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Wind Turbines: Designing With Maintenance in Mind



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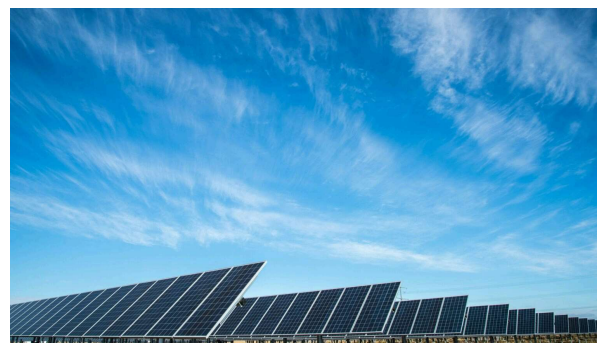
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Unscheduled maintenance costs can weaken a company's bottom line, so wind turbine manufacturers are beginning to design with maintenance in mind.

BY TERESA HANSEN, ASSOCIATE EDITOR

Wind energy technology is no longer an infant technology in the research and development stage. It has become not only a mature renewable energy technology, but also a mature electricity generating technology. According to the American Wind Energy Association (AWEA), more than 74,000 MW of wind capacity was installed worldwide at the end of 2006. A substantial portion of this capacity has been in commercial operation for more than a decade. During this time, manufacturers have learned a lot about wind turbine maintenance and are now designing a new generation of wind turbines with maintenance in mind.

Wind turbine maintenance costs are typically less than maintenance costs for conventional forms of electricity generation, which has helped make wind energy more economically competitive. Scheduled wind turbine maintenance is usually completed twice a year, resulting in about 12 to 18 hours of downtime for each maintenance event. Generally, only a few turbines in a facility are down at one time for maintenance activities. The only time the entire facility is brought off-line is for substation maintenance, which usually lasts for only about 12 hours and occurs twice a year during low production periods.



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Tower climbing is an important maintenance and repair issue at existing wind installations. Climbing to the top of large wind turbine towers is like climbing a 20-story building. Photo courtesy Clipper Windpower Inc.

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While scheduled wind turbine maintenance costs are relatively low, unscheduled maintenance can be another story. Until recently, the original equipment manufacturers (OEMs) have shouldered much of the burden associated with unscheduled maintenance and repair under maintenance/warranty agreements. In the past couple of years, however, this trend has shifted somewhat, causing maintenance and repair to become larger issues for facility owners.

“Large (greater than 1 MW) turbines are beginning to come out of their maintenance/warranty periods,” said Bob Gates, Clipper Windpower Inc.’s senior vice president, who spoke at the 2007 POWER-GEN Renewable Energy and Fuels conference held in March in Las Vegas. “In many cases, someone other than the OEM now has to learn about maintenance.”

A typical wind turbine warranty covers the first two to five years of the wind turbine’s 20-year useful design life. Gates said that often owners, such as utilities that have power plant maintenance experience, will opt for the shorter

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warranty, saving money up front by taking the maintenance risk earlier. Other owners, such as financial institutions, may elect to take as much warranty as they can get, meaning they pay more to let the OEM carry the maintenance risk.

Unscheduled maintenance cost has not deterred wind energy's growth, but in some cases has degraded companies' bottom lines. As Gates explained during his presentation, "Maintenance Considerations for Improved Financial Results," unscheduled maintenance has "degraded profits of turbine manufacturers during the warranty period. Maintenance costs have been hitting manufacturers and will soon begin hitting owners." Greater than expected unscheduled maintenance costs can negatively affect a company's internal rate of return (IRR).

Obviously, avoiding unexpected maintenance issues is the best way for a company to maintain its projected IRR. "Many of the manufacturers are designing better based on maintenance experience," Gates said. By designing with maintenance in mind, OEMs are aiming to mitigate unscheduled maintenance costs.

COMPONENT PROBLEMS AND SOLUTIONS

Generator and gearbox rebuilds are wind facilities' two most costly maintenance items. Not only are the replacement components expensive, but major expense is also associated with obtaining and mobilizing the large crane needed to repair these components, said Gates. Besides the actual crane costs and in/out costs, a long lead time to get the crane to the site and set up is common, resulting in longer than planned down time and additional lost revenue.

To improve generator performance, manufacturers are improving wind turbines' electrical architecture. Larger turbines (greater



than 1 MW) have typically used variable speed constant frequency (VSCF) technology to produce 60 Hz output from the wind turbine's variable input speed. This technology was developed in the 1990s and is limited by the solid state switches used at that time. According to Gates, one unintended consequence of this technology is the production of a stray current in the generator rotor. This stray current follows the path to ground and, by doing so, arcs across the generator bearings, causing the generator to fail.

Turbine OEMs have recognized this problem and are working to develop less complex VSCF systems, Gates said. Some manufacturers of new turbines are using permanent magnet generators that eliminate current in the rotor and thus eliminate arcing damage. These new simpler controller/converter designs use today's solid state technology, which is much improved over the solid state technology of the 1990s. In addition, these controllers/converters contain fewer parts to maintain and/or fail, making the design "simpler and more reliable," Gates said.

Gearbox reliability has suffered more than perhaps any other maintenance area as wind turbines have become larger. Charles Schultz, chief engineer at Brad Foote Gear Works and author of the book *An Introduction to Gear Design*, said, "Wind turbines are one of the most demanding applications for gearboxes due to variable loads that are extremely difficult to predict." As the wind turbines get bigger, the design challenges also get bigger, he said. The larger blades common on larger machines result in massive torque through the three-stage gearbox typically used in these large turbines.

The blades common on large machines, like those pictured here, result in massive torque through the three-stage gearbox typically used in these turbines. This torque-related stress has made gearbox reliability the biggest maintenance problem for most wind turbine operators/owners. Photo courtesy

PPM.

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In an attempt to meet the increased torque requirement, manufacturers have developed huge, costly ring gears and bearings. When these components fail (often due to torque-related stress) replacement components are expensive, as well as difficult and time consuming to replace. Because these components are heavy, replacement almost always requires a crane, which, as mentioned earlier, results in lead time delay and lost production revenue.

To mitigate the problems associated with large turbine gearboxes, manufacturers are working on various gearbox improvements. Clipper developed a distributed load path gearbox, said Gates. Clipper's design uses multiple generators and a multiple path, distributed gearbox that splits the load. This split load path reduces strain on gears and simplifies the design. Because the design uses multiple smaller generators, it potentially allows generator replacement without the lead time delay and cost of the external crane. (See "Drive Train Innovation Raises Wind Turbine Efficiency, Offers Gearbox Improvements", *Power Engineering* June 2006 for more detail.)

DESIGNING FOR SERVICE

In addition to better designed generators and gearboxes, manufacturers are also designing with service in mind. Because costs and lost revenue associated with bringing in an external crane can be huge, some manufacturers are including on-board service cranes in new machines. In Clipper's turbine, for example, the on-board crane is large enough to handle replacement of generators, pitch gears and motors, gearbox high-speed gear sets, yaw gears and motors, and hydraulic, electrical and cooling components, Gates said.

Manufacturers are also considering human factors in new turbine designs. Through years of maintenance and repair, they have learned that making components such as generators, rotors, bearings and high speed gears easy to remove and replace is important.

"It is also important to make components easier to access," Gates said, "allowing ample working space for technicians." This is especially true when it comes to rotor hub access. Gates stressed that making the rotor hub accessible to technicians from the inside (thus eliminating the need for them to work on the outside of the tower) will likely result in more and better attention to the hub during routine maintenance. Also, installing visual inspection ports for gears can be helpful.

"A picture can be worth a thousand words," Gates said.

Tower climbing is another important maintenance and repair issue at existing wind installations.

"Climbing a large wind turbine tower is like climbing to the top of a 20 story building using a ladder," Gates said. He explained that tower climbing limits work force career opportunities because, for the most part, "it is quite strenuous

and requires a tremendous amount of strength and stamina to climb a 200-foot-tall ladder.”

Because climbing to the top of wind towers may become more difficult for technicians as they age, manufacturers and owners may lose the valuable knowledge and skill that these technicians obtain through time on the job, Gates said. Recognizing this problem, many wind turbine designers are adding service lifts inside the turbine tower. This remedy allows technicians to extend their careers, allowing owners to maintain the valuable knowledge and skill these individuals have acquired. In addition, Gates believes it will result in more and better attention to turbine maintenance because access to important components is much easier and quicker, enabling the technician to spend more time when he or she arrives at the top of the tower. He also said that service lifts should result in a reduction in long-term injury costs.

PREDICTIVE MAINTENANCE

Predictive maintenance (PdM) was another issue Gates addressed. Most traditional power generators have been including PdM in their maintenance program for years. PdM is generally defined as a type of maintenance that emphasizes early prediction of failure using non-destructive techniques such as vibration analysis, thermography and oil analysis. Just as in a fossil-fired plant or a nuclear plant, a wind facility maintenance program should include PdM.

A good PdM program can identify needed repairs before they become more costly or lead to a catastrophic failure. Gates pointed out that PdM can also save on the cost of non-required maintenance. For example, a good program will identify when-or even if-an oil change is needed, eliminating added expense that often occurs with routine oil changes based on only hours of operation. A PdM program can also allow the

owner to schedule repair activities for greater efficiency and reduced costs. This can be done by staging equipment and supplies in advance and scheduling repairs and maintenance during low wind periods, Gates explained.

PdM can only be effective if it includes remote sensing and data recording.

“FPL is probably the best at using these tools to determine maintenance needs,” said Gates. Data recording tools enable the OEM and/or owner to perform basic trend monitoring and set up alarm functions. The information these tools collect also helps technicians become more familiar with each machine and its normal operating parameters.

Reducing unscheduled maintenance is a goal for all wind turbine manufacturers and owners/operators. The wind energy industry recognizes that reducing maintenance and repair costs improves the rate of return (ROR). Wind turbine OEMs are using the lessons learned at existing wind facilities to eliminate the designs that create unscheduled maintenance and risk and to add design features that will enhance reliability and improve financial performance.

WIND ENERGY WRAP UP

Renewable energy's share of electricity generation mix is steadily increasing and wind energy is leading the pack. The U.S. wind energy industry has sustained an average growth rate of 22 percent per year over the past five years, according to the American Wind Energy Association (AWEA). According to AWEA statistics, at the end of 2006, 11,603 MW of wind capacity was installed in the United States. An additional 3,000 MW is expected to be installed in 2007.

COST

This growth rate is due, in part, to wind energy's cost. "Wind energy is often the most economical form of renewable energy to develop," said Ryan Jacobson, Black & Veatch's Wind Energy Project Manager, who spoke at the 2007 POWER-GEN Renewable Energy and Fuels conference in Las Vegas in early March. In the past 10 years, wind energy's price has dropped substantially, according to statistics from FPL Energy, one of the world's largest wind power generators. Early in its development, wind energy cost as much as 30 cents a kWhr, but has now dropped to as low as 3 to 6 cents a kWhr, according to FPL Energy. Its data indicate that construction costs for wind-power generation facilities range from \$1.3 million to \$1.7 million per MW of capacity, considerably higher than the estimated \$700,000 per MW of capacity for a natural-gas fired combustion turbine plant.

The story, however, doesn't end there. Once constructed, wind facilities have no fuel costs and therefore are not affected by fuel price volatility common with natural gas-fired power plants. In addition, because wind turbines don't emit CO₂ or other greenhouse gases, wind energy will not be affected by the carbon regulations that many experts believe will be enacted in the not-too-distant future. This will make wind more competitive with coal-fired generation. AWEA figures show that U.S. wind installations avoid 19 million tons of CO₂ emissions. (This figure is based on the current 11,000 plus MW of wind capacity being generated from the average U.S. electricity fuel mix.)

TRANSMISSION

Wind energy's intermittent and unpredictable nature makes it more difficult than traditional generation technologies to tie into the grid. A wind turbine generally runs 60 percent to 80 percent of the time, according to AWEA. A turbine operates at its full power output level only



about 10 percent of the time. On average, newer, modern wind turbines in higher quality wind sites operate at a capacity factor of about 35 percent. This low capacity factor is partially a function of economic design. It is possible to design a more efficient wind turbine by reducing the generator's size and making the blades larger. Such a design would result in a higher capacity factor, but would also be much more costly than current designs.

As wind facilities become larger and forecasting tools become more sophisticated, it is becoming easier to predict the output from a large wind facility. "Wind is getting to the point in some areas where the projects are large enough that forecasting is necessary," said Richard Krauze, Business Strategy and Development director at 3TIER, Seattle, Wash., a company that specializes in understanding how weather and climate affect renewable energy generation. Krauze also spoke at POWER-GEN Renewable Energy and Fuels.

Although wind energy's capacity factor falls short of many traditional generating technologies' capacity factors, it still has one of the highest energy payback ratios (EPRs) of any power technology, according to AWEA. EPRs compare the amount of energy produced by a power plant to the amount of energy it takes to build, run and eventually decommission the plant. The more efficient the technology, the higher the EPR.

PRODUCTION TAX CREDIT

The Wind Production Tax Credit (PTC) has been a major force in wind energy's growth. The tax credit was put into place first in 1994 and has dramatically affected wind production economics. The PTC was enacted to provide an incentive for companies, such as utilities and independent power producers, to develop and operate wind generation facilities. Unfortunately for the wind industry, the PTC's staying power has been affected by political maneuvering and it has

come and gone through the years, causing a lot of instability in the wind energy industry. The latest tax credit was enacted in the 2005 Energy Policy Act and provides a 1.9 cent per kWh tax credit. It was recently extended through the end of 2008, which means that facilities built by December 31, 2008 will receive the PTC for 10 years.

Whether 26 percent growth rate is sustainable, remains to be seen. Several experts who spoke at the 2007 POWER-GEN Renewable Energy and Fuels conference said they do expect wind to continue its boom for some time.

To illustrate how unplanned maintenance can impact a company's bottom line, Bob Gates of Clipper Windpower provided this example at PGREF. The example includes two scenarios for a 100 MW wind project where the expected IRR is 9 percent:

Case 1: Two generator and one gearbox rebuild on half the turbines spread over 20 years

Case 2: Two generator and one gearbox rebuild on each turbine spread over 20 years

Assumptions:

1. Crane in/out and use = \$225,000
2. Generator rebuild = \$25,000
3. Gearbox rebuild = \$100,000
4. Crane lead time = three months (25 percent revenue loss for the year on each event)

RESULTS:

Case 1 Results:

1. Internal rate of return (IRR) drops from 9 percent to 7.6 percent; a reduction of 16 percent
2. \$62 million nominal loss of value over installation's 20 year expected life



Case 2 Results:

1. Internal rate of return (IRR) drop from 9 percent to 6 percent; a reduction of 33 percent
2. \$124 million nominal loss of value over installation's 20 year expected life

Source: "Maintenance Considerations for Improved Financial Results," Bob Gates, Senior VP, Clipper Windpower Inc. Presented at POWER-GEN Renewable Energy and Fuels, March 6, 2007.

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