and optimization.

The key to the success of nacelle-mounted LIDAR lies in the ability to measure the free stream wind in front of the wind turbine, where the wind has been minimally disturbed by the turbine itself. Some nacelle-mounted LIDAR can measure out to 400 meters upwind of the turbine, which is typically well beyond what IEC 61400-12-1 advises for power performance assessment: a distance equivalent to 2.5 times the rotor diameter.

To explain the utility of nacelle-mounted LIDAR, this article will discuss three of the most popular uses: operational power curve, yaw misalignment correction and wind sector curtailment optimization. The first two are useful for identifying and mitigating underperformance due to turbine-specific issues, while the final use is more about optimizing the wind plant as a whole.

There are a number of causes of turbine underperformance. From an operator's perspective, wind-related causes, such as poor wind resources or excessive wind flow complexity, are impossible to control. Other causes of underperformance, such as yaw misalignment and blade pitch error, can be mitigated and offer the potential for wind turbine asset optimization. These elements can have a substantive impact on turbine and plant-level annual energy production (AEP).

When a turbine is underperforming, using traditional nacelle-mounted sensors to analyze the wind speed and direction in conjunction with power from the SCADA system is often insufficient unless the errors are egregious. The turbine control sensors are behind the sweep of the turbine blades, creating turbulent and complex flows around the nacelle. Because nacelle-mounted LIDAR can measure the free stream wind in front of the turbine, the complexity added by rotor wash is eliminated – reducing variance in the wind speed measurements.

It is possible to compare the power output of neighboring turbines to identify underperformance, but determining whether the underperformance is wind resource-related or turbine-specific is difficult. In this case, using a nacelle-mounted LIDAR to diagnose problems that were initially revealed through neighboring turbine analysis, rather than simply detecting an underperformance, can provide real value.

The traditional method for evaluating the performance of a turbine is to use hub-height wind measurements from a meteorological tower upstream of the turbine. Unfortunately, the cost of installing one of these towers upwind of a known or suspected underperformer is typically a deterrent from taking action. So, what happens when the underperforming turbine is kilometers away from the reference

Owners and operators are turning to nacelle-mounted LIDAR to optimize turbine performance. Photo courtesy of Renewable NRG Systems

met mast on an operating wind farm or the wind farm lacks a met mast altogether?

One answer to this problem is to use a mobile nacelle-mounted LIDAR. In cases when the systems have been compared to available IEC-compliant met masts, the correlation between the wind speed and direction measures has been extremely high. These studies provide confidence that using nacelle-mounted LIDAR when no met mast is available provides practically equivalent data. That means that every turbine on a wind farm could have a "virtual" met mast to provide power curve measurement for performance monitoring.

Nacelle-mounted LIDARs also have advantages compared to met masts. A met mast can only provide valid wind data from a narrow wind sector upstream of the turbine due to the fact that the tower's location is fixed. A nacelle-mounted LIDAR can take equivalent measurements no matter what direction the wind is blowing. This allows data to be collected much faster. It also means any difference in power curve that depends on wind direction can be isolated and explored further.

Correcting yaw misalignment

Yaw misalignment is one of the correctable problems facing wind farm operators. To leave it unaddressed means lost production and increased fatigue loading on turbine assets. Field results have shown that nacelle-mounted LIDAR has a proven ability to address this issue. The most obvious cause of yaw misalignment is a misalignment of the wind vane itself. The wind vane may have been installed incorrectly at the time of commissioning or during replacement, which can occur when the operator switches from an ultrasonic to mechanical sensor or vice versa.

Switching sensor types can cause the transfer function, or the relationship between the sensor's raw signal output and the actual inflow to the turbine, to be incorrect. In some cases, the transfer function may have been erroneous from the start. Regardless of the sources of yaw misalignment, identifying its magnitude and correcting it can provide AEP gains.

The impact of yaw misalignment on turbine power is potentially quite significant, especially if it is greater than 4° or 5°. Based on various LIDAR campaigns where Renewable NRG Systems measured yaw misalignment prevalence, nearly 50% of suspected or known underperformers were losing 1% or more AEP due to misalignment. These results are based on data collected over various types of turbine models and acquired in onshore flat and complex terrain, as well as offshore.

Although these findings are based on a small sample that offers only a relative degree of statistical significance, other recent studies indicate similar patterns. The correction strategy starts with using the LIDAR to quantify the misalignment and measure the operational power curve before the correction. This is typically a two-week campaign that will provide operators with enough measurements to accurately determine the average static yaw correction required. This correction can mean a change in the sensor alignment or a change to the controller of the turbine. Once the correction has been implemented, operators can then measure the "after" operational power curve, which will show the power gains. The increased AEP through improved yaw tracking comes from corrected wind vane alignment. An operator can ensure that the turbine yaw is very well aligned – to within less than 1°.

A burgeoning topic in wind plant optimization is wind sector management. When wind plants are designed, there are myriad issues that go into the micro-siting of individual turbines outside of wind resource consideration. The result: When the wind is coming from a particular direction, some turbines on a wind farm can be affected by the wake of others. This can put additional stresses on the downstream wind turbines and affect the power production of the upstream turbine as well. In some cases, it may be beneficial to curtail one of the turbines to reduce loads and increase energy production. For each affected turbine, the operator must determine the direction in which the turbine should be curtailed.

Traditionally, these wind sectors are set during the design phase of the project based on data from the wind resource assessment campaign and associated models. This can lead to wind sectors that are suboptimal: possibly too wide due to the inherent uncertainty of the modeling or simply inaccurate enough to cause a downwind turbine to operate in waked flows. Nacelle-mounted LIDARs that measure wind at long distances allow operators to measure the exact locations of wake areas of operation. This allows operators to refine the curtailment area to be only as wide as absolutely necessary while ensuring the turbine does not operate in waked flow.

Future uses

LIDARs are able to measure the incoming wind speed before it reaches the wind turbine rotor. That's why LIDAR-based wind measurements can be used in feed-forward control systems designed to reduce turbine loads through improved blade pitch control.

By reducing loads on critical components and increasing the potential power extracted from the wind, the performance of wind turbine controllers can be improved. As a result, integrating a LIDAR system has the potential to lower the cost of wind energy.

The benefit of LIDAR-assisted turbine control is most relevant on next-generation turbines, which can take better advantage of potential fatigue load reductions at the time of turbine design. The use of LIDARs can make turbines lighter and more reliable. Gains in reduced loads can also inform the re-optimization process of turbine design, leading to an improved turbine efficiency and increased future AEP.

Although recent research projects tend to show that LIDARs can result in significant net capacity factor increases and AEP improvements, the main promise of permanently mounted control LIDAR is primarily in loads reduction. LIDAR-assisted turbine control can reduce fatigue loads by anticipating the approaching wind field. Its main benefit is improved collective pitch control yields, rather than individual pitch control. By reducing fatigue loads, LIDAR can increase turbine lifetime and, therefore, reduce the cost of energy.

This survey of the uses of nacelle-mounted LIDARs for operational wind turbines shows the varied cases in which the systems can be used to optimize wind plant output, as well as how use may increase in the future. NWP

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