Monitoring a Wind Turbine Farm from Afar

Tom Francisco, Azima DLI, Woburn, Massachusetts

This article describes a remote, online, vibration monitoring service provided for a European wind turbine farm by Azima DLI. Please note that the monitoring equipment and system configuration are general purpose and adaptable; therefore, the concepts and configurations described here are just as applicable to monitoring pumps in a remote pumping station or motors, blowers and other rotating machinery located on a factory floor. These wind turbines are monitored by web-based online systems and remotely managed and controlled by Azima DLI on behalf of the client. Similar remote monitoring services are provided to other clients using portable data collectors where the client collects data and transmits via the Internet to Azima DLI for analysis.

System Configuration. Each wind turbine is equipped with a 16-channel SpriteMAX system that is responsible for collecting vibration and other dynamic signals or scalar process data. These units are Ethernet and WiFi enabled, and in the case of this particular wind farm, they communicate via radio-based LAN. Mimic displays on the client's computers provide up-to-date status information for each unit. The SpriteMAX units also communicate with Azima DLI using a secure remote monitoring portal on the Internet. This gives engineers the ability to manage, monitor, control and update the units from afar. In most cases, the online monitoring system is installed as part of a multiyear remote monitoring service contract; in other cases, the client purchases the online system hardware.

State-Based Monitoring. Wind turbines are complex machines with numerous shafts and planetary gears as shown in Figure 1. The rotational rate of the main shaft depends on wind speed, blade pitch and power output. In the case of this particular installation, there are two generators attached to each unit, one engaged during lower wind speeds and the other during higher speeds. Therefore, there are two specific states under which the machines can operate.

To make sense of all of these variables, an intelligent monitoring system detects the current operational state of a machine, collects vibration data and then compares these data to a baseline collected under similar conditions. This is called "state-based" monitoring, because a unit is tested under specific test conditions, and the vibration data are compared to other tests conducted under the same conditions. This approach is important to enable comparison of vibration data generated under similar conditions. It is nearly useless to compare data from a machine at or near no load to a baseline recorded at or near full load. In the case of SpriteMAX, there is no limit to the number of test states that can be defined, with the goal being to define them in such a way to cover the entire range of unit operation. This is a key feature of any intelligent monitoring system.

Information, Not Data. A key feature of the system is that it does not simply collect data and transmit it somewhere else for someone to analyze. Who is going to look at new vibration signatures that arrive every few minutes from hundreds of wind turbines operating around the clock all over the world? In the case of unintelligent systems that do not collect data under discreet operating conditions, who is going to try to make heads or tails of heaps of random data?

Unfortunately, these questions sometimes don't get asked until after a system has been installed. Fortunately, online monitoring systems like SpriteMAX contain intelligent rule-based diagnostic systems onboard that can detect individual faults such as unbalance, misalignment, bearing wear, or gear tooth problems and then assigns severities to these faults. Engineers are notified of any changes in status and then confirm the diagnosis by manually analyzing the raw

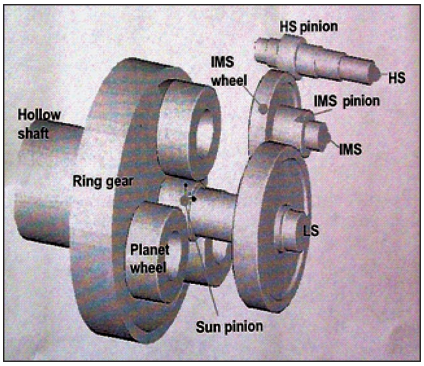

Figure 1. A typical wind turbine features numerous shafts and planetary gears.

data. The client is then notified if any action is required.

Even in the absence of alarms, engineers routinely monitor all units to update baselines, fine-tune alarms and ensure that the system is functioning properly. In short, the intelligence built into the system in terms of collecting, qualifying and analyzing data allows Azima DLI to efficiently manage enormous amounts of data and focus on the machines with problems. This results in cost-effective and accurate diagnoses.

A Shaft Bearing Problem. The following is an example of a remotely detected problem in a rolling element bearing in the intermediate shaft of the gearbox on a wind turbine in Europe. Reports and data were reviewed on a weekly basis by Azima DLI engineers, located in Seattle,

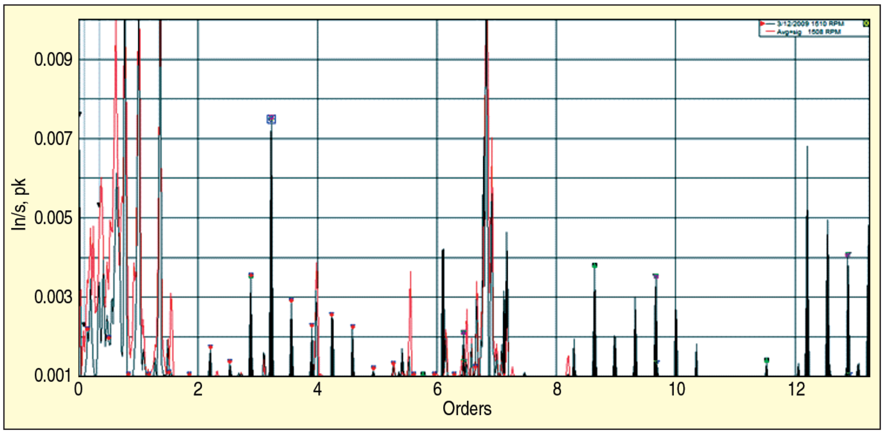

Figure 2. A vibration spectrum showing a machine with an "increased to serious" fault severity.

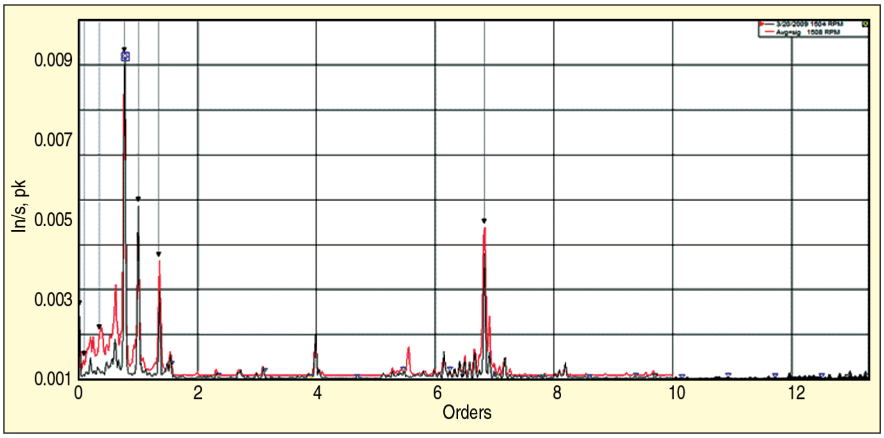

Figure 3. A spectrum collected just after the gearbox was rebuilt.

Figure 4. The damaged bearing that caused the potential machinery failure.

via the WATCHMAN Reliability Portal and the client was contacted via e-mail as the fault progressed. The gearbox had been overhauled six months earlier due to a near catastrophic failure of the same intermediate shaft bearing and the unit was still under warranty. The following is a brief timeline describing the evolution and resolution of the problem:

Jan 26, Early Warning: High-frequency noise is detected by the system and considered possible bearing wear. Manual analysis by Azima DLI downgrades this fault and recommends taking no action.

Feb 10: High-frequency demodulated data indicate the presence of bearing tones. An engineer confirms that this is very early warning of a bearing problem, but no action needs to be taken.

Feb 17, Something Happening: Increased vibration at the first gear mesh frequency with intermediate shaft-rate sidebands is detected.

Feb 23: Intermediate shaft-rate sideband vibration has stabilized.

Feb 27, Making the Call: An engineer notes that the intermediate shaft-rate sidebands indicate a bearing problem that could worsen at any time. He recommends securing the wind turbine. The turbine rebuild company is notified by the client, but they are not convinced that the problem exists.

Mar 6: Azima DLI reiterates to the client that there is ample evidence of bearing wear.

Mar 13, Decision Time: Automated alarms alert the client that the fault severity has increased to "serious." The client secures the unit and contacts Azima DLI. A senior engineer confirms the diagnosis and recommends immediate shut down and repair. A vibration spectrum from this date is shown in Figure 2. The black peaks in the data are bearing tones with intermediate shaft-rate sidebands. This indicates a fault on the inner race of the intermediate shaft bearing. The red data in the plot indicate the baseline for this test state. Note that the black peaks are "new," and did not exist in the baseline.

Mar 20: Less than 2 months since the first indications of a problem, the unit was overhauled, and new data were collected with a new bearing. The company that rebuilt the gearbox and the client were happy that the fault had been detected and remedied before causing collateral damage. Figure 3 shows a spectrum collected just after the rebuild; note the absence of the series of black peaks and also the degree to which the black plot matches the red baseline. The damaged bearing was sent to the manufacturer for analysis (see Figure 4).

Benefits of Remote Services. Looking at the timeline, note that this unit received more than weekly attention by engineers who were able to successfully work with the client and the company that rebuilt the gearbox from a location seven time zones away to detect, follow and then resolve this quickly emerging problem. The combination of intelligent online monitoring technology, the Azima DLI WATCHMAN Reliability Portal and extensive vibration analysis experience converged to offer this client the ability to leverage an enormous amount of external expertise even though this expertise was located on a different continent. One of the most important items to note here is that monthly or quarterly vibration monitoring would not have been adequate to detect this problem with sufficient warning to prevent catastrophic failure of not only the bearing but most likely the entire gearbox.

Regarding the financial implications of the situation, it is also fortunate for the client that the problem was detected while the unit was still under warranty. The rebuild company was also happy that the problem was caught before costly collateral damage resulted. Because the data indicated which bearing was at fault, the overhaul time was reduced and the unit was brought back online quickly. Obviously, a great deal of expense was avoided by not having to fly engineers to the site to manually collect data or attempt to troubleshoot the problem. Again noticing the timeline, an engineer would have had to have been on site and testing the unit frequently to detect the rapidly deteriorating situation and shut the machine down in time. In this age of outsourcing, it should be noted that the client did not have to hire, train and retain his own vibration analyst.

As noted earlier, remote monitoring services are currently being used to monitor all sorts of rotating machinery in every industrial sector. In some cases, as in this example of a wind farm, it makes sense to use an installed, intelligent, online monitoring system to facilitate data collection and local alarming and to transmit data for review. In other cases, it makes more sense to use portable data collectors to collect data on a routine basis, perhaps monthly, and to transmit the data to Azima DLI via the WATCHMAN Reliability Portal for review. In either case, remote monitoring services are allowing clients to partner with and take advantage of an enormous amount of technical expertise without having to invest in that expertise themselves. More and more the industries are seeing a trend toward the outsourcing of condition monitoring services, and this case study helps to illustrate why.

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Earthquake Simulation

At 11:04 a.m. on December 11, 2008, a rumbling was heard at the northeast end of the University of Nevada, Reno, as an "earthquake" shook a four-span, 110-foot, 210-ton concrete bridge with motions comparable to an 8.0 earthquake. The bridge was in the University's world famous earthquake simulation laboratory.

The bridge, constructed over many months atop three enormous shake tables, is a test bed for cutting-edge construction technologies of the future. Many of the new materials –including nickel-titanium bars, elastomeric materials, and polyvinyl fiber concrete – are being tested in a bridge system for the first time.

The bridge columns swayed and cracked, with small chunks of concrete falling off the structure. The 400 sensors relayed gigabytes of data through 400 channels as the 10-second quake stressed the quarter-scale model bridge with its 60 cubic yards of concrete and 16,000 pounds of steel.

"These were all new designs, and we've learned they performed better than conventional construction," professor M. Saaid Saiidi, principle researcher said. "Of the three new designs we tested, two of them had very little damage, we are quite pleased with the results so far."

This test is the largest of its kind in the United States. The test was part of a series of three tests of materials and design to make bridges safer. The first test in Feb. 2007, used a standard-design bridge of the same size, and the third bridge test will continue the look at new innovative designs and materials.

"There is no other facility in the country as big and with the equipment we have to conduct these types of tests," Saiidi said. Three 50-ton capacity shake tables acted in unison to shake the 200 tons of concrete and steel that swayed, buckled and cracked at twice the acceleration intensity of the 1994 Northridge, CA earthquake tore at the structure. The bridge model was shaken with bidirectional forces to realistically simulate an earthquake.

The UNR research team is taking advantage of unique features of materials such as nickel/titanium alloys, polyvinyl fibers mixed with cement, and rubber materials to potentially revolutionize seismic design of future bridges to help protect lives, prevent damage and avoid bridge closure even when there's a strong earthquake. "To save lives, bridges are made so they do not collapse, even though they are no longer usable," Saiidi, said. "The question is, what is the impact of having to close numerous damaged bridges in a city like New York, Los Angeles or San Francisco at a time when these bridges are needed the most for fire trucks, ambulances, and other emergency vehicles?"

The experiment is part of a multi-university project funded by the National Science Foundation (NSF) under the George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES) research program.

UNR civil engineering researchers and guests look over damage on two of three piers after the earthquake simulation test Dec. 11, 2008. (Photos by Jean Dixon/University Digital Initiatives.)

UNR doctoral students Carlos Cruz, left, and Chunli Wei take photos and measurements after the earthquake simulation test.

Other UNR faculty involved in the $2.4 million project are Dr. I. Buckle and Dr. G. Pekcan. Researchers from U.C. Berkeley, U.C. San Diego, Florida International University, Georgia Tech, Stanford University, Kansas University and University of Illinois, Chicago, Tokyo Institute of Technology, and the University of Ljubljana have been involved in other aspects of the project.

The NEES equipment site at UNR is a biaxial, multiple shake table facility (with three identical biaxial tables) that is suitable for conducting research on long, spatially distributed, structural and geotechnical systems. The facility is also capable of testing conventional structural and non-structural systems by using the tables in a large-table mode, and operating them as a single unit. Three biaxial tables are used as a single unit, with a table size of 14 × 14 feet, maximum specimen mass of 50 tons, and a force rating of 82 tons.

The University integrates this system into its research program, undergraduate and graduate assistantships and internships, high school summer camps, and K-12 outreach. The University also provides training opportunities for outside researchers and other individuals through on-site courses and workshops.

A video of the final shake test can be viewed at www.unr.edu/newsroom, which includes the actual shake test, b-roll and sound bites from interviews with the principle investigator.