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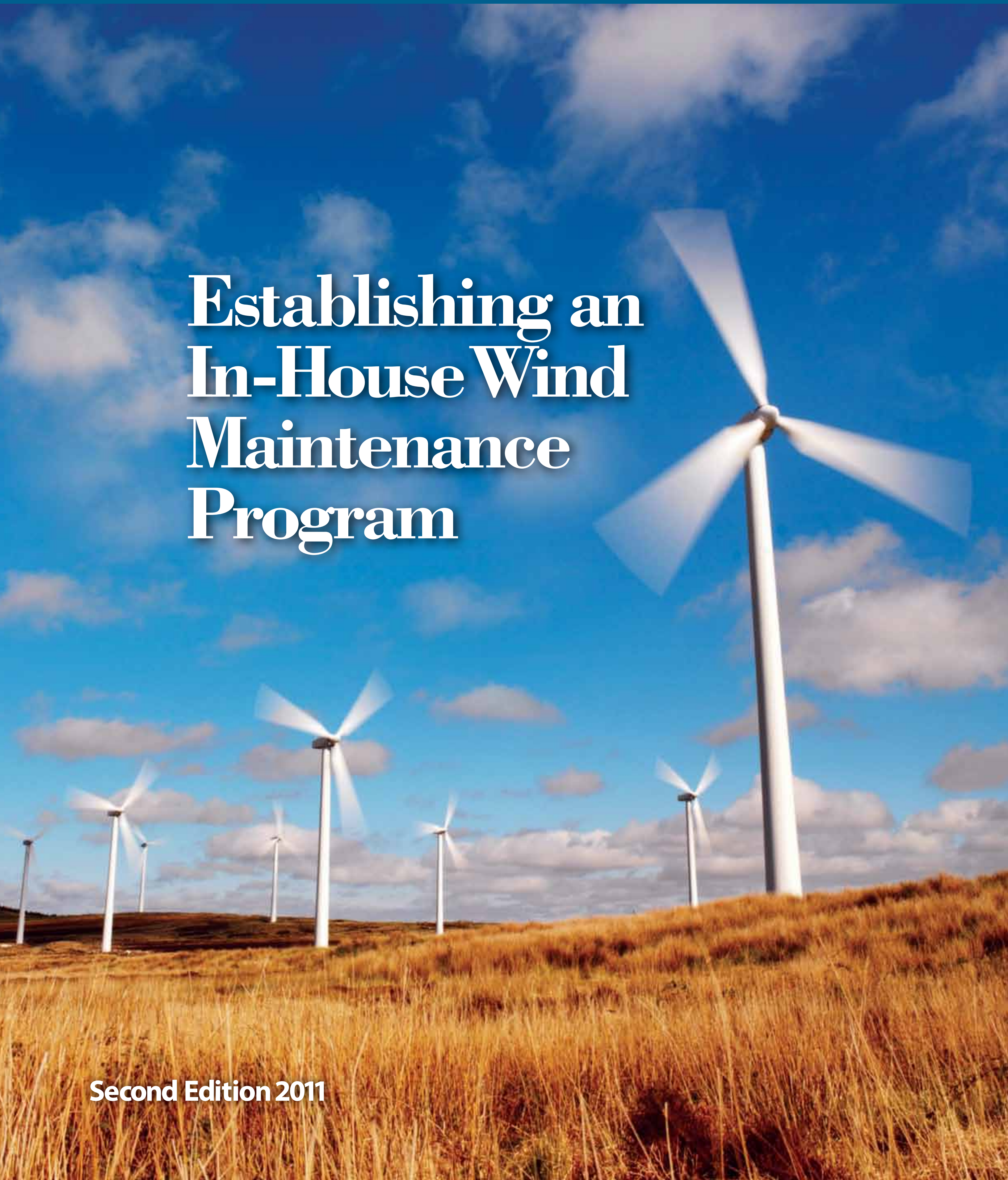

Establishing an In-House Wind Maintenance Program

Second Edition 2011

Establishing an In-House Wind Maintenance Program

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U.S. DEPARTMENT OF ENERGY WIND AND WATER PROGRAM

PROJECT CO-SPONSORS

List of Abbreviations

American Public Power Association (APPA)

American Wind Energy Association (AWEA)

Basin Electric Power Cooperative (Basin)

Balance of plant (BOP)

Combined cycle gas turbine (CCGT)

Condition monitoring (CM)

Earth System Research Laboratory (ESRL)

End of warranty (EOW)

Energy Northwest (EN)

Light detection and ranging (LIDAR)

Lockout/tagout (LOTO)

Los Angeles Department of Water and Power (LADWP)

National Oceanic and Atmospheric Administration (NOAA)

National Renewable Energy Laboratory (NREL)

National Rural Electric Cooperative Association (NRECA)

Nebraska Public Power Association (NPPA)

Nebraska Public Power District (NPPD)

Oklahoma Gas and Electric (OG&E)

Operations and maintenance (O&M)

Original equipment manufacturer (OEM)

Photovoltaic (PV)

Power purchase agreement (PPA)

Puget Sound Energy (PSE)

Sacramento Municipal Utility District (SMUD)

Sandia National Laboratory (SNL)

Supervisory Control and Data Acquisition (SCADA)

Southern California Edison (SCE)

Southern Minnesota Municipal Power Association (SMMPA)

US Department of Energy (DOE)

Utility Wind Integration Group (UWIG)

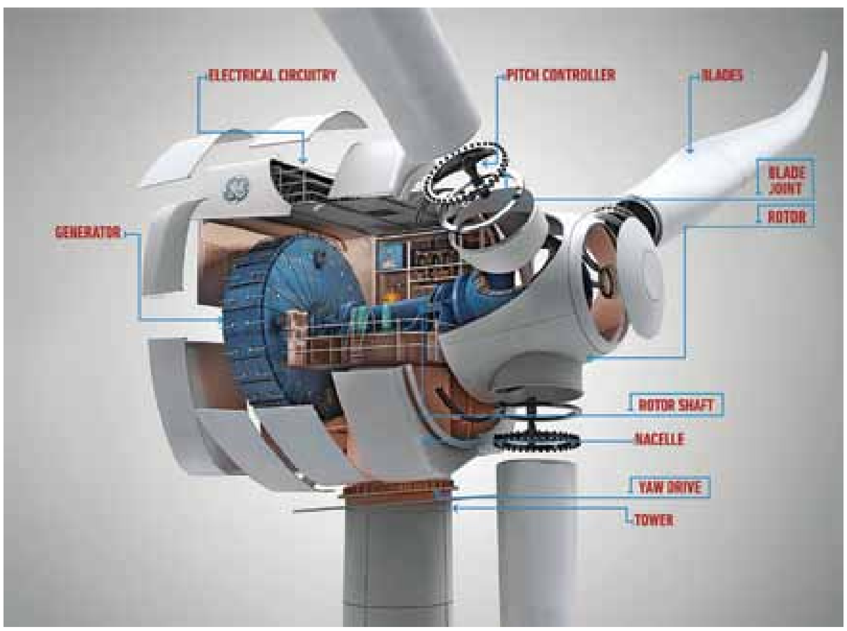
Variable speed constant frequency (VSCF)

Weighted average capital cost (WWAC)

Wind turbine generator (WTG)

Background and Acknowledgements

Maintaining a wind plant is a complex undertaking. A single wind turbine may have more than 10,000 mechanical and electrical parts, and a typical wind project is located far from the manufacturer's warehouse or any emergency repair services. As one maintenance solution, utilities that own wind projects typically buy extended warranties from the turbine manufacturers to cover parts and labor for both scheduled maintenance and repairs. Yet new alternatives for utility wind project operations and maintenance (O&M) have been emerging. Many utilities that have wind generation are now considering the pros and cons of in-house maintenance programs, and some, such as California's Los Angeles Department of Water and Power (LADWP), have moved ahead to implement in-house programs.



Source: Popular Science

To support utilities in developing O&M strategies, the American Public Power Association (APPA) DEED Program along with the U.S. Department of Energy (DOE) Wind and Water Power Program, Wind Powering America Initiative, and Western Area Power Administration cosponsored a wind O&M guidebook in 2008. Entitled Establishing an In-house Wind Maintenance Program, it was produced by BCS Inc., with support from the sponsors and enXco, LADWP, the Nebraska Public Power Association (NPPA), Nebraska Public Power District (NPPD), and Sandia National Laboratory (SNL).

In the short time since that guidebook was published, the wind industry has undergone significant evolution. Installed U.S. wind capacity has almost doubled, reaching nearly 40 GW.(1) With this rapid growth, utilities can access improved turbine products and services, and apply new O&M practices. This updated guidebook, funded by the Wind Powering America Initiative through Western Area Power Administration, addresses current needs. It includes significant contributions from utilities and other stakeholders around the country, representing all perspectives and regardless of whether or not they own wind turbines or projects. These stakeholders include Alliant Energy, Basin Electric Power Cooperative (Basin), CPS Energy, Energy Northwest (EN), enXco services, LADWP, Nebraska Public Power District (NPPD), Oklahoma Gas and Electric (OG&E), Puget Sound Energy (PSE), Sacramento Municipal Utility District (SMUD), Southern California Edison (SCE), and Southern Minnesota Municipal Power Association (SMMPA).

The authors also appreciate contributions and support from two utility service organizations, a utility technical group, and a trade association. The service organizations are APPA and the National Rural Electric Cooperative Association (NRECA). The utility technical group is the Utility Wind Integration Group (UWIG) and the trade association is the American Wind Energy Association (AWEA).

APPA and NRECA represent the nation's more than 2,900 consumer-owned utilities that provide electric service to more than 60 million Americans. These two service organizations are nonprofit, non-partisan entities that advance the public policy interests of their utility members and the consumers they serve. Current information about wind project O&M practices is useful in helping consumer-owned utilities to (1) determine the cost and benefits of wind power, (2) provide reliable electricity service at competitive costs, (3) advance diversity in utility resource portfolios, and (4) protect the environment. Both APPA and NRECA host workshops, training programs, and meetings that address current wind power topics and issues.

The UWIG mission is to accelerate the development and application of good engineering and operational practices supporting the integration and operation of wind generation for utility applications. AWEA supports the development and deployment of cost-effective wind energy in the US. They each host workshops, training programs, user groups, and annual meetings to analyze wind technology issues, opportunities, and solutions for utility applications.

All of the above named organizations have helped make this update possible. This wide range of utility wind plant owners and stakeholders has provided information centering around eight factors associated with wind plant maintenance best practices.

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Categories for a Best-Practice Review

A list of U.S. utilities that own wind plants is provided in Attachment 1. The list is from AWEA data and reports developed in 2010. Regardless of whether they contract for O&M services or tap in-house resources, all utilities that have wind generation need to keep a close eye on O&M best practices, technologies that affect O&M needs, and O&M program strategies and costs. For the purpose of this report, utility and industry stakeholder experiences with wind project O&M are divided into eight broad categories, listed below. These categories are further described in Appendix 2.

Defining the Approach

Some utilities have their own programs. Others contract out for the services. Still others use a combination of in-house and contract services.

End of Warranty (EOW) Activities

These activities involve transfer of responsibility and accountability for the wind project from the Original Equipment Manufacturer (OEM) to the utility.

Extended Warranties

Utilities that own wind plants typically buy extended warranties from the turbine manufacturers to cover parts and labor for scheduled maintenance and covered repairs.

Technology Advances

Turbines are more reliable today due to equipment improvements including a) condition monitoring (CM) systems, b) improved manufacturing quality, and c) addition of lifts to deliver workers more easily to the equipment.

Staff Requirements

The number of on-site technicians (either in-house or contractual) necessary to maintain a wind facility depends on several conditions.

Budgeting for Maintenance Costs

Standard O&M budgets include scheduled maintenance, unscheduled maintenance, spare parts, insurance and labor.

Safety and Risk Determination Guidelines

There is a need to incorporate a safety component into any maintenance plan or training program that complies with established safety standards.

Other Program Elements: Training and the O&M Plan

These key elements and miscellaneous stakeholder comments merit discussion.

Defining the Approach: In-house, Out-sourced, or Something In Between

Once a wind power plant is operational, the key to strong long-term performance lies in the maintenance program. A reliable and cost-effective maintenance program must be in place to ensure efficient operation of turbines and the balance of plant (BOP) throughout the life of the facility. The maintenance program may be considered in three phases: unscheduled maintenance, scheduled maintenance, and condition monitoring (CM). Utilities that own wind plants may choose a combination of in-house and contractual labor to implement the three phases of the maintenance program.

Some utilities, such as LADWP and Energy Northwest (EN) (2, 3), have a totally in-house program. EN has had its own wind O&M program since commissioning its first wind generation project. Today, the utility owns and maintains 96 MW of wind generation. EN has found in-house O&M benefits include building staff familiarity with the particular histories of each unit and with the whole plant, from project inception through the early break-in phase and on into the end-of-warranty long-term maintenance program.

LADWP is a relative newcomer to wind ownership, but it, too, chose to own, operate and maintain its wind generation. Its first wind project--the 135-MW Pine Tree Wind Power Plant north of Mojave, Calif., has 90 1.5 MW wind turbine generators (WTGs) and at the time of this report was in full production for approximately two years.

A number of other utilities use a hybrid approach. For example, Alliant Energy uses in-house staff for maintenance of roads, collection systems, and substations, because those in-house skill sets are already in place from maintaining other utility assets.(4) Further, Alliant found that its staff could handle most of the unscheduled maintenance and was more likely than a contractor to be available whenever an unscheduled need might arise. Still, Alliant uses contractors for scheduled maintenance and CM, because these activities have defined scopes and performance indicators that are fairly easy to manage under contract.

Taking a slightly different hybrid approach, NPPD has its own staff do most of the O&M and preventative maintenance.(5) Its biggest challenge is getting the necessary parts and equipment. The utility uses contractors to acquire cranes when needed and to assist in large projects, like gearbox maintenance and main shaft replacement.

Still other utilities—for example, PSE—use contractors to perform all of their maintenance activities. (6) PSE has a large wind project (429 MW), but it suggests that the size of utility's wind asset is not the only factor that determines whether in-house staffing or out-sourcing is the most cost-effective approach. For example, positive or negative past experience and organizational philosophy come into play, and PSE has seen good results with its contractors.

End of Warranty Activities

Warranties do not last forever. As the warranty period is approaching its end, the utility needs to engage in end of warranty (EOW) activities. In the long run, these activities may be the most important duties of a project owner. They involve an assessment of the condition of the wind facility based on a quality assurance inspection and transfer of responsibility and accountability for the wind project from the OEM to the utility.

The quality insurance inspection is the last chance to get corrective action from the OEM. It determines which equipment and components are in acceptable condition and which are not. It employs visual and mechanical review, testing, and analysis, followed by detailed reporting and recommendations. Testing includes oil and grease analysis, vibration measurements, and infrared scans. Prior to the inspection, the utility needs to identify and interpret EOW clauses within its service contract. This step provides the boundaries of the inspection, whether the inspection is done in-house or by a qualified contractor. The EOW clauses describe equipment covered, provide definitions for terms such as defects and timelines, define OEM and utility roles, and outline the O&M process. Stakeholders stress that it is important for the utility to understand EOW clauses, adhere to them, and meet or beat any deadline requirements.

Typical components identified in the EOW clauses include

Foundation	Blade bearing
Tower structure	Generator
Blades	Generator slip ring
Converter	Yaw system
Cables	Roads
Bedplate	Substation equipment
Gearbox	Transformers
Pitch systems	

Assuming that these are utility-scale wind generators, each generator inspection will take at least one day to complete. Additional time is needed after inspection for analysis, reporting, and warranty claim submittal. A good timeframe would be to initiate inspections two to three months before EOW, to complete inspections two to three weeks before EOW and to conduct the analysis, reporting, and warranty claim submittal at least one week before EOW. If a third-party contractor does the inspections, the contract should be awarded at least one month in advance.

When choosing a contractor, the utility should consider the inspection safety record, experience (in general and with specific wind project equipment), staff qualifications and experience, organizational depth, approved OEM training, and additional services, such as sourcing of parts, rebuilding and repairing components, and advanced analysis techniques.

Looking at time requirements, wind plant managers may require several crews and overtime to meet or beat deadlines. EnXco wind program managers suggest a total cost of $1,000/turbine for a basic inspection, $3,000/turbine for a moderate content inspection, and $5,000/turbine for a "bumper-to-bumper" inspection.(7)

A large wind plant inspection could require weeks of labor, and depending on the plan, it could require several crews working overtime to meet a tight EOW deadline.

There are many factors that may affect the cost of EOW inspections, including:

- OEM
- Site requirements
- Specialized equipment, such as cranes
- What is included in the EOW contract
- Local travel costs
- BOP items
- Time requirements

Nevertheless, the EOW inspection can be very cost effective. EnXco staff offered some examples. During one of their inspections, a borescope found and documented gear tooth breakage in some WTG gearboxes. A magnet swept the collected debris. The utility included photos in its claim submittal, and the OEM replaced the gearboxes under warranty. In another example, the visual and borescope inspection of several WTG slip rings found rusty oil leaking from bearings and abnormal scoring. The claim submittal was accepted by the OEM and the slip rings were replaced under warranty. In yet another example, tooth face damage was found in inspecting pitch gears, and cracking was found in inspecting turbine blades. Both claim submittals were accepted, and the OEM replaced the gears and blades under warranty.

At the Pine Tree Wind Farm, LADWP reported many turbine failures during the past two years. The utility has summed these up as "birthing pains," which are relatively normal as wind technology is adjusted to function efficiently at a particular site. To resolve problems before the end of warranty coverage, LADWP hired a company to perform EOW inspections, focusing mainly on the gearboxes and generators with sound wave attenuation and borescoping. These inspections proved to be very beneficial. LADWP believes timely identification of some problems prevented very significant and expensive failures.

Extended Warranties

Since 2008, the length of a standard wind product warranty has grown to about two years to five years, but utilities that own wind projects still tend to purchase extended warranties, typically for up to five years beyond the standard warranty. Most warranties include labor and equipment, such as cranes for removal and replacement of defective parts; however, some warranties cover only replacement of defective parts, requiring the utility to provide the labor and equipment to remove and replace the parts.

In addition to the manufacturers that offer extended coverage, some third-party providers have moved into the extended warranty market. These companies offer agreements structured like an insurance policy with levelized O&M costs. EN believes that standard warranties for WTGs and BOP will stay in the five-year range, with options to extend. EN recommends that a utility that is interested in greater coverage should expect to opt for third-party O&M or provide its own labor.

Significant factors in the choice among extended warranty options include the amount of the annual fee, the services covered by the fee, the length of time of the agreement, and the capabilities of the provider to respond quickly with the necessary (and sometimes scarce) parts. Further, utilities should be aware that most extended maintenance and repair fees are adjusted annually. The adjustments may be tied to a published index or may be a straight percentage.

Sacramento Municipal Utility District (SMUD) owns the Solano Wind Project with a total project capacity of 102 MW.(8) The project was originally constructed with a five-year warranty, which was extended to 10 years. SMUD initiated construction in 2011 to more than double the project size and issued a turnkey contract for necessary equipment and services. This contract includes a ten-year

warranty with an option to extend to 15 years. It includes all labor and materials necessary to meet generation availability goals, and it provides bonus payments and liquidated damages. SMUD has elected to use this service model rather than develop in-house capabilities, as it provides for known (or predictable) costs, and the equipment risk is transferred to the OEM.

LADWP chose to enter into a two-year "parts only warranty" with labor being provided by in-house employees represented by the electrical workers union. Part of the construction contract included OEM training, which was very beneficial in setting up the maintenance program. One challenge was that the utility did not initially have experience for working on big-ticket items, such as gearboxes, generators, and blades. Before the utility could prepare, some of these items failed. LADWP learned that it takes about two years to get a large wind project dialed in, so a three- to five-year modified parts-only warranty, including labor for big ticket items, would be most effective.

NPPD does not have an extended warranty on its turbines. Project managers there said utilities should be involved with their own maintenance because vendor support has proven inadequate. They draw a comparison to the utility's experience years ago, when gas turbine/combined cycle units started to be developed. The utility's efforts then to learn strong maintenance strategies paid off. Still, NPPD agrees that the learning curve can be steep. For that reason, project managers there are evaluating the use of a short-term maintenance contract that includes parts and labor.

PSE commented that the five-year manufacturer's warranties that are common today might not be the norm as the wind industry matures. PSE added that extended all-in service agreements are also being offered today; these include parts and labor for in-out repairs, but usually no provisions for proactive replacement of serial defects that could affect similar equipment throughout a wind project. It foresees that utilities will look beyond the manufacturers, to in-house maintenance staff or third-party contractors. As the wind industry matures in the United States, there will be more trained technicians, and parts will become more readily available through third-party suppliers, similar to the automotive industry.

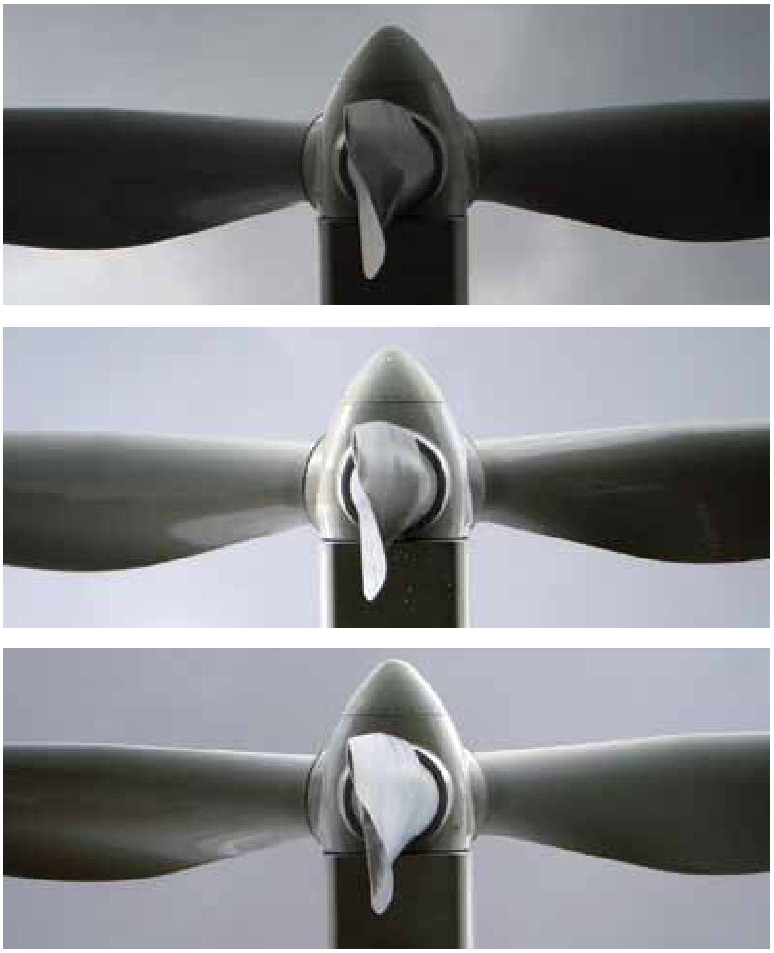
Utility O&M Experiences

Wind project stakeholders find that they can piggyback on scheduled maintenance and conduct additional maintenance at the same time. A work crew can conduct this "opportunity maintenance," while it is already on the job. Opportunity maintenance activities include:

- Oil flushing/changes
- Tower torque checks
- Bolt tensioning
- Retrofits
- Gearbox borescope inspections
- Blade inspections
- Infrared surveys
- In-service vibration analysis
- Turbine condition-based monitoring assessments

The majority of O&M work centers around the gearbox, typically in the form of gearbox component replacement and overhaul. The utilities contributing to this report have found that the high-speed shaft between a gearbox and generator is a critical point of failure. Misalignment here can harm or destroy gear tooth bearings and seals, with disastrous consequences. A precision shaft alignment at the time of turbine installation and periodic checks can help prevent component failures, up-tower repairs, and catastrophic failures. For instance, fixing a bearing up-tower can cost $10,000 to $15,000. Catastrophic failures can cost up to $260,000. A good alignment program can stop these problems before they start.

Condition-based monitoring (CM) systems use remote sensing and analytics to predict gearbox failures and other maintenance requirements. These systems reduce the need to physically visit wind turbines, which are often in remote locations and require climbing or rising to heights of 100 feet or more. They measure and monitor the physical operation of gearboxes and other moving parts that are subject to changing loads and highly variable operating conditions that create high mechanical stress on wind turbines. Measurements may include vibration, strain, acoustics, temperature, voltage, current and electrical power.



Wind plant operators monitor turbine blade pitch to detect and correct pitch misalignment. Ideally, these blades on one turbine at the PSE wind project should have the same pitch. They do not; however, PSE operators have not found a significant degradation in performance. This exemplifies how keeping data on plant performance can reduce the need for O&M. Source: Chris Walford, PSE Consulting Engineer, 2011.

For example, if CM reports that a component is experiencing vibrations outside its normal specifications, project managers can take predictive maintenance steps to inspect the component and initiate repairs or replacements before a breakdown occurs. In-service vibration analysis is an effective technique for assessing the condition of the gears and bearings, identifying problems early, and recommending an early solution. The analysis can detect gear damage such as scoring and abrasive wear, bearing defects, such as cage fractures and ring damage, alignment errors, looseness, imbalance, and resonance areas. Laser cladding (a process that applies powdered metal to a surface with a laser) is one repair technique that can restore damaged parts instead of replacing them. Oil flushing is also important, because clean lubricants support reliable wind turbine performance. The use of CM can also lead to improved O&M logistics and planning, for instance advanced warning of impending issues of multiple turbines in one area can allow for advanced scheduling of down time and equipment needed to perform repairs.

Utility experiences with yaw bearings and teeth have shown that repairing the teeth can be especially costly. They need good lubrication to hold up against static and dynamic loads and stress during wind turbine operation. Lubrication supports smooth rotation for the orientation of the nacelle under all weather conditions. Some wind turbine manufacturers now use self-lubricating gliding elements instead of a central lubrication system. Despite state-of-the art design, the bearings and teeth are subject to wear and need to be regularly inspected, adjusted, and replaced as needed.

Utilities are monitoring pitch control performance in wind projects. Depending on wind speed, a turbine's pitch system turns the blades into or out of the wind direction. The system typically adjusts the blades a few degrees every time the wind changes. This keeps the rotor blades at the optimum angle to maximize output for all wind speeds. Accumulated performance data will show how important this is, and when a maladjustment really is a problem to fix.

Wind stakeholders are finding that service history tracking tools are valuable. New software can track and analyze inspections and service work on components from construction through commissioning, as well as life-cycle performance. A technician can access this information to learn the full history of a component's performance and problems. Managers and purchasing agents can use software tools to look at an entire fleet of equipment, to review performance of certain parts, to determine fault and serial issues, and to estimate the total cost of wind project ownership.

Because LADWP had no wind energy experience to draw from, it hired a consultant from the start to set up the O&M program. With the consultant's advice and the suggestions and training provide by the OEM, the utility was able to implement its in-house O&M program rather easily.

Basin Electric Power Cooperative's (Basin) O&M program implementation also has been relatively smooth. One contributing reason here might be the experienced power plant manager who oversees the operations.(9) In fact, the entire crew of technicians at Basin are well qualified to keep operations running smoothly. Basin reports that wind technicians find utility employment attractive, because it is stable and well-compensated. Basin uses in-house technicians for almost all of its work, with supplemental third-party support as needed. For a typical wind project, the first year is likely to require more support, as some O&M service work is required to meet the manufacturer's requirements.

Technology Advances

The authors of this report conducted numerous interviews with OEMs and wind project operators. All of the projects encompassed in the interviews consisted of three bladed horizontal-axis turbines; thus the discussions in this section and the remainder of the guidebook focus on those types of turbines. Below are listed the anecdotes from the interviews.

- OEMs are improving horizontal-axis turbine electrical architecture to enhance generator performance. Turbines larger than one MW historically have used variable speed constant frequency (VSCF) solid-state technology to produce 60 Hz output from the turbine's variable input speed. However, variable-speed technology produces a stray current in the generator rotor. The stray current follows the path to ground and by doing so, can cause arcs across the generator bearings, resulting in generator failure. OEMs are working to develop less complex VSCF systems. Some OEMs offer new turbines that have permanent magnet generators to eliminate current in the rotor and eliminate arcing damage.

- EN is experiencing increased reliability with its newer 2.3-MW compared to its older1.3-MW turbines. The reliability of the larger turbines is not due to increased size, but due to improvements in design and manufacturing quality. The smaller turbines have experienced many gearbox and main bearing failures. The nature of the failures does not lend itself to any preventative actions, aside from the wholesale replacement of the component. Thus, the utility does not use Supervisory Control and Data Acquisition (SCADA) systems or CM on these turbines. SCADA systems collect data from various sensors in wind turbines or towers and send the data to a central computer that then manages and controls the data. The larger turbines are still under warranty and have SCADA and CM. The system has diagnosed a handful of gearbox problems. As a result, components within the gearbox have been replaced, averting catastrophic breakdowns, such as broken teeth and seized bearings.
- EN has not installed any turbine production enhancements due to the low capacity factors associated with wind plants. Project managers report that, because of low wind speeds at the site, production cost of the energy exceeds the market value. The managers are operating the plant mainly to satisfy Renewable Portfolio Standard (RPS) requirements.
- Following a relatively strong preventative maintenance plan, SMMPA has installed stall strips, software upgrades, yaw brakes, and caliper upgrades.(10)
- At NPPD, project managers agree that wind, like any new technology, will get better as the industry grows. Improvements of note so far are CM and a variety of process improvements. These include long-term maintenance based on increasing operational data, lifts, and the use of bucket trucks to help minimize the need for excessive climbs.
- As part of SMUD's service agreement, its turbine manufacturer has implemented product improvements to increase reliability. These are typically market-wide modifications (i.e. not just SMUD's project site), including both hardware and software. The utility collects data via its SCADA system. It provides the data to the OEM for trend monitoring. SMUD believes that, in general, it is not turbine size, CM, or lifts that have made a difference in overall wind plant performance, but simply the characteristics of a maturing industry, in terms of better products and engineering.

- Among the contributors to this report, the value of CM is widely debated. Basin is planning to implement CM, but the system is not yet installed. LADWP attempted to do the same, but was unable to install CM equipment without affecting the warranty. The utility is just now coming out of warranty and is looking for a third-party company to install CM equipment as a future O&M strategy.
- PSE finds that SCADA and CM systems are now common on new equipment, and the incremental cost is negligible. The utility has partially retrofitted the systems on selected units, but for the most part, it has not purchased project enhancements. Lifts and assists certainly make O&M easier, but PSE reports that it has not seen noticeable improvements in reliability.
- Yet the industry trend points to more SCADA and CM system usage. Several utilities reported experiences where the OEM proactively changed a major component before it failed, based on what they saw on the systems. While technically not an improvement to the equipment, they say that the systems lead to greater reliability and should lead to better products in the future.

Staff Requirements

The number of on-site technicians necessary to maintain a wind facility is still difficult to determine at this stage in the industry's evolution. The 2008 version of this guidebook recommended 1 technician for each 6 to 8 turbines. Recent process improvements, such as installation of service lifts, have driven utilities to revisit this recommendation. Basin estimates that the ratio will decrease to one technician per 10-11 turbines

EN began its operation with a crew of 6 for 49 turbines. It has since added 14 more turbines and 4 more technicians, resulting in a ratio of 1 technician per 7 turbines. That is fewer, but still in keeping with the 2008 recommendation. EN has been experiencing considerably more forced outage work than the OEM had originally predicted. The utility believes that the addition of service lifts does not reduce the number of technicians required, but effectively improves mine safety and working conditions.

SMUD notes that staffing plans need to consider not only the number of turbines, but also where they are located, whether they are divided between sites, and whether the work crews are getting enough training time. SMUD notes that turbines are trending toward larger sizes and less frequent scheduled maintenance (typically at yearly intervals), which should reduce staffing requirements. SMUD still recommends regular turbine visits to inspect for problems such as leakage, arcing, and vibration as a means to catch and correct problems before they become failures. SMUD also cites the benefits of service lifts for safety and worker retention, but not necessarily as a way to reduce O&M staff size.

Through contact with other owner/operators, participation in AWEA seminars, and its own experience, LADWP has determined that it should be able to provide wind plant O&M with 1 technician per 6-7 turbines. At the Pine Tree wind plant, that ratio works out to a total of 13-15 technicians, but due to budget constraints, the utility has been working with a total of only 10 technicians. As a result, the utility has experienced an extreme need of overtime. LADWP suggests that a relatively higher level of staffing is required during break-in and warranty periods. As turbines come out of warranty, the utility anticipates that labor needs will decline.

NPPD has a ratio of 1 technician per 6 turbines in 3 teams of 2 persons each. Project management believes that the ratio will not change. In its opinion, lifts will keep workers healthier, but will not affect staffing. PSE, OG&E, and other utilities report that a ratio of 1 technician for every 8 turbines is accurate. However, depending on the workload, some utilities have found it is necessary to augment with additional, temporary contractors. Most utilities think service lifts improve safety, technician job satisfaction, and overall efficiency of wind plant operation.

Basin's O&M program demonstrates the importance not only of getting enough staff on board, but also of making sure that hires are well qualified. One of its program's strengths is having an experienced power plant manager to oversee the operation. Basin's philosophy is that, at minimum, all key personnel should have O&M experience. Setting up critical procedures, promoting safety, such as lockout/tagout (LOTO), and keeping inventory and maintenance schedules are all priority activities, which must be well managed. At best, all hires should have O&M experience or training. Staff should be onsite to monitor the commissioning of a new turbine and preferably to participate in commissioning. This experience pays off as staff continue to optimize performance at the new facility. Project owners should also plan to provide turbine-specific training.

O&M Program Budgeting

The stakeholders contributing to this report provided few rules of thumb for developing a wind plant O&M budget. This is due in part to the relatively short history of the industry and lack of broadly representative operational data. Also, some OEM contracts restrict sharing specific data. Without specific data, it is difficult for a utility to prepare a defensible O&M budget.

NPPD has addressed this difficulty in several ways. Initially, the utility had little idea what kind of failure rate to expect or what a repair and replacement budget might look like. Staff found several studies, but no candid reporting from other wind project operators. It was hard to find out what might fail during warranty and even harder to anticipate a root cause. During the first year of its plant operation, NPPD prepared "what if" scenarios to predict budget line items. Coincidentally, NPPD placed two technicians on site during construction and commissioning. Their experiences helped the utility to refine O&M cost predictions. Today, NPPD budgets for three replacement generators per year and one gearbox every five years. In the event of an unanticipated breakdown, staff goes through an internal process to secure unspecified budget funds.

When utilities share O&M information, their networking can be valuable. For example, PSE has found that its O&M costs are driven by turbine age to some extent, but more so by the specific turbine model (not type) and major components used. The utility estimates the O&M range for a five-year-old 1-MW turbine to be between $40,000 and $70,000 per year, or around 1 to 1.5 cents per kWh generated.

Taking a conservative approach, OG&E predicts a 20 percent failure rate on major components of the wind plant, requiring up tower repair or involving a crane. The utility notes that currently, the industry is experiencing failures in gearboxes, main bearings, and generators that involve a cost from $30,000/turbine (up tower repair) to $500,000/turbine (requiring a crane). These failures typically occur in the first two to three years of operation. Additionally some failures that require complete unit replacement occur in the first one to two years, but full replacement of those flawed units is usually covered by warranty. OG&E also includes BOP maintenance requirements in its budget.

In support of its annual Integrated Energy Policy Report, the California Energy Commission (CEC) conducted a May 2011 workshop to gather feedback on various types of generation, to examine current best practices, and to review lessons learned. The CEC plans to use this information in analyzing and estimating current and future generation costs. Table 1, below contains the information provided by Southern California Edison (SCE) for different fuel types.(12) Tables 2 and 3 are the assumptions used in developing this information. Given the general lack of such information in the industry, utilities might use these variable costs of wind generation as a basis for their O&M budgets.

Table 1
Fixed and Variable Levelized Generation Costs ($/mWh) for Renewable Generation

Factor	CCGT	Solar PV	Wind
Fixed	$77.56	$260.37	$61.96
Variable	$96.90	$18.35	$14.29
Total	$174.46	$278.71	$76.25

Table 2
Financial Assumptions

Financial Information	Cap Structure	Cost of Capital
Equity	52.0%	12%
Debt financed:	48.0%	6%
Discount rate (WACC)	7.96%	6.30%
Inflation rate from base year to start year	2%	–
Inflation rate from start year forward	1.56%	–

Table 3
Technology Assumptions

Technology	Gross Capacity (MW)	Study GWh
Combined cycle standard - 2 turbines, duct firing	550	1,210
Solar – Photovoltaic (single axis)	25	42
Wind – Class 3/4	50	140

Source: "SCE Wind and Other Generation Fixed and Variable Costs," prepared for the California Energy Commission Workshop on 2011 Integrated Energy Policy Report. CCGT: Combined cycle gas turbine. PV: Photovoltaics. WACC: Weighted average capital cost.

In general, the stakeholders contributing to this report found that generator and gearbox rebuilds are the two most costly maintenance items. Replacement components are expensive, and there is a major cost for the crane needed to repair these components. In addition, it takes a long lead-time to get the crane to the site and set up. This adds to down time and lost revenue.

Basin budgets $500,000 per year for gearbox replacement. It has implemented CM to identify problems early, so bearings can be replaced "up-tower" before failures ruin the entire gearbox.

EN has an annual budget of $5.5 million for O&M for a 96-MW plant that has 49 1.3-MW and 14 2.3-MW turbines. It secured a five-year extension on the gearbox warranty for the smaller MW turbines. That total budget includes $700,000 per year for bearing replacements in the smaller turbines. The larger turbines are still under warranty.

SMUD pays a fixed annual service fee to a third-party O&M provider. This fee increases during the contract term (currently 10 years) to account for aging units. SMUD project managers are considering starting a maintenance account for costly items, such as generators and gearboxes, as the end of the warranty period nears.

LADWP originally budgeted $5 million per year for O&M on its 90 wind turbine generators, but this proved to be inadequate during the break-in period, even accounting for warranty coverage. LADWP found that this amount should be increased by at least 20 percent to cover contingencies that may arise. Having little best-practice information to go by, LADWP did not consider gearbox replacement. This expense should be considered when negotiating the warranty, and it should be budgeted for in subsequent years. A gearbox replacement costs about $500,000. LADWP is now prepared to replace one or two gearboxes per year out of its fleet.

Safety and Risk Determination Guidelines

The stakeholders contributing to this report emphasized the need to incorporate a safety component into any maintenance or training program. In some cases, this approach simply complies with established safety standards. Before technicians perform any type of maintenance, they should receive permission from a supervisor. Management must determine whether the procedure is an acceptable risk and ensure that adequate safety measures are in place. This includes examining fall protection and the LOTO system.

The 2008 Guidebook cited seven major causes of wind project accidents:

- Distractions
- Unsecure equipment
- Electric shock
- Misuse of equipment
- Loose footing
- Dropped items
- Not following established procedures

Wind and weather are the biggest challenges to safely repairing a damaged wind blade in the field. High winds prevent technicians from getting up on the blade to make the repair. Besides increasing the safety risk, cold weather impacts the composites and their ability to cure after a repair.

Whether or not large repairs should be conducted up-tower or on the ground depends on the type of damage and its location. The safest place for blade repair is on the ground. The blade typically can weigh five to seven tons, and the force of the wind flexes it. It relies on tensile (lengthwise) strength, and if damaged, this strength may be compromised. Wind and the force of gravity could complicate a blade repair up-tower. It may be harder to return the blade to its originally engineered specifications up-tower.

Up-tower repair, including work done inside the nacelle, requires working in a fully-confined space. Procedures should be approved before this kind of work begins. There are several means of access to the blades and nacelles, including a combination of ladders, lifts, crane-hoisted baskets, and ropes. For example, in blade repair, technicians can lower themselves from the turbine, using ropes to allow 360-degree access to the tower and blades. Workers may use separate bearing ropes (ropes fabricated to hold a designed maximum weight) and hauling systems to lift heavier equipment, tools and materials.

Substation maintenance is another activity that the O&M staff may need to perform. Technicians must be well trained on the safety aspects of substation work. Related activities include monitoring settings, reading gauges, LOTO procedures, operating switches, and isolating components.

At EN, safety is a core value. The utility holds weekly safety meetings. Every new task is planned before execution with a job hazard analysis and mitigation plan. The EN wind program has experienced one incident of electric shock. At SMUD, safety is and always should be paramount in a turbine maintenance plan. Substantial hazards exist in the turbine nacelle, and proper training and procedures are essential.

At LADWP, safety and training are foremost considerations. Technicians receive initial training in climbing and rescue techniques, provided by an outside contractor. The contractor also provides an annual refresher course. LOTO training is also given in-house on an annual basis. The technicians inspect their climbing gear daily, as well as having it inspected by co-workers on a monthly basis. Bi-weekly safety meeting are held to discuss relevant topics. Technicians receive work authorizations from the supervisor as well as from the station operators before any work is performed. Technicians only work in pairs due to the hazards and remoteness of the project site. They also maintain constant radio contact with the control room.

LADWP staff prepared an emergency action plan before Pine Tree went into service, because the wind plant has some unique safety hazards. The plan covers many safety concerns. It is updated on a regular basis to cover any newly recognized hazards as they come up. Weather is a main concern as the temperature can exceed 110 degrees for long periods of time. Lightning and freezing weather can be a problem, too, accompanied by snow and ice. For example, high winds, icy road conditions, and turbines shedding ice require that all personnel stay off-site or retreat to the maintenance building. This is strictly enforced. Also, the site has a large population of Mojave green rattlesnakes, and crews are constantly reminded to remain vigilant of this. Kern County Fire has the GPS coordinates for three landing zones on the site and will have a helicopter respond in minutes should snakebite occur. Because safety is constantly being stressed, Pine Tree has had very few occurrences of accidents or injuries. The only incidents so far have been vehicle accidents in the vicinity of the remote site.

NPPD's culture dictates that all work done requires some type of procedure. OEM manuals outline basic procedures, but as a utility doing O&M, NPPD takes those manuals as only a starting point for safety. The utility takes the OEM information, steps through the process and ensures that procedures meet utility policy and expectations for safety. NPPD staff believes that people put a lot of pressure on themselves. If human performance tools are being used, like pre-job briefs, two minute drills, looking for possible error traps, then a lot of accidents will be prevented.

Many utilities believe that technical training and safety go hand in hand: the best-trained worker is usually the safest worker. The term "a rookie mistake" came from somewhere. Well-trained technicians are familiar with the equipment, voltages, pressures, and other conditions they will meet in the field, so they will be prepared to safely address any associated hazards.

Program Elements: Worker Training and the O&M Plan

Environment, Safety, Health and Quality employee, Michael Stewart conducts a hoisting and rigging safety training at the National Wind Technology Center. Stakeholders who have contributed to this report stress the importance of this type of training. (Source: Corkery, Patrick – NREL Contract Photographer)

There are three key elements in an effective wind project O&M program. In addition to the safety issues addressed in the previous section, a strong program must address maintenance training and maintenance plans. Vocational schools, manufacturers, or contractors typically provide wind technician training. Program managers or crew supervisors should track who has received training on a particular aspect of O&M. This helps in assigning the right workers to each specific maintenance task, or in looking for outside help as needed. Additional comments on the topic of worker training are included below. Likewise, several contributors discussed the development of the maintenance plan, and their comments are reflected below.

Worker Training

To safely and effectively perform O&M activities, utilities need to provide technicians with training and testing procedures. Training includes how to read drawings, how equipment (turbines, inverters, gearboxes, yaw motors, voltmeters, transformers, capacitors, and switches) works, what the limits of the equipment are, and how to manage hazards. The utility, a training contractor, and/or the OEM may provide training, in the classroom or online, using computer based exercises, reading, and self study. Supervisors may schedule safety meetings, on-the-job sessions, demonstrations, simulations, and class work. Some utilities have found that tracking the performance of a portion of the wind project's turbines on different circuits can provide practical lessons in troubleshooting, as well as reducing failure incidents.

A training schedule should include developing skills in the use of analytical equipment, such as borescopes. A borescope consists of a rigid or flexible tube with an eyepiece on one end and an objective lens on the other, linked together by a relay optical system in between. It may be fitted with a camera, and is used for inspection work where the area is inaccessible by other means. Even though this tool is valuable, there are some locations where it may be difficult to use. OEM training manuals suggest where and when to use this tool.

Table 4
Borescope Tool Applications for Wind O&M

Component	Accessibility	Coverage	Relevance
High-speed shaft CRB rotor-side	Good	Good	High
High-speed shaft TRB gen-side	Difficult	Limited	Medium
Intermediate shaft CRB rotor-side	Difficult	Limited	High
Intermediate shaft TRB gen-side	Good	Good	Medium
Low-speed shaft FCB rotor-side	Good	Limited	Low
Low-speed shaft FCB gen-side	Difficult	Limited	Low
Planet TRB	Very difficult	Very limited	High
Helical gearing	Good	Good	Medium
Planetary gearing	Good	Limited	High

PSE provided this summary of applications for using a borescope in wind plant O&M.
Source: "Hopkins Ridge Condition Assessment," Chris Walford, PSE Consulting Engineer, 2011

Basin, EN, and NPPD reported that they send all of their technicians to OEM training. EN uses a computer-based training program, with emphasis on mechanical and electrical components, controls, and hydraulics. NPPD's training department has set up a program to keep track of training that has been provided and when requalification is required. This training covers issues related to maintenance, electrical systems, safety, and environmental regulation. Specific topics include CM, oil sampling, generator testing, and other predictive practices. In addition, supervisors provide just-in-time training prior to doing any repair that has not been done for a while.

The O&M Plan

A good maintenance plan is important for several reasons, including for the needs dictated by project finance requirements. To achieve the best possible bond rating, the utility may need to present its O&M plan and risk assessment, including a comprehensive turbine warranty that covers scheduled and unscheduled maintenance. The warranty should include the repair and replacement of defective equipment, as well as full root-cause analysis and remediation of serial defects in major components and guarantees for the availability of spare parts for 20 years. It is important to have a plan that includes analysis and remediation of serial defects. If such defects go unrecognized, the wind plant's technical and economic performance will decline over the long term.

A good maintenance plan includes allocations for regular audits, tracking and evaluating failures, repairs, wind turbine generator availability, and downtime. The plan should couple probability of failure with the consequences of failure, and assign a risk rating to each failure mode. Some utilities have developed spreadsheets that describe each failure, consequence, and risk associated with turbine-generator components. For example, these utilities consider the probability and consequence of gearbox bearing failure to be high. They consider the probability of main shaft failure to be low, but with high consequences. There are still unknowns with this approach, too, such as the probability of yaw claw spring failure, which would result in the loss of the ability to keep the blades facing the wind. Fortunately, the consequences of that particular type of failure are not catastrophic.

OEM maintenance schedule recommendations vary, but each typically covers various parts and systems at intervals of 4, 6, 12, 24, and 48 months. Repairs may be grouped by maintenance type. Older turbines have special maintenance needs, requiring overhaul every 5 years. Scheduling up-tower maintenance during months of typically better weather will increase productivity.

Incorporating a plan for predictive maintenance allows operators to repair a weak turbine part before it fails. While some utility stakeholders are still assessing the value of SCADA and CM systems, trends indicate they should be highly recommended for this purpose, as they allow an operator to monitor a turbine's overall performance. An operator should also plan a cleaning schedule and anticipate events requiring unscheduled maintenance. A quality control system can minimize unscheduled maintenance.

EN reported that it does not do overhauls and allows 6-month maintenance intervals on all of its turbines, even the larger turbines which normally are scheduled for 1-year maintenance. Larger recommended repairs are evaluated for their effect on turbine availability and are scheduled appropriately. Gearbox oil changes are done every 5 years.

SMUD has found that performing the manufacturer's recommended services on schedule is essential to turbine reliability and plant availability.

LADWP also follows a maintenance plan established by the OEM. When its plant comes out of warranty, the utility will most likely adjust the frequency of this maintenance to every 8 or 9 months rather than every 6 months. Wind project managers believe that this frequency will meet the needs of the WTGs, without sacrificing the integrity.

At NPPD's wind plant, maintenance is scheduled in accordance with the same philosophy that would be applied in any power plant. For example, typical power plants schedule their outages during low load times. NPPD schedules wind plant work during the low wind season. There is always emergency work, but the majority of work has minimal impact on expected production. NPPD uses a software program to plan and schedule work and to keep repair histories for turbines and components.

Several utilities see the trend going to predictive maintenance and away from preventative maintenance. For example, a preventative maintenance schedule might dictate that the gearbox oil be changed every 4 years but a predictive maintenance schedule would dictate that the technician take annual oil samples and change the oil after analysis determines that it needs to be changed. Thus, an oil change might happen every 2 years or every 6 years, depending on the health of the gearbox.

Additional Comments from Stakeholders

The stakeholders contributing to this report offered additional notes on SCADA systems, predictive maintenance, CM, and specific operations and components such as gearboxes, component integration, lubrication, and turbine wake and inflow, indicating emerging O&M trends.

SCADA, Predictive Maintenance, and CM

SCADA systems aid in improving turbine performance, particularly in cold climates. The technology may be used to detect trailing- and leading-edge ice formation. It can initiate different control systems, such as pitch, stall, and active stall control. Also, rather than rely on visual inspections, it can detect when ice has melted, so the turbine may resume normal operation.(13)

Predictive maintenance is a rising trend in the wind industry, and many stakeholders believe it merits special consideration. Predictive maintenance, which is well known to more mature industries, uses high-tech CM technologies and may be the most cost effective of all O&M strategies, because it reduces maintenance costs and breakdown frequency, increases machine life and productivity, and reduces spare parts inventories and the use of overtime.

CM systems monitor the status of all components subject to wear.(14) In a wind system, the gearbox, bearings, and generator, are steadily monitored and data is archived on the basis of the acoustic frequencies measured. Automated analysis typically draws up a comparison between the ideal and actual situation. In the event of a discrepancy, it signals a preventive service operation to be planned before any damage gets serious.

With CM, turbine inspections and services may be planned in advance, rather than as a reaction to damage done. The data recorded by the CM system for each wind turbine may be evaluated in a database containing stored plant history. The historical data on individual turbine types and product families are evaluated, in addition to the values of the individual turbines. PSE foresees CM procedures evolving so CM will become part of the utility's overall monitoring program, including SCADA monitoring, performance monitoring, fault categorization, failure tracking, and spare parts management.

As noted above, wind stakeholders are still debating the merits of CM, with some wind project owners delaying their investments in CM and others believing that the investment has great value. Overall, the trend is toward greater reliance on CM. Wind manufacturers are being asked to review the impact of CM on WTG warranties.

Gearboxes

Early main-shaft gearboxes on kilowatt-sized machines were off-the-shelf industrial units with minor modifications. As turbines got bigger, gearboxes were designed for each turbine model. There is a trend toward lighter overall turbine weight, improved durability, and design for maintenance. As one example, in some models, the bearings that support the main shaft and rotor are being integrated into the gearbox itself. This integration can increase access and reduce overall drive train size and gearbox stress.

Component Integration

The market is seeing more integration between gearboxes and generators, which results in lower turbine size, weight, and cost. Integration can result in reduced numbers of gear stages and shafts. By combining the power density of hydraulics and the weight benefits of electronics, hydraulics engineers are looking for ways to increase reliability, improve turbine operating efficiency, and reduce maintenance. New hydraulic systems cool and condition gearbox oil for lubrication and monitor temperature, pressure, vibration, oil particles, and moisture. Cooling and monitoring the gearbox help reduce downtime, gearbox failure, and expensive repairs. Improvements in sealing and connector technologies allow field replacement and repairs without the use of heavy or welding equipment on-site and extend the life of rotational devices.

Lubrication

Wind equipment requires specialized lubricants that blend a base lubricant with additives to aid the performance of individual bearings. In some cases, operators are using specialty synthetics instead of mineral oils. Another trend is to monitor the lubricant using a CM system. Particle-counter units can track system contamination trends, and give early warnings. LED lights or digital displays indicate low, medium, and high contamination levels. This helps operators to keep lubricants clean and increase turbine lifespan. Also, because wind turbines are built installed on higher towers and in more extreme conditions today, the trend is toward using low-viscosity lubricants to minimize cold weather effects. However, in some conditions, the use of low-viscosity lubricants can cause an increase in micro-pitting and other contact related issues.(15)

Turbine Wake and Inflow

To improve energy production by wind projects, the National Oceanic and Atmospheric Administration's (NOAA) Earth System Research Laboratory (ESRL) is launching a Turbine Wake and Inflow Characterization Study to make visible the wakes produced behind wind turbines. This turbulence can damage turbines downstream in a project, decreasing productivity and potentially raising warranty issues. The study includes an experiment using a high-resolution scanning-Doppler light detection and ranging (LIDAR) technology to create three-dimensional modeling of wind speeds and directions in turbine wakes. (16)

The NOAA team plans to capture turbulence and other wake effects in a broad wedge of air up to seven kilometers long and one kilometer high. The team will use the scanning LIDAR to take a detailed look at the atmosphere in front of and behind one of the 2.3-MW turbines on a NREL site. The team plans to capture the effects of ramp-up and ramp-down events, when winds suddenly gust or die down. It also will gather data on what happens downstream when winds shift direction quickly. The study is part of an overall NOAA and DOE strategy to enhance the accuracy and completeness of resource information for weather-dependent renewable energy technologies and infrastructure.

Other Comments

While all stakeholders stressed the importance of preventative maintenance, EN underscored completing preventative maintenance on schedule. EN also recommended drafting the agreement with the original manufacturer so the OEM must permanently fix design and/or installation problems that consume crew time. EN has a serial defect clause in the warranty on its 2.3-MW turbines, stipulating that if 20 percent of the turbines exhibit the same failure, the OEM will do a root cause analysis and develop a corrective action plan, followed by fleet-wide repairs. The clause was not in the warranty on EN's 1.3-MW turbines, for which over half the gearboxes and main bearings needed to be replaced.

SMUD added comments suggesting four key actions:

- Talk to other wind project operators and particularly operators of the same turbines. You will learn a lot. Consider joining a users group or forming one for your turbines if one doesn't exist.
- Inspect the turbines regularly, even between maintenance cycles.
- Keep turbines clean, particularly clean up any lubricants or liquids that leak or spill. These pose a safety hazard to technicians. Technicians will also take better care of equipment if they know the utility or O&M contractor cares enough to keep it clean.
- Utilize all the data that is collected by the turbine SCADA system, i.e., data mining can be a very powerful tool.

LADWP's Pine Tree project OEM recommended purchasing "maintenance kits" every six months to support maintenance activities. The kits consisted of the estimated amounts of grease, filters, brake pads, and other items that would be needed and cost around $400K twice a year. After several years LADWP determined that it was purchasing more parts than necessary. It has established a target range of inventory for the warehouse to keep on the shelves. After warranty, these purchases can be made from other vendors at a reduced rate.

Conclusions

Based on stakeholder discussions, utilities have a good handle on understanding most of the factors of an O&M program described in the introduction. Those factors are EOW activities, extended warranties, utility O&M experience, technology advances, safety and risk determination guidelines, and O&M program key elements. Utility wind project managers have a strong sense of all these factors – especially the safety and risk determination guidelines. They aim for a zero-incident worksite. They recognize that this aim requires root cause analysis when incidents occur, as well as intervention in unsafe behaviors, identification of hazardous conditions or practices, and reporting of "near misses."

There were small discrepancies among the stakeholders on staff requirements for the wind plants. The ratios of number of on-site technicians (either in-house or contractual) necessary to maintain a wind facility ranges from one technician per six turbines to one technician per ten turbines. Most of the stakeholders reported that recent technology advances, such as lifts and CM applications do not reduce staff requirements, but some believe that these advances will reduce the requirements. As the utilities gain more O&M experiences and share them in venues such as AWEA and UWIG working groups, they may reach a better consensus.

The most difficult factor to reach agreement on is Budgeting for Maintenance Costs. Standard O&M budgets include allocations for scheduled maintenance, unscheduled maintenance, spare parts, insurance and labor. Most contracts between OEM's and utilities have a clause prohibiting disclosure of any of the contents of the contracts, including O&M costs. There are similar restrictions in many power purchase agreements (PPAs). In other words, valuable information of O&M costs exists; it just can't be shared.

To increase transparency in data collection and availability, AWEA and UWIG working groups are communicating separately from and in collaboration with OEMs. In addition, there are three national collaboratives supported by the U.S. Department of Energy (DOE) that are partnering with wind plant operators to collect wind plant O&M failure data. The Gear Box Reliability Collaborative is led by National Renewable Energy Laboratory staff with a goal of identifying and diagnosing premature failure of wind turbine gear box components.(17) Sandia National Laboratory is creating a Continuous Reliability Enhancement database for Wind (CREW). This database will be the foundation for analyses to identify primary failures and associated improvement opportunities, enable reduced operating and maintenance costs, and provide industry benchmarks for utility-scale turbines of one megawatt and higher.(18) Sandia has also created the Blade Reliability Collaborative, which oversees a widespread tracking system to monitor reliability of the fleet, archived in a national reliability database.(19)

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Appendices

1. U.S. Utilities That Own Wind Assets

From a review of AWEA reports and data, as of 2010 there are 53 electric cooperatives, investor-owned, and public power utilities that owned wind assets. The majority of the utilities are electric cooperatives or public power utilities; however, on average, investor-owned utilities have a higher average level of assets. Tables A1 through Table A3 identify the sites and sizes of those assets for all three types of utilities. These three tables do not reflect the significant commitment utilities across the country have made to the wind industry in the form of power purchase agreements. Such agreements allow utilities that can't take advantage of tax credits, to get reasonably prices wind power to their customers.

Table A1
Electric Cooperative Utilities With Wind Assets

Utility	Size MW	Site(s)
Alaskan Village	1	Toksook Bay, AK et al.
Basin	125	Minot, ND et al.
Fox Islands	4	Fox Island, ME
Illinois Rural	2	Pike County, IL
Iowa Lakes	21	Lake Lakota, IA et al.
Kotzebue	2	Kotzebue, AK
Minnkota	2	Petersburg, ND
Tanner	4	Klickitat, WA

Table A2
Investor-Owned Utilities With Wind Assets

Utility	Size MW	Site(s)
Alliant Energy	267	Franklin County, IA et al.
Kansas City P&L	100	Spearville, KS
Madison G&E	41	Worth County, IA et al.
MidAmerican Energy	1284	Pocahontas County, IA et al.
PacifiCorp	1032	Arlington, WY et al.
Minnesota Power	25	Taconite Ridge, MN
Montana-Dakota Utilities	50	Cedar Hills, ND et al.
Oklahoma G&E	221	Spirit Wind, OK et al.
Otter Tail Power	138	Lake Ashtabula, ND et al.
Portland General Electric	275	Biglow, OR
Puget Sound Energy	429	Wild Horse, WA et al.
We Energies	147	Fon du Lac Co., WI et al.
Westar	149	Flat Ridge, KS
Wisconsin Public Service	109	Howard Co., IA et al.
Xcel Energy	127	Mower Co., MN et al.

Table A3
Public Power Utilities With Wind Assets

Utility	Size MW	Site(s)
AMP-Ohio	4	Bowling Green, OH
Arkansas River Power	2	Lamar, CO
Cowlitz PUD	193	Harvest Wind, WA
Energy Northwest	96	Benton Co., WA
Eugene Water & Elect. Board	6	Foote Creek Rim, WY
Hull	2	Hull, MA
Iowa Dist. Generation	2	Kossuth Co., IA
Klickitat PUD	53	White Creek, WA
Lakeview L&P	53	White Creek, WA
Lenox	1	Lenox, IA
LADWP	135	Pine Tree, CA
Lincoln Electric	1	Lincoln, NE
Missouri Joint MEUC	5	Rockport, MO
Moorhead	2	Moorhead, MN
MEAN	10	Kimball, NE
Nebraska Public Power	59	Ainsworth, NE
Oklahoma MPA	51	Woodward, OK
Omaha Public Power	1	Omaha, NE
Osage Utilities	2	Osage, IA
Palmdale Water District	1	Palmdale, CA
Princeton	3	Princeton, MA
Sacramento MUD	168	Solano Co., CA et al.
SMMPA	8	Fairmont, MN et al.
Stuart	1	Stuart, IA
Travis City L&P	1	Travis City, MI
Turlock Irrigation District	137	Klickitat Co., WA
Wall Lake	1	Wall Lake, IA
Waverly L&P	2	Waverly, IA
Wilmar	4	Wilmar, MN
WPPI Energy	2	Worthington, MN

2. Wind Maintenance Guidebook Market Assessment Guidance

This open-ended assessment document was developed by the stakeholders to assist them in sharing their O&M experiences with one another. The stakeholders shaped their input in eight broad categories described below.

Extended Warranties

Utilities that own wind plants have typically chosen to buy extended warranties from the turbine manufacturers that cover parts and labor for both scheduled maintenance and repairs. What is the typical warrantee length (such as two years or five years)? Do warranties include labor/equipment for removal and replacement of defective parts, or just replacement of defective parts? How do you see this trend evolving?

Utility O&M Experience

If your utility has its own O&M program, what has been your experience in setting up and implementing it? If you don't have such a program, what have you heard from your peers who do? Are you using third-party support for a major portion of your O&M or using in-house technicians for the majority of the work?

Technology Advances

The 2008 guidebook notes that turbines are more reliable today due to equipment improvements, including a) condition monitoring systems, b) increased turbine size and c) addition of lifts. Do you agree with this statement and what other improvements, if any, have you seen or do you anticipate? Have you implemented condition-based monitoring systems? Why or why not? Some turbine manufacturers are offering enhancements to increase production. Are you implementing those enhancements? Why or why not? Results?

Staff Requirements

Although the number of on-site technicians (either in-house or contracted) necessary to maintain a wind facility depends on several factors, the 2008 guidebook recommends one technician per six to eight turbines. What are your comments and/or experiences? Does the addition of service lifts reduce the number of technicians required?

Budgeting for Maintenance Costs

Standard O&M budgets include scheduled maintenance, unscheduled maintenance, spare parts, insurance and labor. What would you recommend budgeting for O&M? During warranty and after warranty, do you include contingencies for gearbox replacement? If so, how much?

Safety and Risk Determination Guidelines

The 2008 guidebook emphasizes the need to incorporate a safety component into any maintenance plan or training program that complies with established safety standards. Before technicians perform any type of maintenance, they must determine whether the procedure is an acceptable risk and ensure that safety measures are in place and functioning properly. This includes examining fall protection and the lockout/tagout system. A technician should also receive permission from a supervisor before performing maintenance. What are your comments on this component and on the major causes of accidents listed below?

- Typical causes of injury
- Distractions
- Unsecure equipment
- Electric shock
- Misuse of equipment
- Loose footing
- Dropped items
- Not following established safety procedures

O&M Program Key Elements

The 2008 guidebook listed three key elements for an effective O&M program. Please share your views on the elements, listed below (including additions, deletions, or comments on other issues, such as reliance on certifications):

1. Safety and risk determination guidelines (addressed above)

2. Maintenance training program - A technician must receive proper training before attempting any form of maintenance or repair. Such training is typically provided by vocational schools, manufacturers, or contractors. One key component of a training program is maintaining a training log of who has received training in a particular area. This helps to ensure that a technician is capable of performing a specific maintenance task.

3. Maintenance plan - The first step in developing a maintenance plan is to establish a maintenance schedule. Adhering to a maintenance schedule is a cost-effective way to ensure that the turbines are functioning properly. For example, GE's maintenance schedule recommends maintenance on various parts and systems at intervals of 4, 6, 12, 24 and 48 months. Repairs might be grouped by maintenance type. Older turbines have special maintenance needs requiring overhaul every five years. Incorporating a plan for predictive maintenance allows operators to repair a turbine part before it fails. Condition monitoring systems are highly recommended for this purpose as they allow an operator to monitor a turbine's overall performance. An operator should also plan a cleaning schedule and anticipate events requiring unscheduled maintenance. A quality control system can minimize such unscheduled maintenance.

Additional Comments

Please provide additional guidance to utilities on operating and maintaining a wind plant and improving its reliability.

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