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WHITE PAPER

Advanced Data-Acquisition is Critical to Developing Today's State-of-the-Art Wind Turbines

Renewable Energy

The term "renewable energy" refers to energy from a natural, self-replenishing source that won't run out. Examples are solar energy, hydroelectric (including tidal energy) and wind power.

All these technologies have enjoyed a storied history. Around 700 BCE, for example, people used magnifying glass-like materials to light fires with sunlight. Similarly, water wheels and watermills were employed in ancient Greece and China as long ago as 400 BCE. Meanwhile, the first recorded windmills are attributed to the Persians sometime around 900 CE, with these devices quickly spreading throughout Europe.

Watermills and windmills experienced a dramatic decline following the introduction of high-pressure steam engines circa the 1750s. However, water and wind saw a resurgence following the discovery of the fundamental principles of electricity generation circa the 1820s and increased electricity use. The first power plants used waterpower or coal, with wind turbines re-emerging as a significant energy source in the latter portion of the 20th century.

According to Verde Energy,[1] wind turbines can convert around 50% of captured wind into energy, which is currently considered more efficient than solar panels, which can capture and convert about 25% of sunlight into useful energy. Furthermore, wind turbines can continue functioning on overcast days and throughout the night.

At the time of this writing, there are around 400,000 wind turbines around the world generating approximately 840 gigawatts of power,[2] with more coming online all the time. A recent report by the US Department of Energy (DoE) predicts that wind turbines will provide **20% of US electricity needs by 2030**.[3]

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New Designs, New Materials, and the Need for Test

The increasing efficiency of wind turbines—and the corresponding reduction in the cost of wind energy—is the result of a combination of factors, including improved power electronics and advanced control systems. The most significant contributors, however, are improvements in aerodynamic designs coupled with the use of advanced materials.

One manifestation of this is larger turbine blades. The blades used in a typical modern land-based wind turbine are around 170 feet (50 meters) long. GE's Haliade-X offshore wind turbine has blades 351 feet (107 meters) long. And China's **LZ Blades currently holds the record with a wind turbine whose blades are 404 feet (123 meters) long.**[4]

Wind turbine blades are required to have an expected lifespan of 20 to 30 years. In their quest for efficiency and reliability, the manufacturers of wind turbines are striving to reduce weight, increase strength, and improve the manufacturability of the turbine blades. Spurred on by climate change, government agencies like the National Institute of Standards and Technology (NIST)[5] in the US and the National Renewable Energy Centre (Narec)[6] in the UK are also concerned with promoting the industry while ensuring safety for all concerned parties.

Thus, following the creation of sophisticated Computer-Aided Design (CAD) models of the components forming the wind turbine, these components—such as the turbine blades—are subject to rigorous testing, sometimes to destruction, to provide proof of compliance with international safety regulations like IEC 61400-23.

This testing includes structural (static), fatigue (dynamic), and modal tests. Modal analysis is used to identify the natural resonant frequencies of the blades and to determine any modal changes to their shape when subject to their expected usage model and wind loading. If necessary, the aerodynamic design of the blades will be adjusted to ensure their critical frequencies are outside what they will experience when rotating with the wind blowing past them. Modal testing employs multiple sensors, including accelerometers and strain gauges.

Structural tests involve applying extreme loads in all directions (leading edge, trailing edge, suction side, pressure side) associated with the turbine blade. These tests predominantly use sensors in the form of strain gauges. By comparison, in the case of fatigue tests, the blade is vibrated at its resonant frequency as determined by modal testing. These tests employ multiple sensors, such as accelerometers and strain gauges. Following the fatigue tests, the structural tests are repeated to verify that the blade can still handle extreme loads after being subjected to high cyclic loading.

The results from all these tests may be affected by environmental conditions such as temperature, so all tests include temperature sensors in the form of thermocouples.

This paper focuses on testing performed during research and development (R&D) and prototyping, which involves most of the instrumentation used. For example, tests on a wind turbine blade can easily require 500+ strain gauges. The most common (and least expensive) strain gauge type is employed in this case. Consisting of an insulating flexible backing supporting a metallic foil pattern, these are attached to the blade using a suitable adhesive. When the blade is distorted due to the application of force, the foil is deformed, causing its electrical resistance to change.

Shorter Wires and Fewer Cables

LAN eXtensions for Instrumentation (LXI) is a standard developed by the LXI Consortium, which maintains the LXI specification and promotes the LXI Standard. This standard defines the communication protocols for instrumentation and data acquisition systems using Ethernet.

When working with strain gauges, only minimal changes in resistance are being measured, so the longer the wires that run from the strain gauges to the measuring instrument, the greater the losses in those signals and the more noise is picked up. Remembering that wind turbine blades can be hundreds of feet long; the solution is to locate a multi-channel measuring instrument as close as possible to a group of strain gauges and then communicate the measured data back to a central collection point using an Ethernet connection. If the distance exceeds the maximum supported length of 328 feet (100 meters) for popular CAT5e, 6, and 6a Ethernet cables, then an Ethernet switch may be employed.

Assuming a test setup including 512 strain gauges (excluding other sensors like accelerometers and thermocouples) and carrying 16-channel measuring instruments, 32 such devices will be required along with 32 Ethernet cables. If the measuring devices also require independent power, then 32 power cables must be deployed. A better alternative is to select measuring instruments that can employ Power over Ethernet (PoE), thereby allowing the instruments to be powered via the Ethernet cables.

What's the Time?

Knowing the values being reported from many sensors is useless unless these values are associated with corresponding times. Suppose a wind turbine blade undergoes a structural test to destruction, for example. In that case, understanding the temporal sequence related to the reported values is critical to understanding the underlying failure mechanism.

Establishing and measuring the temporal ordering of events requires those events to be timestamped. In turn, these timestamps must be associated with a typical timescale synchronized to a standard "grandmaster clock" with sufficient accuracy and precision.

One solution is to provide an external clock signal, which can trigger all the measuring instruments, but this requires 32 more cables, the lengths of which must be accounted for in the timing calculations. An alternative is to use the existing Ethernet connections.

By default, Ethernet—which employs a packet-based and packet-switched architecture—does not provide a time-deterministic method of communication. The lengths of the Ethernet cables can affect the time-of-flight of the signals, and any Ethernet switches and routers will add their delays into the mix.

The solution is to select measuring instruments that employ the Precision Time Protocol (PTP), more commonly known as IEEE 1588 or just 1588. In this case, the host processor, connected to the grandmaster clock, sends a data packet to one of the measuring instruments. The host timestamps the packet as it departs, and the measuring instrument adds its timestamp when the packet arrives. The measuring instrument then sends the data packet back to the host. This time, the measuring timestamps the packet as it departs, and the host instrument adds its timestamp when the packet arrives.

Any PTP-enabled Ethernet switch or router in the packet's path will update the timestamps on the packet as it passes through the device with the transport delay associated with that device. Using these timestamped values, it's possible for the system to (a) work out how long it takes for a packet to travel between the host and the measuring instrument and (b) determine any error in the clock located in the measuring instrument, which can subsequently be corrected by the host sending a control packet saying, "*update your clock by xxx amount.*"

It's important to note that the description provided here is a gross simplification. For example, there may be large numbers of measurement instruments, multiple packets can be in flight at the same time, different packets can take different paths through the network, switches may buffer one packet while passing another, and—if uncorrected—the clocks in the measurement instruments may drift over time. However, by sending multiple packets and making constant adjustments, the times associated with measurements can be determined and recorded with sub-microsecond accuracy.

It's also important to note that, although the LXI Standard embraces PTP/IEEE 1588, its inclusion in an LXI-enabled instrument is not mandatory. As a result, not all instruments that are described as being LXI-compliant are capable of supporting PTP/IEEE 1588.

Advanced Wind Turbine Data Acquisition

VTI Instruments provides a wide range of products and systems to monitor and record the data that characterizes large structures' physical integrity and performance like engines, aircraft, and wind turbines.

Concerning the R&D structural, fatigue, and modal testing of wind turbine blades presented in this paper, VTI Instruments offers a suite of full-featured data acquisition families for use with strain gauges, accelerometers, and thermocouples.

For example, the EX1403A 16-channel precision bridge and strain gauge sets a new standard for strain and bridge measurements, delivering the highest performance measurements possible while controlling overall test hardware costs. With its ability to provide both constant voltage and constant current excitation, the EX1403A can measure all standard strain gauge configurations (1/4, 1/2, Full) as well as any standard bridge measurement (pressure, force, displacement).

The EMX-4350 smart, dynamic signal analyzer incorporates best-in-class analog design methodology to deliver industry-leading measurement accuracy. This instrument is ideal for a wide range of applications, including noise, vibration, and harshness (NVH), machine condition monitoring, rotational analysis, acoustic test, modal test, general-purpose high-speed digitization, and signal analysis.

Meanwhile, the EX1401 16-channel isolated thermocouple and voltage measurement instrument delivers accurate and highly repeatable thermocouple (±0.2°C) and voltage measurements by implementing fully integrated signal conditioning, providing 24-bit analog-to-digital converters (ADCs) and offering independent Cold Junction Compensation (CJC) on a per-channel basis.

All these instruments are LXI certified, include support for PTP/IEEE 1588, and are enabled by associated data acquisition software, such as general-purpose, modal, and high-speed data acquisition packages. Furthermore, the EX1403A and EX1401—which need to be mounted close to the sensors—support Power over Ethernet.

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Conclusion

Over several decades, VTI Instruments has built an enviable reputation in test and instrumentation circles. For example, many companies obsolete their solutions every few years, replacing them with newer and more expensive models. By comparison, although we are constantly reengineering our test and instrumentation solutions to take full advantage of the latest tools and technologies—possibly adding additional functionality along the way—our new solutions remain identical in form, fit, and function to our earlier devices.

This means that if you purchased a 100-channel solution a couple of years ago and need another 100 channels now, you don't need to throw everything away and start again—you can add another 100 channels. Although the new instruments may be more modern "under the hood," they will look and function the same and work seamlessly with your existing devices.

More recently, we have started to make our presence felt in the wind turbine arena. As a result, many companies and government-funded institutions are turning to us for their wind turbine-related test instrumentation and data acquisition solutions.

References

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