Advanced Fiber Optic Condition Monitoring System for the Entire Wind Turbine Life Cycle

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Abstract: IFOS demonstrates here its fiber-optic-based solution for wind turbine blade manufacturing monitoring and pre-installation inspection. The proposed sensing system is a wind turbine condition monitoring system (CMS) for blade, the gearbox, tower and generator monitoring.
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1. Introduction

As wind energy systems increase their penetration into the national electrical power base, long-term reliability of wind turbines becomes of even greater importance. New tools and methods are needed to perform real time and predictive condition monitoring on major wind turbine subsystems, including blades, gearboxes, towers, and generators. Moisture absorption, fatigue, wind gusts, and lightning strikes can be factors that damage wind turbine blades. Such stressors, as well as normal fatigue cycles and aerodynamic loads, cause fatigue damage. Moreover, these blades are massive structures with a 1.5-2.5 MW turbine weighing some 22,000 Lbs and blades 10" thick at base, usually made of fiberglass, vinyl esters and epoxies with low specific modulus and low natural frequencies. Under loading, the deflections and strains of the cantilevered blade can be quite large. While the design lifetime for blades is from 10 to 30 years, predicting the exact fatigue life is difficult. If fatigue damaged rotor blades fail, they can cause catastrophic damage to a wind turbine. The cost of such damage is not limited to equipment replacement but also possible loss of revenue due to down-time, cost of rolling a crane (perhaps $100k) to difficult terrain and repair costs of maintenance crew etc. To ensure peak performance and maintain high turbine availability, a method is needed for continuous monitoring of the condition of the blade with warning of possible failure in real-time or on the fly adjustments such as, for instance, blade attack angle adjustments or gear change.

As stated in ECN Report [1], there are several techniques available for wind turbines condition monitoring purposes including: vibration analysis, gearbox oil analysis, thermography, physical condition of materials, strain measurement, acoustic measurements, electrical effects, process parameters, visual inspection, performance monitoring, and self diagnostic sensors.

Over the typical 20-year average lifetime of a wind turbine, with CMS deployed there would be five repairs of significance. Without CMS, there will be only three repairs-but those repairs will be much bigger such as a full replacement or rebuilding a gearbox which can cost well in excess of $300,000. The use of CMS can help an operator decide when to replace some gears in a gearbox at a cost of $30,000 instead of waiting for a catastrophic failure to occur [2].

2. The IFOS Solution

The IFOS approach provides an all fiber-optic fully integrated CMS capable of real time, monitoring the critical wind turbine components including the blades, gearbox and the tower structure simultaneously and applying sensor fusion and decision analytic techniques for faults prediction and reporting.

The IFOS CMS is (1) capable of withstanding extreme environments, including high temperatures, high humidity, extreme cold, corrosive offshore environments, and wind-blown sand and dust; (2) flexible in nature, capable of providing a variety of crosscutting condition monitoring applications; and (3) easily integrated into the total wind control platform (including integration into wind turbine fleets or into remote, stand alone, unattended turbines). Both fiber optic sensors and the sensors interrogator are capable of long lifetimes and economically viable when manufactured at large quantities (500+). The IFOS wind turbine CMS scheme based on a multiplexed array of temperature, strain, acoustic emissions (AE) and accelerometers is shown in Fig 1.

Wind Turbine Component	Installed Fiber Optic Sensors
Blades	Temperature, Strain/AE, Accelerometer
Gearbox	Strain/AE, Accelerometer
Generator	Strain/AE, Accelerometer
Tower structure	Strain/AE, Accelerometer

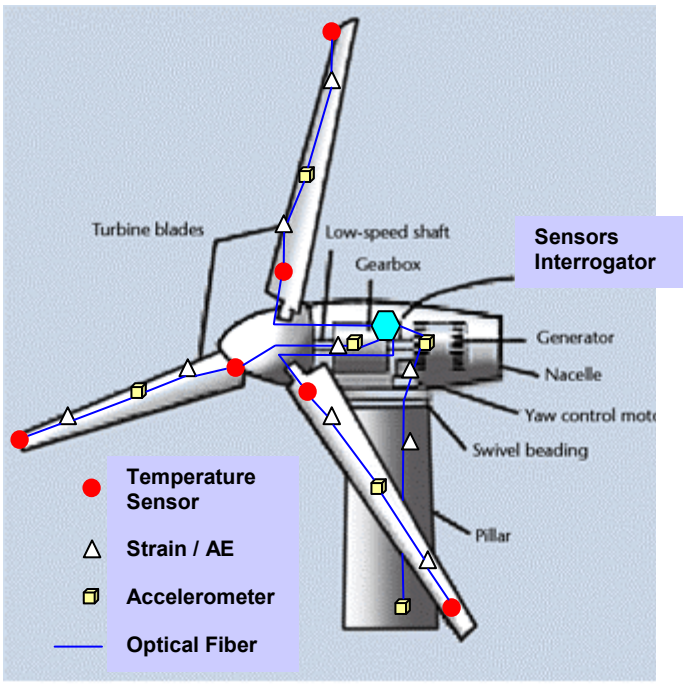

Figure 1. Fiber Optic Sensors Array for Wind Turbine CMS Application

Vibration monitoring techniques such as acceleration enveloping methodology [3] have been used to identify and characterize two main groups of vibrations in a wind turbine, namely gear mesh frequencies and bearing defects. Such frequencies excite structural natural frequencies that "amplify" the vibration resulting from the failing components and make them easier to detect. The IFOS CMS strategy is based on advanced signal processing techniques, coupled with new and improved damage detection algorithms. The damage identification techniques based on measured dynamic information provide coarse identification over a large 3-D structure. Meanwhile the identification technique based on wave propagation offers detailed information of the damage.

With significant advantages over traditional electrical sensors, FBG sensors have been widely used for CMS and proven as an invaluable tool for structural diagnosis and prognosis. FBG sensors are electrically passive, immune to electromagnetic interference and pulses. FBGs are well suited for low-profile integration with the blade and gear structures. IFOS will review and evaluate the use of FBG sensors in conjunction with both electrical and optical slip rings as the Ingress-Egress solution. We will look at reliability, integration complexity and cost to deliver optical power and to communicate high-speed optical signals from the operating wind turbines to a remotely stationed processing unit used in common among several turbines. Taking full advantage of the multiplexing capabilities of advanced FBG sensing technology, IFOS has developed a high speed FBG interrogator that has the unique ability to monitor simultaneously dynamically multiplexed signals at very high frequencies from a large number of sensors along a single or multiple fibers. This sensing technology is highly scalable and will have a significant positive technical and economic impact on meeting future needs in wind turbine monitoring.

3. References

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[3] Hatch, C., "Improved Condition Monitoring Using Acceleration Enveloping,"2Q04 ORBIT, pp. 58-61,2004.