PREDICTING GEARBOX HEALTH

As is the case with any major capital investment, monitoring the condition of your wind turbine simply makes sense. NRG Systems explores the issue.

By Eric Bechhoefer

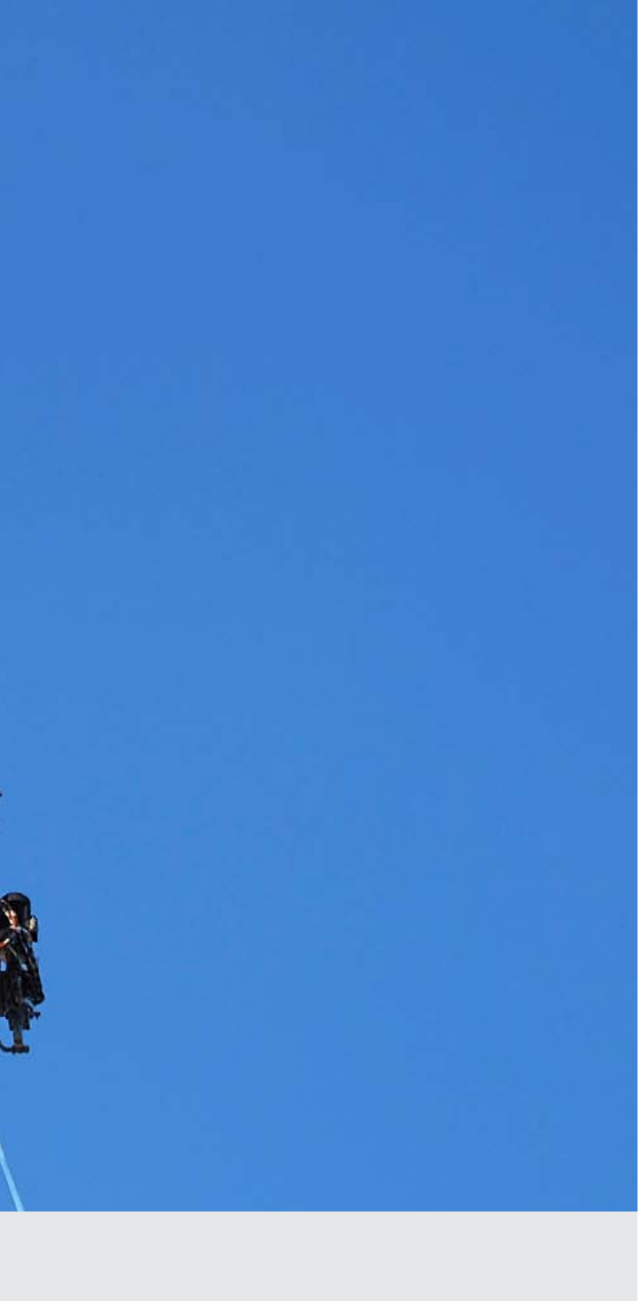
Dr. Eric Bechhoefer is lead systems engineer at NRG Systems and an acknowledged specialist in the field of rotor dynamics and wireless sensor technology. Go to www.nrgsystems.com.

AS THE NORTH AMERICAN WIND energy market matures and turbines reach the end of their warranty period, condition-based maintenance (CBM) is generating a great deal of buzz. No matter where a turbine is found, or how long it's been in operation, keeping your finger on the pulse of its internal workings will enhance productivity and increase active service life. Let's begin with a general discussion of CBM techniques before turning to whether or not you're a good candidate, and what you can expect as a return on your investment (ROI).

EXISTING OPTIONS

There are a number of commercial condition monitoring (CM) systems that provide diagnostic capabilities for wind turbine gearboxes. While useful for asset management and logistic support, the current products are deficient in two major areas. First, their ability to define a level of damage is immature (e.g., how bad is bad). Second, these systems have limited ability to predict when a component will go bad (e.g., the damage threshold).

The ability to define a damage threshold is complicated by the metric, or condition indicators (CI), used to identify component health. For all but shaft order 1 vibration—the vibration associated with 1 x the rotation rate of a shaft, which has a physical



meaning—there are rarely defined limits. For example, there is no physical limit for gear CIs such as residual kurtosis, or any other CI. In general, when a CI value is "large" (e.g., residual kurtosis greater than 8) it is assumed that the gear is bad.

Additionally, for many components there is no single CI that works for all failure modes, making it difficult to compare relative failure across components. For bearings there are condition indicators for the inner race, outer race, and roller element. For gears, which have at least six different failure modes, there are numerous CIs that work for some failure modes, but not all. While side band modulation can detect a gear misalignment, it is ineffective for a soft tooth. Similarly, residual RMS (root mean square) work well for gear tooth pitting, but is not effective for an eccentric gear.

LEARNING FROM AEROSPACE

One technique that has been successfully used in aerospace CM systems is the Health Indicator (HI). The HI fuses "n" number of CIs into a single, common indicator of health. For example, the HI can range from 0 to 1, where:

- A nominal component is 0 to 0.5;
- A serviceable component ranges from 0.5 to 0.75;
- A component out of limit ranges from 0.75 to 1, and;
- A component with an HI greater than 1 indicates continued operation would result in collateral damage to other components in the gearbox.

The HI can be designed to have a constant false alarm rate. This is initially set by sampling nominal component data, then using statistical techniques to model the data, account for CI correlation and, ultimately, ensure that a when the HI is greater than 1 it is appropriate to do maintenance. This methodology is useful because, instead of asking the question "when is the component bad," it asks the question "when is the component not good?" It enables operators to see when components are going bad and take proactive steps to avoid more costly damage.

THE VALUE OF PROGNOSTICS

The HI concept facilitates prognostics by enabling maintenance when a component is no longer good. Using the HI, the remaining useful life (RUL) of the component is then simply the estimated time until when the HI is 1. The operator knows that when the HI is 1, it is necessary to do maintenance (because the component is "not good").

The prognostic is also dependent on a fault model. Damage of rotating equipment comes from fatigue, which is a function of torque. It's no surprise that a wind turbine will fail sooner when operating under high loads (e.g., large torques). Paris's Law relates the rate of change of damage (e.g., crack length) to cyclic loading. In most cases the parameters needed for Paris's Law are calculated in the lab. NRG Systems has developed a patent-pending methodology to estimate the unknown parameters by reconstructing them from a state observer. Instead of crack length a surrogate for damage, the HI, is used. By integrating Paris's Law it is possible to estimate the cycles, or time, remaining until the HI is 1.

As a result, this prognostic (or measure of RUL) provides valuable information to operators about

Fig. 1: Gearbox, rotor shaft, and disk brake assembly (Scout Moor Wind Farm Construction).

when components might go bad and under what conditions. This allows for real-time decision making, such as curtailment under high winds to extend the life of a component. Conversely, the RUL can be used to perform opportunistic maintenance. For example, if a maintenance crew were onsite to tend to more costly damage, they could do well-informed preventative maintenance during the same maintenance event, saving time and money down the road.

While these systems aren't there quite yet, there's much we could learn from other industries to continually lower the cost of operations and maintenance and strengthen the competitiveness of wind.

CONSIDERING ROI

Now that we understand the basics of CBM practices and technologies for wind turbines, what is the actual value? Why should you as an owner or operator of wind farms want to spend money on it? The answer is because there is a lot of evidence to suggest that condition-based maintenance can significantly lower operational costs. The question is how to quantify these cost savings.

NREL's Gearbox Reliability Study, among other things, is striving to validate the performance of condition monitoring technologies. Sandia Laboratories has a similar technology program, focused on improving wind turbine performance and reliability to reduce the cost of energy. While NREL's emphasis has been on the gearbox, Sandia has focused on monitoring blade structural loads. Both groups are helping to quantify the performance of CBM practices.

CBM SAVINGS

But how are operational costs reduced? Condition monitoring does not change the design of the turbine, but it can give operators insight into the material condition of the monitored components. This insight can influence maintenance practices and logistics. For example, CBM can give early warning for an imminent generator or gearbox bearing failure. Replacement prior to failure can allow for an uptower repair ($50K) versus a downtower repair where the generator or gearbox must be dropped onsite, repaired, and reinstalled (new gearbox = $250K plus Crane Rental = $150K).

Or CBM can be used to conduct maintenance opportunistically. If the operator needs to bring the crane out for a downtower repair, knowing the condition of all the turbines in a wind farm would allow the opera-

Fig. 2: The nacelle of a wind turbine.

tor to perform maintenance on any other questionable turbines at the same time. This could save the operator from bringing the crane out again for another down-tower event. Additionally, there is the opportunity cost savings of being able to operate the turbine and generate revenue, instead of having a tower offline waiting for a crane.

WORKSHOP EXAMPLES

At a recent AWEA Project Performance & Reliability Workshop, a number of CBM cost-saving metrics were quoted. GE Wind Services announced plans to provide extended 10-year warranties, based in part on installing condition-based maintenance equipment on their 14,000+ fielded 1.5MW machines. This may be due to the reported 10-30 percent reduction in maintenance costs associated with monitored machines.

Other examples of reduction in maintenance costs were presented by Roland Kewitsch of Schenck USA. He gave the first example I have seen of what I would call "active preservation." Based on their condition monitoring system, they found a gearbox in the process of failing. By curtailing production on this machine in high wind conditions, they were able to extend the life of the gearbox by eight months. This facilitated maintenance during the summer, when production is lower and impacts on revenue are less.

IS CBM FOR YOU?

The decision to install CBM is based on a positive return on investment. While most operators agree that CBM greatly reduces operational costs, many existing projects simply have not budgeted the $20K or so per turbine cost to buy and install a system. I would say that as CBM systems mature:

- Operators will learn how to use a CBM system better and the tangible return on investment will increase;
- Insurers and owners will insist on, or provide financial incentives to, install CBM systems prior to commissioning;
- The cost of a CBM system will drop, making the initial investment more attractive.

All of which suggests that there will be many more condition-based maintenance systems installed in the future. As Jean-Marie Robin of 01 dB-Metravib stated, "You simply wouldn't not monitor a 1.5MW industrial machine when the incremental cost of changing a gearbox on a wind turbine can equal a year's profits." I would agree.