ELECTRIC POWER RESEARCH INSTITUTE

Wind Energy Lubrication Maintenance Guide

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Wind Energy Lubrication Maintenance Guide

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Product Description

Background

With the rush to develop today's massive wind energy sites, more attention should be paid to the inevitable need to perform routine maintenance and develop practical means of assessing the condition of the components within the nacelles and other outside support equipment for the wind farms. Current operating models have not adequately established accurate assumptions or expectations on the unavailability of the windmills and the impact on lost generation. Contracts for purchase of their generation output are being affected by these losses, causing increased concern about overall reliability. The current business model is not adequately focused on equipment health and reliability as is seen in more conventional power generation facilities. However, that is about to change.

There is a developing concern among wind farm owners that generation revenues are being lost at much higher rates than expected because of unavailable machines. Machines that are off-line for long periods due to equipment degradation and failures do not generate revenues to pay back the investments. Even though they might have equipment warranties or maintenance agreements, there are no warranties or liquidated damages for lost generation sales when a wind energy asynchronous generator is off-line due to an unexpected outage.

Objectives

The objective of this project is to collaborate with wind farm owners, operators, original equipment manufacturers, and vendors to develop tactical guidelines for reliably maintaining 1–2 MWe wind energy turbine generators.

Approach

Researchers contacted wind turbine repair vendors, service providers, and operators for maintenance recommendations. In addition, an Internet literature search was used to identify potential information sources. Researchers also reviewed ANSI/AGMA/AWEA 6006-A03, *Standard for Design and Specifications of Gearboxes for Wind Turbines,* as well as past Electric Power Research Institute (EPRI) technical reports on wind turbines and lubrication practices.

Results

This report summarizes operation and maintenance practices, with minimal theoretical content.

Applications, Value, and Use

These guidelines can be used for in-house development of maintenance crews, to provide training for contract maintenance crews, and to provide a consistent maintenance program for lubrication practices on the 1–2 MWe wind turbine generators typically found in on-shore applications.

Keywords

Gearbox
Lubrication
Maintenance
Wind turbine

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Section 1: Overview

A wind turbine generator is designed to produce electrical power at widely variable wind speeds. A wind turbine generator has a maximum rotational speed based on the structural limits of the connected rotating components, the nacelle housing structure, the tower structure on which the wind generator is mounted, and the tower foundation that supports the entire unit. Figure 1-1 shows an example of a wind turbine generator.

Wind turbine generators are often located in harsh environments, with exposure to dusty conditions, moisture from weather, and often extreme temperatures. They are typically designed and operated to require minimal routine maintenance and servicing due to safety concerns for personnel and the relative inaccessibility of the components. Wind turbines are often located in remote areas where maintenance and repair of components are very expensive and time consuming due to inaccessibility of the equipment and the requirement for repair tools such as large portable cranes.

Figure 1-1
Wind turbine generator example

A wind turbine generator basically consists of a wind-driven blade assembly connected to a gearbox assembly connected to a generator to produce electrical power. The blades of the blade assembly must be able to change pitch (rotate) to aid in efficient and safe operation because wind speeds and gusts can change radically in short periods of time. The nacelle housing must be able to rotate to better align with the wind direction for improved efficiency. The bearings and gears of the gear boxes must be able to function at low speeds with high stress loading and at high speeds with lower stress loading conditions. The rotation of the wind-driven blade assembly produces stresses on the main bearing; the gearbox internal bearings, shafts, and gears; and the bearings of the generator.

The correct lubrication and lubrication systems for 1–2 MWe wind turbine generators are critical considerations for reliable and efficient operation of the units. Each component of the wind generator system requires the proper lubricants and lubrication systems specific to their applications to maintain their reliable operation.

The wind turbine industry is maturing as more units are being installed, more data are being collected, original equipment manufacturers (OEMs) are improving their engineering, and product suppliers, such as lubrication suppliers, are developing better products for use on the units.

Section 2: Technical Description

Wind turbine gearbox, generators, and associated equipment are located in the nacelle housing at the top of the tower structure, often hundreds of feet in the air. Figure 2-1 shows an example of a wind turbine generator nacelle and tower structure. Performing maintenance on wind turbine unit components is quite difficult and risky due to limited accessibility, with the work being performed in close quarters at high elevations. Repairs and servicing of components can also be expensive, especially if a large rental crane is required for removal or replacement of components. Performing effective preventive and predictive maintenance on wind turbine generator components can help enable better planning of maintenance activities with less risk and overall lower operation and maintenance costs.

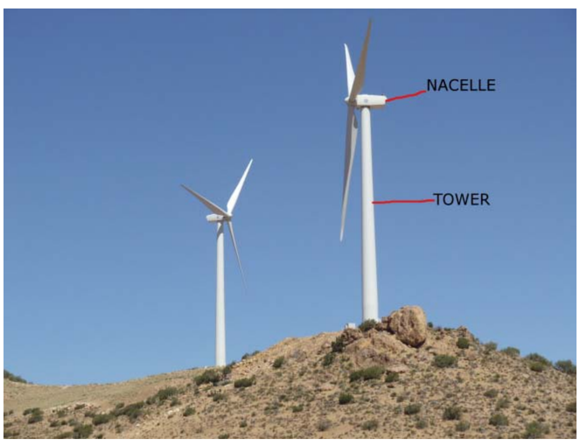

Figure 2-1
Wind turbine nacelle and tower structure

Due to lack of accessibility, most wind turbine generators are heavily equipped with instrumentation—temperature sensors, pressure sensors, vibration probes, lubrication sensors, and other similar devices—to allow for remote monitoring and trending of components and major assemblies. Typically, supervisory control and data acquisition systems are used for data acquisitions from wind turbine instrumentation. Components and assemblies that require grease lubrication often have automatic lubricators to add grease as needed. Applications with lubricating oils often have continuous monitoring of the oil conditions, using multiple sensors and remote trending. Typical lubrication monitoring sensors measure real-time characteristics and values such as oil viscosity, acid number, moisture, and presence of metal particles. These values can be trended over time in modern control systems to produce an alarm if readings go outside predetermined ranges. Wind turbines can then be stopped for inspection and service before catastrophic failures occur.

All moving components of the wind turbine generator require lubrication to effectively move as required. The main components requiring lubrication on a wind turbine generator unit include the following:

- Blade pitch gears and bearings
- Nacelle yaw gear and bearings
- Gearbox drive and bearings
- Generator bearings
- Main bearing

All of these components and lubrication points are located at the top of the unit tower, with limited access.

2.1 Blade Pitch Gears and Bearings

The blades used on wind turbine generators are used to control the input speed of the unit from the wind. The blades must be able to change pitch or rotate to either increase or decrease pitch during normal operation. During times of wind gusts or high wind speeds, the blades must be able to slow or stop the rotational speed. During normal operation, the blade rotations are typically slow, with high stress loads on the bearings and gears to combat the usual wind loads.

The blade pitch gears are typically open to the environment and constantly exposed to dust and moisture. Typically, grease is the lubricant used for blade pitch gears with mounted automatic lubricators. The lubricators supply grease at a fixed or adjustable rate. Special, environmentally friendly lubrication might be required for these applications.

The use of automatic lubricators mounted within the nacelle can help technicians safely add grease for both the blade bearings and the pitch gears without having to use special rigging to rappel outside the nacelle to service these components.

2.2 Nacelle Yaw Gear and Bearing

Yaw or slewing bearings can support axial, radial, and moment loads, acting either singly or in combination and in any direction. The bearings can be made up of several designs—ball bearings, cylindrical roller bearings, or polymer pads and slides. The ball and cylinder bearings require lubrication, whereas the polymer pads and slides typically do not. The yaw bearing is mounted on a seating surface between the nacelle structure and the tower. The yaw bearing is bolted on the seating surface and is one of three variations—without a yaw gear, with an internal yaw gear, or with an external yaw gear. The yaw gear is typically driven by electrical or hydraulic motor gear drives and requires lubrication, typically with grease.

The bearing is typically packed with grease during installation, and grease is added at a fixed or adjustable rate using a mounted automatic lubricator during operation. The yaw gear can be open to the environment and constantly exposed to dust and moisture. Some wind turbine units are experimenting with self-lubricating, gliding elements instead of a central or automatic lubrication system for yaw bearings and gears. Special, environmentally friendly lubrication might be required for these applications in some locations.

2.3 Main Gearbox

The main gearbox is one of the most critical components of a wind turbine generator, and it typically presents the most challenging lubrication requirements. The gearbox components face high stress loads due to extreme load changes and extreme temperature conditions. The gearbox and related equipment are located in the nacelle. The gear box receives the fan assembly rotation speed and torque. It speeds up the blade rotational speed through a series of gear trains and drives the generator or series of generators.

The gearbox is typically a closed unit, with a breather to handle temperature fluctuations inside the housing. Most wind turbine gear boxes contain an internal electrical heater for removing moisture caused by temperature changes or the environment. Gearbox gears, shafts, and bearings are typically lubricated using oil through a splash-type or forced-type circulating system. Some gearboxes have a combination splash and forced circulating oil system within the gearbox.

Splash lubricating systems can be found on some smaller units. The gear box housing has a sump of oil located in the bottom of the gearbox housing, where oil is splashed up by the rotation of the gears and shafts to provide a bath for the gears and bearings. Slingers can also be used on the gearbox shafts to help splash the oil. Proper oil levels must be maintained for a splash oil system to function properly.

Many current wind turbine units have a forced-type lubrication system. Forced lubrication systems consist of a circulating system that takes oil from the gearbox sump or a separate oil tank and sprays lubricating oil at specific locations in the gearbox. The circulating system consists of motor-driven or shaft-driven pumps that transfer the oil from the sump or tank through a filtration and temperature control system to the required lubrication points at the bearings, gears, and shafts. The pumps should be capable of providing the required flows and pressures of the lubrication oils across all the gearbox internal components. The gearbox filtration system should consist of a set of filters appropriate for each specific application. Figure 2-2 shows a spare gearbox with a forced lubrication system.

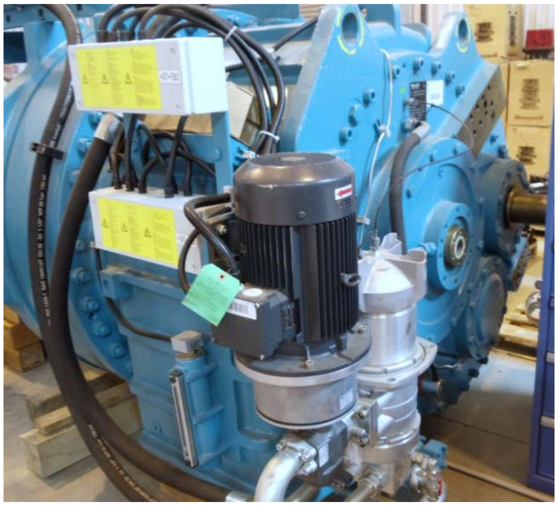

Figure 2-2
Gearbox and oil pump

The American National Standards Institute (ANSI) adopted a standard specifically for wind turbine gearboxes, ANSI/AGMA/AWEA 6006-A03, *Standard for Design and Specification of Gearboxes for Wind Turbines*, which was developed by the American Wind Energy Association and the American Gear Manufacturers Association for designing, manufacturing, operating, and maintaining wind turbine gearboxes [1]. The International Organization for Standardization (ISO) also adopted this standard as ISO 81400-4:2005 [2]. Wind turbine generator operators should consult the OEM for recommendations on the specific oil to be used for each application. The OEM will have evaluated the types and brands of oils available on the market with their material compatibility and performance characteristics with their gearbox components such as gears, seals, bearings, gear teeth surface hardening metallurgies, and coatings.

The gearbox lubricating oil is required to handle all loadings and stresses on the components for startups and continuous operation. For some applications, the lubricating oil must be heated during startups and then cooled after normal operating conditions are established. Maintaining the required operating temperature of the lubricating oil is extremely important for reliable operation and extended life.

2.4 Generator Bearings

Lubricants used for wind turbine generator bearings are typically mineral oil–based or synthetic-based greases. Most wind generator bearings are ball bearing types. The grease must be able to handle the stress loads of the bearings across all anticipated temperature ranges and be compatible with the seals, bearings, and bearing housing painted materials. Greases that are not compatible with the seals and painted materials can cause them to deteriorate and cause leakages or introduce foreign materials. Recommended generator bearing greases are typically identified by the OEM. The generator bearing grease should be suitable for long-term use of six months or longer before replacement. Generator bearings are typically hand packed at the OEM or maintenance repair shop location. It is important to identify the specific grease to be used when developing purchasing or repair specifications. In service, the generator bearings have grease added at a fixed or adjustable rate using a mounted automatic lubricator or added during scheduled maintenance.

2.5 Main Bearing

Lubricants used for wind turbine main bearings are typically mineral oil–based or synthetic-based greases. Wind turbines located in extreme environmental condition locations typically require synthetic-based grease. The grease used must be compatible with the main bearing seals and painted components.

Main bearings experience the full weight load of the blade assembly and the thrust loading from the wind. Typically, main bearings are a ball or roller thrust bearing design. The bearing configuration varies depending on the design and the specific application. The specific grease used must be able to handle the stress loads of the bearings across all anticipated temperature ranges, particularly during startups when rotation speeds are low and stresses are high. Main bearings are typically hand packed during the installation process. In service, the main bearings typically have grease added at a fixed or adjustable rate using a mounted automatic lubricator or added during scheduled maintenance.

Section 3: Lubrication Specification

Selecting the proper lubricant for each component application in a wind turbine unit requires inputs from the OEM and the operator's lubrication supplier. The chemical composition of wind turbine lubrication is not standardized. Much research has been done by major lubrication suppliers for wind turbine applications in the recent past. The lubricating oil needed for a specific wind turbine unit can be quite complex depending on the additives required. The lubricant supplier will typically recommend and supply the lubricant formulation that is best suited to the OEM's lubrication requirements using their base oil with the appropriate additives available to them. Approvals of the selected lubricant from all parties, including the OEM, should be required before putting a wind turbine unit in operation. Several lubrication suppliers have developed specialty, high-performance synthetic lubricants to be used on wind turbine units. Owners and operators of wind turbine units recognize the value of the new, high-performance synthetic lubricants in longer lubrication cycles, increased component efficiencies, better wear protection, less downtime, and overall cost savings.

The selection of lubricants to be used for each specific wind turbine application often depends on some or all of the following criteria:

- Anticipated environmental conditions
- Anticipated lowest and highest temperatures expected during operation
- Requirement for use of environmentally friendly lubricants
- OEM lubricant requirements for each specific component
- Operator lubricant supplier recommendations for each specific component
- Potential standardized use of a single grease and single oil for all components
- Cost of the base lubricant and additives

Lubricants for wind turbine components can consist of oils or greases, depending on the specific application. Lubricants can be mineral-based, synthetic-based, or a combination, depending on the application. For most wind turbine applications, the lubricant selection is primarily based on the normal anticipated operating conditions, including the lowest anticipated temperature during startups, the highest anticipated temperatures during full-load operation, and the anticipated stress loading in extreme conditions.

Most wind turbine units currently use specialty synthetic lubricating oils and greases because these generally outperform mineral oil–based products under the same conditions. Synthetic-based oils and greases have better wear protection, allow for more efficiency due to reduced friction, and can effectively operate over wider temperature ranges than equivalent mineral oil–based products. The major advantage of mineral oil–based over synthetic-based lubrication products is their lower initial cost. Additives to the lubricants are used to aid in resisting moisture, oxidation, and corrosion. Lubricants used in the wind industry today are expected to perform for at least three to five years of operation before replacement.

Environmental temperatures can vary over a wide range from season to season for some wind turbine applications. Most wind turbine generators have controls that shut down the unit when the temperature goes below a preset temperature, typically 0°F (-18°C), or above a preset temperature, typically 150°F to 160°F (66°C to 71°C).

Care should be taken if a change of lubricant oil formulation or change of supplier occurs. If a lubricant supplier changes their product formulation or recommends switching to a new product, they should supply evidence of the compatibility of the old to new formula. If there is a change of lubricant supplier, the new supplier should provide evidence of the compatibility of the new to the old product, as well as evidence that it meets the OEM's recommendations.

3.1 Base Oil Viscosity

Oil viscosity across all the operating conditions of a wind turbine gearbox is the most important characteristic for selecting the proper lubricant. Typically, the required viscosity grade of the gearbox lubricating oil is based on the anticipated operating conditions of the wind generator from the lowest cold start to the highest operating temperature. Currently, many wind turbines in the United States use ISO viscosity grade 320 lubrication oil for their wind turbine gear box applications. Maintaining the proper viscosity of the oil lessens the wear rate of the gears within the gearbox by helping to maintain oil film thickness on the components across the operating temperature ranges. The viscosity should be documented, analyzed, and trended by sampling the oil during each planned inspection. A change in viscosity is one of the major factors in determining the need for oil replacement in the gearbox. A decrease in viscosity can often be a sign that the oil is contaminated or is operating at higher-than-expected temperatures. An increase in viscosity can be a sign of oxidation.

3.2 Additives

Lubricating oils used within the wind turbine gearbox have chemical compound additives to help stabilize the oil during operation and provide for longer service life. Oil deterioration often causes some of the following problems in wind turbine applications:

- Varnish deposits
- Sludge deposits
- Rust and corrosion

- Lacquering or waxing
- Acid corrosion
- Increased friction and component wear

Each lubricating oil supplier has different additives to help defend against these problems in its product formulation. The gearbox OEM should be consulted to ensure that the lubrication additives added to the supplier's oil will be compatible with the internal component coatings and seals of the gearbox. Typical additives that can be added to gearbox lubricants include those shown in Table 3-1.

Table 3-1
Typical additives

Additive Type	Function
Antioxidants or oxidation inhibitors	Reduce oil deterioration at higher temperatures
Detergents or dispersants	Disperse particles from oil while in service
Antifoam or defoamants	Prevent air entrapment
Antirust or anticorrosion	Prevent rust due to water contamination
Viscosity index improvers	Reduce friction, provide more lubricity and increased efficiency
Pour point depressants	Reduce wax buildup at low temperatures
Demulsifers	Rapidly remove water
Extreme pressure	Improve film strength on components

Additives are consumed during normal operations and deteriorate over time. Reduction in additives will be identified during sampling analysis.

Current high-performance synthetic lubricants used for wind turbine applications are scientifically balanced combinations of additives, with the base oil designed to provide the best equipment protection under the most extreme temperature environments over an extended length of time for the specific wind turbine location.

3.3 Greases

Greases used in wind turbine applications must be able to function across the expected environmental temperature extremes. Typical temperature ranges can vary from -40°F to 200°F (-40°C to 93°C) for some locations. Greases should be able to be pumped at the lowest expected temperature, particularly if using an automated or central greasing system.

Greases are used on all the up-tower bearings, with the most important ones being the main bearing, generator bearings, yaw bearings, yaw gears, blade pitch gears, and blade pitch bearings. Each of these bearings and gears requires different lubrication requirements due to loads and stresses experienced during operations. In the past, different greases have typically been used for wind turbine applications and required multiple greases up-tower during servicing. The industry has challenged lubrication suppliers to develop single greases that can be used for multiple applications on the units. The grease must also be able to handle the following:

- Low-speed, high-stress conditions during cold weather startups for the main bearing
- High-speed and high-temperature conditions of the generator bearings
- Low-speed, high-stress conditions of the yaw and blade pitch bearings

Several lubrication suppliers have developed specialty greases for wind turbine applications, with a single type of grease developed to handle all the important bearings and gears. Specialty synthetic-based greases are the most widely used products in current wind turbine unit applications. Many wind turbines in the United States use ISO viscosity grade 460 synthetic lubrication oil as the base fluid for their wind turbine main, blade pitch, and yaw bearing grease applications. Many wind turbine generators use ISO viscosity grade 100 synthetic lubrication base oil for their wind turbine generator bearing grease applications.

3.4 Storing and Handling

Procedures should be in place that provide for the immediate acceptance of delivered drums and containers of lubricants and their placement in a designated storage location at the site. All lubricants should be stored in a condition and location that minimize exposure to the elements. Oil drums exposed to the elements are subject to environmental extreme temperatures, direct sun, and rain, which increase chances of compromising lubricant quality. A designated storage building or enclosed structure is typically needed to store lubricants. The building or structure should provide protection from weather, have limited access, and have appropriate fire suppression and spill protection equipment.

Because wind turbine lubricants are typically expensive, specialized lubricants, operators should develop site practices and procedures to minimize the amounts of lubricants to be purchased and stored at the site. With proper planning, the specialized lubricants should be ordered so that only short-term storage is required before use.

3.4.1 Receiving of Lubricants

A documented procedure is necessary for receiving and inspecting new lubricant deliveries, including acceptance criteria. This should include an agreement with the lubricant supplier regarding their role in providing assistance with lubricant storage and handling practices. Because lubricants needed for a specific wind turbine unit can be complex and specialized, care should be taken to ensure that the proper lubricant for the application is received and properly labeled.

Packaging material should be inert to the product oil and conform to all applicable shipping rules and regulations. Packages should be plainly marked with the manufacturer's name, oil brand name, product code, lot number, type of material, volume content, and any other information required by law. The condition of the containers should be checked, including any damage, signs of neglect, signs of outdoor storage (faded labels, and so on), or leaks. Any packaging or container leaks are subject to contaminant ingress and compromise the lubricant quality. Leaking containers should be rejected and immediately returned to the supplier.

3.4.2 Initial Sampling and Testing

Sampling methods should be consistent with the sampling best practices described in Section 4.2.2, Lubricant Sampling. Initial sampling of lubricating oil drums and containers helps establish that the proper lubricating oil was received and establishes the basis for the site's preventive maintenance plan. Samples taken from new oils help to establish a baseline for comparison with oil samples taken during physical inspections.

3.4.3 Disposal

Because lubricating oils used for wind turbine applications are typically complex and often synthetic based, disposal of used oils must be addressed for each specific location. Used gearbox lubricating oils, whether mineral- or synthetic-based, should be recycled with a certified waste contractor, if possible. All lubricating wastes—including waste oils, cleaning materials, greases, used oil filters, contaminated rags, and so on—should be removed from the site using a controlled waste manifest in labeled containers. All waste materials should be disposed of by a licensed waste carrier to a licensed waste disposal site, according to local or state environmental permitting requirements.

Section 4: Preventive and Predictive Maintenance

Lubrication practices for wind turbine units should be similar to those for most standard mechanical systems. The EPRI report *Lube Oil Predictive Maintenance, Handling, and Quality Assurance Guideline* (1004384) is a good resource for setting up a maintenance program for wind turbine generator lubricants, particularly for the gearbox oils [3]. In addition, ANSI/AGMA/AWEA 6006-A03, *Standard for Design and Specifications of Gearboxes for Wind Turbines*, provides recommendations and information for operating and maintaining wind turbine gearboxes [1].

Lubricating oil life can often be improved with better filtering, sealing, and cooling systems. Maintenance and servicing of these systems during planned wind turbine inspections is important.

The gearbox lubricating system should be designed so that any contaminants that get into the oil will be collected in an area away from the rotating parts. Typically, the oil sump should be large enough to allow contaminants to settle to the bottom. The gearbox sump should also include magnetic plugs to attract metal contaminants. Checking the magnetic plugs for debris during servicing can help identify a potential component failure before it becomes catastrophic.

Performing maintenance activities on the lubricants and lubrication systems on wind turbine generator units can be complicated due to the extreme operating conditions and inaccessibility of the equipment. For many wind turbine applications, technicians do not physically inspect the wind turbine equipment for periods of three to six months. Rather, plants rely on evaluating data collected from various instrumentations to assess the condition of the equipment.

Following the OEM recommendations for planned inspections and maintenance is the first step to help maintain reliability and efficiency of the wind turbine components. Over-lubricating and under-lubricating can both contribute to bearing failures.

4.1 Preventive Maintenance

4.1.1 Cleanliness

The major best practice for any lubricant is to keep the lubricant clean during storage, during replacement transfer, and when in service. Contamination of lubricants is one of the primary reasons that equipment life is reduced in any mechanical system.

Table 17 of ANSI/AGMA/AWEA 6006-A03 provides oil cleanliness recommendations for wind turbine gearboxes to meet ISO standard 4406 [1, 4]. The typical oil cleanliness target from an ISO 4406 particle count chart is 16/13.

Gearboxes should have a filtering system to remove any contaminants from the oil during service. The filters should be inspected and changed during planned inspections. It is good practice to obtain samples of the contaminants removed by the filter system to aid in developing measures to identify potential problems and to help prevent found environmental contaminants from getting into the gearbox oil.

Care should be taken when replacing gearbox oils. Use of a portable system (see Section 4.1.4, Changing Gearbox Oils) can help maintain the cleanliness of the lubricating oil and gearbox internal areas during oil replacements.

Maintaining cleanliness and protecting the bearings in a gearbox are critical for long-term operations. Traditionally, shaft contact lip–type oil seals have been used for sealing on gearbox rotating shafts. Continuous seal contact with rotating shafts leads to wear over time and eventual leakage. Currently, some gearbox OEMs are specifying isolator-type seals in place of the lip-type seals to help seal rotating shafts. Isolator-type seals are noncontact seals and can be of various designs, typically based on labyrinth seal design technologies. Isolator-type seals have been shown to provide more reliable sealing over extended periods than lip type seals.

4.1.2 Planned Inspections and Servicing

Schedule physical inspections during months of better weather conditions for increased productivity. Typically, up-tower inspections should occur at three- to six-month intervals until data can be collected to support extended inspection periods. All lubrication spills and leaks should be cleaned up, and the source of the spill or leak should be corrected.

Annual visual borescope inspections of the gearbox and generator internals can potentially identify problems before they become apparent in other areas. Lack of accessibility to inspect all internal components will be a problem for some units.

Inspection of the gearbox breather should occur at each planned inspection and servicing. The breather vents the gearbox inside air to the outside during operation. If the breather is dirty and clogged, the temperature changes inside the gearbox during operation can cause either a pressure buildup or a vacuum condition. Pressure buildups or vacuum conditions can lead to seal damage over time and allow contaminants to enter the gearbox.

Table 4-1 shows a typical wind turbine lubrication maintenance checklist schedule. A schedule such as this one should be considered in the site's planned maintenance inspection procedures.

Table 4-1
Typical inspection intervals

Task	Every Three to Six Months	Every Year	Every Five Years
Perform up-tower physical inspection	X		
Inspect for and clean up lubrication spills and leaks	X		
Lubricate main bearing	X		
Inspect gearbox oil levels	X		
Lubricate yaw bearing		X	
Lubricate generator bearings	X		
Lubricate blade bearings	X		
Change gearbox oil filters	X		
Take gearbox oil samples	X		
Change gearbox oil			X
Perform gearbox borescope inspection		X	

4.1.3 Use of Centralized and Automatic Lubricators

With the development of single greases to be used for many wind turbine applications, some wind turbine units have found it cost effective to use automatic and central greasing systems for applying a measured amount of grease at predetermined intervals to the important bearings and gears located up-tower. Advantages of these systems are that a metered amount of grease will go to each bearing or gear at a preset time interval and hard-to-access grease points can be greased. One disadvantage is that the bearing or gear can be over-greased during low operating periods. Most wind turbine lubrication suppliers have automated and central systems as part of their product line. Automatic and central lubrication systems should be engineered for each specific wind turbine application.

Information received during research for this project revealed that too few automatic lubricators have been installed to provide data to justify their use at this point. Opinions were that these appear to work well in warm climates but not as well in colder climates.

4.1.4 Changing Gearbox Oils

Gearboxes typically have oils replaced every three to six years or according to OEM service hour recommendations. Replacement of the gearbox oil should be based on sampling analysis results. Manually changing oil in a gearbox up-tower in the field can be a time-consuming and difficult task. Manually draining and removing the used oil in a safe and environmentally friendly manner and ensuring that clean, new oil is installed in the gearbox is a challenge. Complete draining of the gearbox oil and cleaning the gearbox internal components is often impossible to achieve manually. This leads to mixing new oil with contaminated, used, residual oil. The primary goal when changing gearbox oil is to ensure that the new oil meets the cleanliness standards required by the OEM or by ISO standard 4406 [4] as specified in ANSI/AGMA/AWEA 6006-A03 [1]. It is recommended that gearbox oil replacements be done using a pressurized draining, flushing, and cleaning system. The cost of using a pressurized system for gearbox oil changes should be recouped in reduced down time and improved chances of longer gearbox life due to improved oil cleanliness.

Several vendors can provide a self-contained, mobile unit designed for wind turbine gearbox oil changes or provide the gearbox oil change service. Use of mobile oil change units is currently the best means for changing wind turbine gearbox oils in an environmentally friendly and efficient manner. The mobile units can typically remove almost all the used oil from the gearbox and clean critical gearbox components. The mobile units typically are mounted on a trailer or truck that can be located at the wind turbine base and connected to the gearbox up-tower by hoses.

Figure 4-1 shows an example of a trailer-mounted unit located at the base of a wind turbine generator. Some of these mobile units require electrical power hook-ups, whereas others provide their own diesel power generation to handle the most remote locations. The mobile units typically consist of a tank for new oil, a tank for receiving the used oil, a flush oil tank, a rinse oil tank, an oil heating system, a filtration system, a pumping station, hose with multiple lines for attaching to the gearbox, piping, valves, and the necessary controls for operating the system.

Figure 4-1
Mobile oil change unit
Courtesy of Sage Oil Vac

Figure 4-2 shows an example of a mobile unit located at the tower base. Mobile units can typically change the wind turbine gearbox oil in approximately 25% of the time that it takes to perform the task manually.

Figure 4-2
Mobile unit at tower base
Courtesy of Sage Oil Vac

The following steps are used to change gearbox oil using a mobile unit:

1. Hoses are run from the mobile unit on the ground to the gearbox up-tower. There are typically three separate lines—a drain line, a flush oil/rinse oil supply line, and a new oil supply line. Figure 4-3 shows an example of a hose line being installed.
2. The used oil in the gearbox is drained (under vacuum for some systems) into the waste oil tank. The use of a vacuum system can speed up the gearbox drain time. The waste oil is removed using the hose drain line to the waste tank. Figure 4-4 shows an example of a drain line connected to the bottom of the gearbox.
3. The gearbox is then flushed out, using flush oil, until all sludge is removed. Flush oil is filtered as it is pumped to the gearbox. In colder environments, it can be heated to aid in pumping. The flush oil is supplied in a separate line and removed using the hose drain line from the gearbox.
4. The gearbox is cleaned again, using rinse oil to remove the flush oil from the gearbox. The rinse oil is filtered as it is pumped to the gearbox in the same manner as the flush oil. In colder environments, it can be heated to aid in pumping.
5. A small amount of new oil is flushed through the gearbox to remove any remaining rinse oil and then drained. The new oil is filtered as it is pumped to the gearbox in the new oil supply line. In colder environments, it can be heated to aid in pumping.
6. The proper amount of new oil is added to the gearbox. The new oil is filtered as it is pumped to the gearbox in the new oil supply line. In colder environments, it can be heated to aid in pumping.

Figure 4-3
Oil change hose hoisting
Courtesy of Sage Oil Vac

Figure 4-4
Gearbox drain line connection
Courtesy of Sage Oil Vac

4.2 Predictive Maintenance

4.2.1 Condition Monitoring

Some wind turbine generators in the 1–2 MWe range have remote sensing and monitoring instrumentation to monitor the condition of the wind turbine equipment during service. Many of the instrumentation data are maintained and trended through the site's supervisory control and data acquisition system and central computer system. Some wind turbine units have little or no monitoring because their owners have determined that it is not cost effective for their operating strategies. As more wind turbine units are being installed and operated, the industry is becoming more mature and recognizing the merits of a predictive monitoring system on the mechanical and lubrication oil systems.

Wind turbine sensors that monitor the gearbox lubricating oil chemistry are capable of detecting changes and trends in viscosity, oxidation, and water contamination. Chemistry changes in the oil help monitor oil deterioration during operation. Sampling frequencies might need to be adjusted based on the sensor data trends.

Other sensors monitor the gearbox condition by detecting debris and particles carried in the oil. As components wear from operation, they produce wear debris. Wear debris and metal pieces found in the oil often identify a bearing or gear problem within the gearbox.

Section 5, Lube Oil Monitoring, of the EPRI report *Condition Monitoring of Wind Turbines* (1010419) is an excellent reference for potential monitoring equipment and techniques [5].

Instrumentation that might be cost effective for some 1–2 MWe applications include the following:

- Vibration accelerometers on the generator and gearbox bearings
- Temperature monitors on the generator and gear box bearings
- Acoustic frequency measurements within the nacelle housing
- Pressure monitors on the lubricating oil supply
- Particle count and debris monitors in the gearbox oil sump and oil supply lines
- Moisture and relative humidity sensors inside the gearbox
- Differential pressure monitors across the oil filters
- Magnetic sensors within the gearbox oil supply lines before the filters
- Gearbox sump oil level monitors

Condition monitoring instrumentation can provide a layer of protection on critical equipment to shut down the unit before a possible catastrophic failure can occur. Today, various sensors are becoming cheaper to manufacture and are likely to be installed on most new units. Although it is ideal to have some instrumentation from a preventive and predictive maintenance point of view, the costs of retrofitting and installing monitoring systems to older units must be evaluated case by case for wind turbine generators. It might be cost prohibitive to install instrumentation on wind turbine units with low operating capacity factors.

4.2.2 Lubricant Sampling

An effective gearbox oil sampling program forms the basis for a preventive or predictive maintenance program for wind turbine units. Careful consideration must be given to the sample point locations and analysis results to ensure that the information obtained is consistent and valid. Development of a sampling process and procedures for a specific wind turbine unit is paramount. It is important that the same procedures be followed so that consistent samples are obtained for trending analysis. An analysis process should include how data are reviewed, with baseline readings of new oil established for comparison to sample test results for trending. Section 5, Lube Oil Monitoring, of the EPRI report *Condition Monitoring of Wind Turbines* (1010419) is an excellent reference for lubrication oil sampling techniques [5].

The benefits of an oil sampling program can be multiple, depending on the specific site. Sampling can help reduce operating costs by having oil changes occur when the oil has sufficiently deteriorated to require changing. Equipment life can be increased when potential problems can be identified through metal analysis trending and corrected before becoming a major problem. Fewer equipment failures improve the unit's availability and production potential.

An effective sampling program helps answer some of these major questions:

- Is the right oil is being used for the specific unit?
- Is the oil quality within OEM specifications?
- What are the additives' conditions?
- What are the contaminants in the oil and can they be eliminated?
- What are metals from equipment wear and can they be lessened?

Typically, sampling of gearbox oil for most wind turbine units should occur during planned maintenance scheduled events, typically at three- to six-month intervals. If the wind turbine unit is located in a severe environment, more frequent sampling might be required.

A good sampling program should include a procedure that identifies sample locations and techniques for obtaining good representative samples of the gearbox oil. Some OEMs will identify oil sample locations for their gearbox units and provide valves for obtaining the samples. As a general rule, samples should be taken before the oil enters the gearbox case at a location before the filter for forced lubrication systems. Splash lubricating systems should have samples taken at the oil sump reservoir midpoint location of the gearbox. Clean sampling bottles must be used. It is important that the same oil sampling procedures be followed at each occurrence to ensure consistency for tracking and trending analysis.

The gearbox oil sample should first be inspected on-site for any immediate sign of problems. A sensory comparison to new oil can typically be done relatively easy. Typical sensory tests include those shown in Table 4-2.

Table 4-2
Sensory tests

Sensory Test	Potential Problem or Issue
Visual test comparison to new oil	Cloudy or milky appearance might be caused by water in the oil
	Dark color might indicate contamination from wear or oxidation
	Sediment in the sample might indicate contamination or wear
Odor test comparison to new oil	Burnt or acidic smell might indicate oxidation

Oil samples should be sent to a reliable laboratory for analysis. Typically, the lubrication supplier or the OEM can recommend a laboratory for oil sample analysis. Often, lubrication suppliers or gearbox OEMs provide oil analysis and trending as part of their service. Owners should perform their own due diligence to identify a laboratory that meets their needs. It is always a good idea to periodically send identical samples to different laboratories and compare the results.

Oil sample analysis should include tests recommended by the gearbox OEM and the lubrication supplier. Typical recommended laboratory tests include those shown in Table 4-3 for comparison to new oil.

Table 4-3
Laboratory tests

Recommended Laboratory Tests	Potential Problem or Issue	Potential Warning Limits
Kinematic viscosity test (ASTM D445 or ISO 3104)	Checks for change in viscosity due to wear, oxidation, or contamination	20% change from new oil based on supplier recommendations
Total acid number test (ASTM D664 or ISO 6619:1998)	Measures acid content to check for oxidation	40% to 75% from new oil based on supplier recommendations
Spectrochemical tests (inductively coupled plasma spectrography, particle qualifier index)	Identifies any metals found in the oil sample; metals found can help identify worn areas or identify contamination sources	Iron > 200 ppm Copper >75 ppm Silicon > 20 ppm increase from new oil
Cleanliness test (ISO 4406)	Counts the number and sizes of particles in the oil due to contamination	Acceptable limit, 16/13 Unsatisfactory limit, 18/15
Water test (ASTM D6304), Karl Fischer test	Measures the amount of water contamination	Increase greater than 0.10% from new oil
Oxidation inhibitors	Measures antioxidation inhibitor level changes as the oil is used	Limits based on supplier recommendations for additives

Section 5: Personnel Qualifications and Training

Work up-tower on wind turbine units is a challenge from a safety and environmental perspective. Each site has unique hazardous conditions and safety requirements and should develop its own tailored program to meet its needs. The training and safety requirements should comply with the site's policies and procedures.

5.1 Training Considerations

5.1.1 Maintenance Training

The technicians at the site must be trained on lubrication maintenance practices for their specific wind turbine equipment. OEM manuals and training programs are resources to be used. Procedures should be developed for proper lubricating requirements for each specific equipment and component. Training on inspection techniques, such as borescope inspections and oil sampling procedures, should be provided.

5.1.2 Safety Training

Working on wind turbine platforms up to 300 ft (92 m) in the air typically requires some specialized personal protection training, including the following:

- Vertical rescue, including self rescue
- Fall protection
- Tower climbing
- Inspection and storage of climbing gear
- Rigging and lifting
- Lockout/tagout procedures
- Emergency response procedures

5.2 Safety Considerations

Safety of the technicians working up-tower is a main concern when performing maintenance on a wind turbine unit. Schedule planned maintenance inspections and servicing during periods of better weather conditions for the site, if possible. Weather conditions such as ice, snow, rain, high wind, and lightning can be a problem. Many sites and service providers do not allow technicians to climb up-tower if the temperature is less than 15°F (-9°C). Subscription to online or radio weather services can provide warning of changing weather conditions and approaching severe weather conditions for an area. Some modern mobile telephones are capable of receiving a warning when severe weather conditions are detected within the user-defined radius of the telephone's global positioning system location.

Some site-specific safety items for consideration include the following:

- **Pre-job safety discussion and planning.** Planning increases the likelihood that desired results will be achieved when performing a task. Planning begins with anticipating and identifying potential safety hazards in a job task and evaluating the subsequent risks of those hazards, especially when working in remote locations and at the elevated conditions of wind turbines.
- **Personal protective equipment requirements.** Technicians should also use the required personal protection equipment—such as safety harnesses, lanyards, and retractable lifelines—at all times when climbing and working up-tower. Some sites might also consider the nacelle a confined space and require additional safety policies and procedures.
- **Lockout/tagout requirements.** The purpose of lockout/tagout requirements is to eliminate unexpected energizing or start-up of machinery or equipment, or the release of stored energy from machinery or equipment that could cause injury to employees. Site-specific lockout/tagout procedures should be followed for each wind turbine unit. Ensure that the tower is properly grounded electrically before climbing up-tower.
- **Climbing and fall protection requirements.** Climbing a wind turbine unit structure can be physically demanding for the technicians. It is a good practice to include a climb-assist system in the design of the tower to aid technicians when ascending the tower. These systems aid the climber by applying a steady upward force to counter the weight of the technician and his or her tools. A service lift designed into the nacelle of the unit can also help move tools and service supplies up and down during maintenance.

  Falling objects from a wind turbine unit are hazards for the technicians below. Retractable tethers and lanyards attached to tools and instruments should be used when servicing and inspecting the equipment inside the nacelle to prevent them from falling to the ground.

  Always have a technician on the ground when others are up-tower. Technicians working up-tower should always be in radio contact with the technician on the ground. Technicians should work in pairs whenever possible.

- **Proper handling of wind turbine lubricants.** Personnel who are exposed to the petroleum- and synthetic-based lubricants typically used in wind turbines should understand the hazards associated with the specific lubricants. Site-specific procedures for handling and disposing of the specific lubricants used on their wind turbine units should be followed. The material safety data sheets for the specific lubricants used should be available to the technicians. Personal safety equipment—such as apron, face shield, rubber gloves, and breathing air filters—might be required. Specific environmental training might be required for some locations in case of spills.

  It is important to clean up any lubricants that leaked during operation or spilled during physical inspections. Cleanup of leaks or spills helps to eliminate slip hazards for the technicians working in the nacelle or climbing the access ladder. Oil spills or leaks on the access ladder create a hazardous situation for technicians during the tower descent.

Section 6: References

1. ANSI/AGMA/AWEA 6006–A03, *Standard for Design and Specification of Gearboxes for Wind Turbines.* American Gear Manufacturers Association, Alexandria, VA. http://www.agma.org.
2. ISO 81400-4:2005. *Wind Turbines—Part 4: Design and Specification of Gearboxes*. International Organization for Standardization, Geneva, Switzerland.
3. *Lube Oil Predictive Maintenance, Handling, and Quality Assurance Guideline*. EPRI, Palo Alto, CA: 2002. 1004384.
4. ISO 4406:1999. *Hydraulic Fluid Power—Fluids—Method for Coding the Level of Contamination by Solid Particles*. International Organization for Standardization, Geneva, Switzerland.
5. *Condition Monitoring of Wind Turbines.* EPRI, Palo Alto, CA: 2006. 1010419.

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