Operations and Maintenance Recommended Practices

Chapter 2 Generator and Electrical

version 2017

ACKNOWLEDGEMENTS

The American Wind Energy Association (AWEA) Operations and Maintenance (O&M) Recommended Practices (RP) are developed through a consensus process of interested parties by AWEA O&M Committee. These RPs represent decades of experience from the members of the AWEA O&M Committee. This expertise, often gained from other industry sectors, helps inform, train and support wind energy technicians and managers in their efforts to improve reliability and project performance. These are, in general, the nuts and bolts of wind energy power plant maintenance and operations. As the industry matures, additional maintenance strategies and operations philosophies will certainly come to the fore, however, these basics will always be required knowledge for new technicians and asset managers expanding their areas of responsibility.

Development of the AWEA O&M RPs started in 2009, with the first edition publication in 2013. The current version is the result of hundreds of hours of volunteer time by many people and we, the AWEA O&M Committee Chairperson, Kevin Alewine, and Vice Chairperson, Krys Rootham, wish to thank all of the individuals who have participated in the AWEA O&M Committee to develop these documents and the companies that continue to allow those efforts, as well as, sharing their technical know-how.

AWEA Operations and Maintenance Committee:

- AWEA O&M Steering Committee
- Balance of Plant Subcommittee
- Blades Subcommittee
- Condition Monitoring Subcommittee
- Data Collection and Reporting Subcommittee
- End of Warranty Subcommittee
- Gearbox Subcommittee
- Generator Subcommittee
- Operations Subcommittee
- Tower Subcommittee
- Tower Auxillary Subcommittee

Again, thanks to everyone for their continued support for development of these recommended practices. Please contact any of us if you have questions or comments (OM@awea.org) regarding the Committee or these documents.

Thanks again for the efforts and accomplishments,

Kevin Alewine, Shermco
Chairperson, AWEA O&M Committee

FORWARD

The AWEA Operation and Maintenance Recommended Practices are intended to provide establish expectations and procedures to ensure all personnel performing service and maintenance on wind turbines have a minimum knowledge base.

The AWEA Operation and Maintenance Recommended Practices (O&M RPs) are not “best” practices nor the only procedures that should be followed. They represent suggestions from experts in the field who have refined their procedures over time. The preferred procedures in the future will no doubt change with improved communications, technology, materials and experience. These AWEA O&M RPs will be revised as needed.

The AWEA O&M RPs were initiated in 2009 and created by members of the AWEA O&M Committee to ensure that the future wind industry benefits from the experience gained from the past. Individual members donated their time and expertise to document these procedures.

The AWEA O&M RPs are organized into “chapters” to address the major functions of a wind turbine and its operation. Individual recommended practices address specific procedures used in each of those areas.

Many other organizations have developed consensus standards, recommended practices, best practices, etc. that also offer excellent supporting information for effective wind farm operations and maintenance. IEEE (Institute of Electrical and Electronic Engineers), NETA (International Electrical Testing Association), SMRP (Society for Maintenance and Reliability Professionals), AGMA (American Gear Manufacturer’s Association) just to name a few. These sources should be reviewed in developing sound maintenance strategies.

OCCUPATIONAL SAFETY AND HEALTH NOTICE

The Occupational Safety and Health Administration (OSHA) was established by Congress through the Occupational Safety and Health (OSH) Act of 1970, to assure safe and healthful working conditions for working men and women by authorizing enforcement of the standards developed under the Act; by assisting and encouraging the States in their efforts to assure safe and healthful working conditions; by providing for research, information, education, and training in the field of occupational safety and health; and for other purposes.

The Secretary of Labor promulgates rules as OSH standards by incorporating national consensus standards and through the federal regulatory rulemaking process. The American Wind Energy Association (AWEA) cannot determine or prescribe how member companies should evaluate their compliance obligations under OSHA's standards. Each employer must make its own determinations depending on the condition of each worksite. AWEA strongly encourages its members to develop their own written program to address worker safety and health procedures, programs, and hazard assessments, as well as provide trainings for their workers in these areas.

The wind energy industry is covered by OSHA regulations for worker safety and health practices. §29 C.F.R 1910.269 is the OSHA standard that regulates employee safety in the operation and maintenance of electric power generation, transmission and distribution facilities and installations, which covers the wind energy industry and §29 C.F.R 1926, for construction activities.

Each employer shall choose to the appropriate regulation and standards to work in the wind energy industry and must be prepared to justify their determination, development, and implementation of their written program. Employers must also consider the regulatory requirements of state occupational safety and health plans. The OSH Act of 1970 encourages states to develop and operate their own job safety and health programs, which there are twenty-six (26) states and jurisdictions that operate OSHA-approved State Plans (SPS). Twenty-two (22) states operate complete state plans, while five states cover public employees only. SPS must set job safety and health standards that are "at least as effective as" comparable federal standards, including hazards not addressed by federal standards.

NOTICE AND DISCLAIMER

The information in this Document was considered technically sound by the consensus of persons engaged in the development and approval of the document at the time it was developed. Consensus does not necessarily mean that there is unanimous agreement among every person participating in the development of this document.

AWEA disclaims liability for any personal injury, property or other damages of any nature whatsoever, whether special, indirect, consequential or compensatory, directly or indirectly resulting from the publication, use of, application, or reliance on this document. AWEA disclaims and makes no guaranty or warranty, express or implied, as to the accuracy or completeness of any information published herein, and disclaims and makes no warranty that the information in this document will fulfill any of your particular purposes or needs. AWEA does not undertake to guarantee the performance of any individual manufacturer or seller's products or services by virtue of this standard or guide.

In publishing and making this document available, AWEA is not undertaking to render professional or other services for or on behalf of any person or entity. Nor is AWEA undertaking to perform any duty owed by any person or entity to someone else. Anyone using this document should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances. Information and other standards on the topic covered by this publication may be available from other sources, which the user may wish to consult for additional views or information not covered by this publication.

AWEA has no power, nor does it undertake to police or enforce compliance with the contents of this document. AWEA does not certify, test or inspect products, design or installation for safety or health purposes. Any certification or other statement of compliance with any health or safety–related information in this document shall not be attributable to AWEA and is solely the responsibility of the certifier or maker of the statement.

If you breach this agreement, your right to further use this Document will be immediately revoked.

This document is proprietary and its use is subject to a legally binding license agreement and disclaimer (the "Agreement"). Do not use this document for any purpose unless and until you read the agreement. By viewing or otherwise using this document, you hereby warrant and represent that you have read and agree to be legally bound by the agreement and are authorized to bind not only yourself to the agreement, but the organization for which you are accessing the document. If the agreement is not acceptable and you are unwilling to be bound by it, please do not view or otherwise make any use of the document.

COPYRIGHT

©2017 American Wind Energy Association. All rights reserved. You may download, reproduce and print this white paper and any portion hereof (the "Document") for internal use only (which use may include internal use by employees of your company), and, by downloading or accessing the Document, you agree: (i) that you shall not sell or otherwise engage in any distribution of this Document; (ii) that you shall not make any alterations, modifications, deletions or other changes to this Document without the express written consent of American Wind Energy Association ("AWEA"); and (iii) to indemnify and hold AWEA harmless for any loss or damage, including reasonable attorney's fees, that the AWEA may incur, directly or indirectly, as a result of your use of this Document.

AWEA assumes no liability for reliance on the contents of this document. AWEA is providing this document for reference only in furtherance of AWEA's nonprofit and tax-exempt mission. AWEA makes no representation or warranty about the information contained in this document, including, without limitation, the suitability of the information contained in this document for any purpose. It is offered only as general guidance and does not constitute legal, medical, or professional advice. This document is not intended to, nor does it, include information regarding safe operations and maintenance practices. Any recommended practices, guidance or standards contained in this document should be considered on a case by case basis and used in accordance with your company's internal safety and other operating requirements as well as all applicable laws, regulations and recommended practices addressing safety and regulatory compliance (such as OSHA and ANSI requirements). You should consider seeking legal or professional advice on all matters concerning safety and regulatory compliance.

Chapter Two: Generator and Electrical

*These RP's did not require updates from the original 2013 version.

RP 201 Generator Collector Ring Assembly Maintenance

The following recommended practice is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance Working Group.

Committee Chair: Kevin Alewine, Shermco Industries
Principal Authors: Benoit White, Mersen; Roland Roberge, Morgan AM&T; Mark Keeland, Schunk Graphite
Contributing Authors: Kevin Alewine, Shermco Industries; Paul Kling, Morgan AM&T

Purpose and Scope

The scope for “Generator Collector Ring Assembly Maintenance” addresses the common maintenance issues related to the collector ring assembly in double fed induction generators that are commonly used in many wind turbine designs. This section is not machine specific and some variations may be required based on specific designs.

Introduction

In double fed induction generators, power is normally transferred to and from the wound rotor by the use of rotating collectors and brush assemblies. These are high wear items and should be included in any regularly scheduled maintenance inspection or process. The normal recommendation is to inspect and clean at least bi-annually, but longer maintenance cycles may be possible with improved materials and designs. Brush life is affected by carbon grade, ambient temperature, and humidity as well as other operating environmental conditions. It is critical to the successful implementation of these procedures that good records are kept of generator maintenance and of any performance issues discovered between inspection intervals. Prior to any disassembly at each step, a careful visual inspection should be performed and any abnormal conditions should be documented, preferably including photographs.

©American Wind Energy Association 2017

Collector Ring Assembly Maintenance Procedures

1. Inspecting the Assembly

Remove the generator collector ring cover(s). View the general condition of the assembly. Note any build up of residue, leaking gaskets, broken or missing components, etc. A 1000 volt phase to phase and phase to ground insulation resistance test of the collector ring assembly is also suggested before and after cleaning. Caution should be used to ensure the test voltage will not damage any electronic components. Review OEM motor testing procedures. Values should conform to the generator manufacturer's specifications, but normally the minimum value should exceed 10 megohms during service and 100 megohms after cleaning. Leads should be disconnected before testing.

1.1. Brushes

1.1.1 Removal

To remove the brush for most designs, push forward on the spring to disengage the latch and lift the spring out of its slide. Other styles of tension devices may be used. Consult the manufacturer's specifications for a specific generator design. Pull the brush out of its holder by its cables without disconnecting it. Note the orientation of the brush to the holder to ensure the brush will properly be reinstalled if it is not to be replaced.

1.1.2. Brush Body

Inspect the brush for minimum length requirement, any unusual wear-marks and free movement of the brush in the holder noting any restriction that may be a sign of material swelling.

NOTE: This should also be a regular test for lightning protection brushes and grounding brushes.

Inspect for chipping or cracking. Assure that the terminals are secure and that shunts, micro switch tabs, etc. and rivet connection, if applicable, are in good working order and properly mounted and connected.

©American Wind Energy Association 2017

1.1.3. Stunt Wires

Discolored shunt wires can indicate uneven current sharing or overheating by insufficient air flow. It is recommended to replace the complete brush set because single brushes can already be damaged. If the shunts are damaged or frayed by vibration, mechanical problems, or too strong air flow, they should also be replaced and the condition corrected. Note any abnormal wear indicators. Verify terminal connections are secure on all brushes.

1.1.4. Vibration Markings

Smooth and shiny side surfaces are a clear indication of radial movement by the brushes in the brush box. That can be caused by out-of-roundness of the slip ring, too high friction also resulting in a shiny slip ring surface or external vibrations such as defective bearings, shafts, couplings, etc. Markings of current transfer between brush holders and brush indicate that the connection between shunt and brush body is possibly damaged. Excessive brush dust in the slip ring compartment can also cause inappropriate current transfer. Frayed shunts or markings from the springs on the brush top also indicate abnormal vibration.

1.1.5. Brush Surface

Rough brush face surfaces may be caused by brush sparking from electrical or mechanical problems (e.g. vibrations). Rough surfaces on grounding brush faces can be an indication of possible converter problems as well as ring surface issues.

Rule of thumb: If one of the brushes has to be replaced and the set is worn more than 25%, all the brushes should be replaced. If all brushes are to be replaced, disconnect them, and remove them from the assembly. Loosen the terminal bolts until the brush terminal can be slid out from under it. If possible, do not fully remove the bolt to avoid dropping it and other hardware into the assembly.

©American Wind Energy Association 2017

1.2. Brush Holder

1.2.1 Holder Box

Inspect entire holder for any indications of arcing or burning damage. Verify that all hardware and electrical connections are secure. Note any abnormal wear indicators.

Springs
Inspect tension devices for any indications of arcing, burning, or discoloration. The spring force should be checked every year with an appropriate spring scale device and springs should be replaced every 3 to 5 years depending on the type of application. Springs with a deviation of more than 10% from the set value should be replaced.

1.2.2. Holder Distance

For a safe guidance of the brushes in the brush holder, it is normally suggested that the distance between holder and slip ring surface is no more than 3mm (0.125”).

1.3. Collector Rings

If possible, the collector ring surface should also be checked regularly for grooving and other damage. Consult OEM specifications for tolerances. The collector ring assembly and the surrounding area should be checked for oil contamination. If oil or grease from the bearing comes into contact with the slip ring surface, an insulating film can be formed which hampers the current transfer. Increased brush wear could be the consequence. The brushes are porous and, in the case of oil contamination, all brushes should be replaced after the collector ring is cleaned.

1.3.1 Excessive TIR (Total Indicator Runout or Out-of-Round)

All collector ring assemblies are installed with round rings. After a few years of service, the collector ring can deteriorate to a TIR greater then 0.010”. This out-of-roundness cannot be seen with the naked eye. Special profilers are required to accurately measure the out-of-roundness. The out-of-roundness develops in many forms such as an oval shape, a shape with multiple lobes or a round shape that has many low spots. The textbook limit for out-of-roundness on a collector ring is 0.003”. The average wind collector ring has a 32-inch circumference.

©American Wind Energy Association 2017

1.3.1 Excessive TIR (Total Indicator Runout or Out of Round) (continued)

The suggested out-of-roundness of collector ring performance evaluation and profiling, the suggested out-of-roundness guideline is:

- Not be more than 0.001" out-of-roundness per 1.000" of travel with a maximum of 0.015" total indicator runout.

If the above criteria is met and there are no signs of brush burning and ring erosion, the collector ring be can returned to operation.

1.3.2. Grooving

Vibration and the environment can cause collector rings to wear or groove after extended periods of operation. The proper brush grade and brush springs can significantly reduce the amount slip ring wear. The generator can be operated with a groove ring as long as the TIR is not too high and the brush remains in contact with the slip ring. A spiral groove is often machined into the collector ring. If the collector ring is worn past the spiral groove, the collector ring should be replaced.

1.3.3. Generator Shaft

The profiler mentioned in 1.3.1 can also be used to measure the shaft runout. With the slip ring removed, measure the shaft indicated runout as it turns. It is not uncommon to find that the shaft is bent. If the shaft variation exceeds 0.006", you should consider contacting a skilled technician or service provider for further evaluation and correction.

1.3.4. Signs of Brush Sparking

Extreme brush sparking may cause a serious flash over. Signs of sparking can be found on the brushes, the brush boxes, the rocker rings, or other paths nearby the slip ring.

©American Wind Energy Association 2017

1.3.5. Brush Dust

Carbon brush dust is a good conductor. Excessive accumulation of dust, therefore, may also create flash over and must be removed regularly during the inspection. Sufficient air flow is essential for successful removal of brush dust. Filters, air tubes, etc. should therefore also be checked regularly. The complete ventilation system should be cleaned and checked for proper operation.

2. Cleaning and Reassembly

2.1. Cleaning Collector Ring Assemblies

The collector ring assembly cover(s) should be completely removed and all components inspected as above before proceeding with cleaning. For these cleaning procedures, it is suggested that appropriate personal protection devices be worn, including a dust mask.

Use a small vacuum, preferably with a HEPA type filtration system, and a non-metallic brush to remove all accumulated dust and other contaminants from the collector ring enclosure, the brush holder assemblies, any supporting rods or fixtures, and the collector ring itself. Contact cleaner or other solvents should not be used directly on the collector ring as they may drive the carbon dust deeper into the insulated area reducing the dielectric properties of the assembly. If it is necessary to use a solvent, spray the solvent on a disposable towel or cloth and use the cloth to wipe the solvent on the unclean area. Do not use solvents on carbon brushes because they could affect the carbon material. The collector ring film (or patina) should not be cleaned with a solvent. If the collector ring surface does require cleaning, only use a mild abrasive tool such as a non-conductive abrasive pad or a flexible rubber abrasive. Always clean from the top down to avoid re-contaminating components.

NOTE: If a brush is not to be replaced, it should remain connected during inspection and cleaning to assure the return to its original location.

©American Wind Energy Association 2017

2.2. Installing Brushes

To install new brushes or to reinstall brushes after inspection, insert the brush into the holder ensuring the proper orientation, then slide the spring clip back into its slot and push it down onto the brush until the spring clip latch clips into the retaining notch. Connect new brushes and check that the connection is tight and the terminal is located correctly under the spring washer. As a final check to assure that the brush is free to move up and down in the brush holder and that the spring clip latch is correctly fitted, pull on the brush leads and lift the brush approximately 12mm (0.5”) and then lower it back onto the slip ring a few times.

2.3. Seating New Brushes

Many new brushes are manufactured with a bottom radius. This radius is not the exact contour of the slip due to manufacturing tolerance, brush holder orientation, and slip ring wear. In order to ensure adequate electrical contact to the collector ring, the brushes must be properly seated. Poor contact at startup can lead to major performance issues, shortened brush life, and even component damage.

Garnet paper or any non-metal bearing abrasive paper is recommended and cloth backed abrasives are often easier to use in many circumstances. The abrasive size should be 80 to 120 grit. Fine sandpaper, such as 400 grit, will easily fill with carbon making the sanding process more difficult. It is important not to leave abrasive particles under the brushes when completed as these could damage the slip ring surface.

Seat one brush at a time while all the other brushes are still connected but out of their holders.

Lift the brush by its shunts and slide a strip of the abrasive cloth under it with the abrasive side of the paper facing the brush. Lower the brush down onto the abrasive cloth and place the spring in its normal engaged position. The spring should apply the pressure to the brush. Slide the garnet paper back and forth under the brush in line with the brush path. After several passes back and forth, remove the brush from its holder and check the face of the brush. The seating is complete when at least 80% of the brush face is abraded. Vacuum out all the accumulated carbon dust and sanding debris and reinstall the brush and spring-clips. Repeat with all the new brushes or used brushes with improper seating marks.

©American Wind Energy Association 2017

2.3. Seating New Brushes
(continued)

Once properly assembled, assure that all bolts are tightened and the brushes are properly connected.

Again, as a final check that the brush is free to move up and down in the brush holder and that the spring clip latch is correctly fitted, pull on the brush leads and lift the brush approximately 12mm (0.500”) and then lower it back onto the slip ring a few times.

Also, make sure that all tools and cleaning materials are removed from the area and the cover gaskets are functioning properly before replacing the cover.

©American Wind Energy Association 2017

RP 202 Grease Lubricated Bearing Maintenance

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.

Committee Chair: Kevin Alewine, Shermco Industries
Principal Author: Korey Greiner, SKF
Contributing Author: Kevin Alewine, Shermco Industries

Purpose and Scope

The scope of "Grease Lubricated Bearing Maintenance" addresses the common maintenance issues related to lubrication of generator bearings and a basic trouble shooting guide to help with service/repair decisions.

Introduction

Conventional utility scale wind turbine generators range from 500kW to >3MW in production capabilities. Most of these units use grease lubricated anti-friction ball bearings that require some type of replenishment on a regular basis on both the drive and non-drive ends of the machine. Often, lubrication supply devices are utilized to partially automate the process, but monitoring and adjustments are required even with these automated systems. A few turbine designs have generators directly mounted to the gearbox and will only have one, non-drive end bearing to be maintained as the drive end bearing is integral to the gearbox lubrication system. Whereas alignment issues are simplified with these direct coupled machines, assuring proper lubrication is still a key element in good maintenance procedures. Alignment and vibration also contribute to premature bearing failures and those issues will be addressed in separate recommended practice documents. Regardless of design, it is critical that the proper amount of lubricant is used: both too little and too much grease will dramatically shorten the life of the bearing.

The proper choice of lubricant is normally specified by the generator manufacturer, but a general overview is included in this recommended practice for informational purposes only. Please refer to industry standard documents for more details.

Direct drive machines use generators that are integral to the main shaft of the wind turbine and the lubrication of those main bearings are discussed in other recommended practices.

©American Wind Energy Association 2013

Grease Lubricated Bearing Maintenance

1. Overview of Grease Lubricated Bearings

Lubricating greases usually consist of mineral or synthetic oil suspended in a thickener, with the oil typically making up 75% or more of the grease volume. Chemicals (additives) are added to the grease to achieve or enhance certain performance properties. As a result of having a thickener package, grease is more easily retained in the bearing arrangement, particularly where shafts are inclined or vertical. Grease also helps to seal bearings against solid particulate and moisture contamination. Excessive amounts of grease will cause the operating temperature in the bearing to rise rapidly, particularly when running at high speeds. As a general rule for grease lubricated bearings, the bearing should be completely filled with grease prior to start-up but the free space in the housing should only be partially filled. Before operating at full speed, the excess grease in the bearing should be allowed to settle or escape into the housing cavity during a running-in period. At the end of the running-in period, the operating temperature will drop considerably indicating that the grease has been distributed in the bearing arrangement. See the generator manufacturer's specifications for more information on running in loads and speeds.

2. Grease Selection

When selecting grease style and manufacturer for bearing lubrication, the base oil viscosity, consistency, operating temperature range, oil bleed rate, rust inhibiting properties, and the load carrying ability are the most important factors to be considered. Please refer to the generator manufacturer's recommendations for the proper grease type for a specific machine.

3. Lubricant Compatibility

If it becomes necessary to change from one grease to another, the compatibility of the greases should be considered.

CAUTION: If incompatible greases are mixed, the resulting consistency can change significantly and bearing damage due to lubricant leakage or lubricant hardening can result.

Greases having the same thickener and similar base oils can generally be mixed without any problems, e.g. a lithium thickener/ mineral oil grease can generally be mixed with another lithium thickener/mineral oil grease. Also, some greases with different thickeners, e.g. calcium complex and lithium complex greases can be mixed. However, it is generally good practice not to mix greases.

©American Wind Energy Association 2013

3. Lubricant Compatibility
(continued)

The only way to be absolutely certain about the compatibility of two different greases is to perform a compatibility test with the two specific greases in question. Often the lubricant manufacturers for common industrial greases have already performed these tests and they can provide those results if requested. Most preservatives used to protect bearings are compatible with the majority of rolling bearing greases with the possible exception of older style polyurea greases. Again, always check with the generator manufacturer before changing or mixing grease types or manufacturers.

4. Lubrication

In order for a bearing to be properly lubricated with grease, oil must bleed from the grease. The oil then coats the bearing components, but is gradually broken down by oxidation or lost by evaporation, centrifugal force, etc. Over time, the remainder of the grease will oxidize or the oil in the grease near the bearing will be depleted. At this point, re-lubrication is necessary to keep the bearing operating properly for its designed life. There are two critical factors to proper lubrication: the quantity of grease supplied and the frequency at which it is supplied. Ideally, re-lubrication should occur when the condition of the existing lubricant is still satisfactory. The lubrication interval depends on many related factors. These include bearing type and size, speed, operating temperature, grease type, space around the bearing, and the bearing environment. Please refer to the generator manufacturer's documentation for lubrication rates and quantities.

4.1. Manual Lubrication Procedure

There is probably a manufacturer's recommendation regarding the hours of operation before lubrication. It is recommended that this be considered a maximum parameter since the periodic maintenance of wind turbines is normally minimized due to the difficulties of access. Make sure all fittings are clean and free from contamination. If the exit port becomes clogged or if the grease hardens within the bearing housing, the excess grease can be pushed out of the generator and onto the exterior or, more importantly, into the interior of the generator, contaminating the windings. Dispense only the amount required. Do not overfill. Refer to the generator manufacturer's specifications regarding the quantity and frequency rate for lubrication of the bearings.

©American Wind Energy Association 2013

4.2. Automated Lubrication

Automated lubrication devices work by adding a measured amount of grease to the bearing housing. The influx of new grease pushes out older material through an exit port. Again, if the port becomes clogged or if the grease hardens within the generator, the excess grease can be pushed out of the housing and onto the exterior or, more importantly, into the interior of the generator, contaminating the windings. Operation of these devices is critical and they should be checked carefully during periodic turbine inspections. Auxiliary power should be available for a test run of the device to assure proper operation. Also, any grease in the automated device storage container where the oil has separated should be replaced.

5. Operating Temperature

Since grease aging is accelerated with increasing temperature, it is recommended to shorten the intervals when in increased operating temperature environments. The alternate also applies for lower temperatures and the lubrication interval may be extended at temperatures below 158° F (70° C) if the temperature is not so low as to prevent the grease from bleeding oil. In general, specialty greases are required for bearing temperatures in excess of 210° F (100° C). Again, consult the generator manufacturer for grease recommendations for extreme temperature conditions.

6. Vibration

Moderate vibration should not have a negative effect on grease life. But high vibration and shock levels, such as those in found in wind turbines can cause the grease to separate more quickly, resulting in churning of the oils and thickener. In these cases the re-lubrication interval should be reduced. The overall importance of testing and controlling vibration is covered in another recommended practice.

7. Contamination

Contaminants have a very detrimental effect on the bearing surfaces. More frequent lubrication than indicated by the manufacturer's recommended interval will reduce the negative effects of foreign particles on the grease while reducing the mechanical damaging effects. Fluid contaminants (water, oil, hydraulic fluids, etc.) also call for a reduced interval. Since there are no formulas to determine the frequency of lubrication because of contamination, experience is the best indicator the appropriate interval.. It is generally accepted that the more frequent the lubrication the better. However, care should be taken to avoid overgreasing a bearing in an attempt to flush out contaminated grease. Using less grease on a more frequent basis rather than the full amount of grease each time is recommended. Excessive greasing without the ability to purge will cause higher operating temperatures because of churning.

©American Wind Energy Association 2013

Summary

This recommended practice is designed to provide basic information and techniques for proper lubrication of generator bearings as well as a troubleshooting guide to aid with maintenance/repair decisions. Proper care and lubrication, when required, will assure long, trouble fee service life for these critical components.

Troubleshooting Guide

Bearings that are not operating properly usually exhibit identifiable symptoms. This section presents some useful hints to help identify the most common causes of these symptoms as well as practical solutions wherever possible. Depending on the degree of bearing damage, some symptoms may be misleading. To effectively troubleshoot bearing problems, it is necessary to analyze the symptoms according to those first observed in the applications. Symptoms of bearing trouble can usually be reduced to a few classifications, which are listed below.

Note: Troubleshooting information shown on these pages should be used as guidelines only.

Common Bearing Symptoms

- Excessive heat
- Excessive noise
- Excessive vibration
- Excessive shaft movement Excessive torque to rotate shaft

Excessive Heat

Lubrication

Wrong type of lubricant
Insufficient lubrication - Too little grease
Excessive lubrication - Too much grease without a chance to purge

Insufficient bearing internal clearance

Wrong bearing internal clearance selection
Excessive shaft interference fit or oversized shaft diameter
Excessive housing interference fit or undersized housing bore diameter
Excessive out-of-round condition of shaft or housing

Improper bearing loading

Skidding rolling elements as a result of insufficient load
Bearings are excessively preloaded as a result of adjustment
Out-of-balance condition creating increased loading on bearing
Linear misalignment of shaft relative to the housing
Angular misalignment of shaft relative to the housing

©American Wind Energy Association 2013

Excessive Heat
(continued)

Sealing conditions
- Housing seals are too tight
- Multiple seals in housing
- Misalignment of housing seals
- Operating speed too high for contact seals in bearing
- Seals not properly lubricated
- Seals oriented in the wrong direction and not allowing grease purge

Excessive Noise

Metal-to-metal contact
- Oil film too thin for operating conditions
- Temperature too high

Insufficient quantity of lubrication
- Under lubricated bearing
- Leakage from worn or improper seals
- Leakage from incompatibility

Rolling elements skidding
- Inadequate loading to properly seat rolling elements
- Lubricant too stiff

Contamination
- Solid particle contamination entering the bearing and denting the rolling surfaces
- Solids left in the housing from manufacturing or previous bearing failures
- Liquid contamination reducing the lubricant viscosity
- Looseness
- Inner ring turning on shaft because of undersized or worn shaft
- Outer ring turning in housing because of oversized or worn housing bore
- Locknut is loose on the shaft or tapered sleeve
- Bearing not clamped securely against mating components
- Too much radial / axial internal clearance in bearings

©American Wind Energy Association 2013

Excessive Noise
(continued)

Surface damage
- Rolling surfaces are dented from impact or shock loading
- Rolling surfaces are false-brinelled from static vibration
- Rolling surfaces are spalled from fatigue
- Rolling surfaces are spalled from surface initiated damage
- Static etching of rolling surface from chemical/liquid contamination
- Particle denting of rolling surfaces from solid contamination
- Fluting of rolling surfaces from electric arcing
- Pitting of rolling surfaces from moisture or electric current
- Wear from ineffective lubrication
- Smearing damage from rolling element skidding

Excessive torque to rotate shaft
- Preloaded bearing
- Excessive shaft and housing fits
- Excessive out-of-round condition of shaft or housing
- Bearing is pinched in warped housing
- Wrong clearance selected for replacement bearing

Sealing Drag
- Housing seals are too tight or rubbing against another component
- Multiple seals in housing
- Misalignment of housing seals
- Seals not properly lubricated

Surface Damage
- Rolling surfaces are spalled from fatigue
- Rolling surfaces are spalled from surface initiated damage
- Fluting of rolling surfaces from electric arcing
- Shaft and/or housing shoulders are out of square
- Shaft shoulder too large and is rubbing against seals/shields

©American Wind Energy Association 2013

RP 203 Generator Off-Line Electrical Testing

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.

Committee Chair: Kevin Alewine, Shermco Industries
Principal Author: Kevin Alewine, Shermco Industries

Purpose and Scope

The scope of "Generator Off-Line Electrical Testing" provides an introduction to basic electrical tests for the periodic testing and troubleshooting of wind turbine generator electrical circuits. It is not intended to provide specific techniques or recommendations for corrections based on the test results.

Introduction

All generators, regardless of their design, contain at least one wound element where most or all of the energy is generated and made available to the system. They are often complicated windings with many opportunities for weakness as well as many connections where high resistance is a concern. When most electrical failures occur, a generator specialist is required for correction or repair, but normal operating conditions can often be verified by normal maintenance staff.

Some electrical tests are designed to merely provide a high level of confidence that the machine can be energized safely, but not as predictive tools regarding the longevity of the windings or even their performance under full load. Higher level testing can safely stress the winding insulating at or above normal operation levels and can help develop trends for predictive maintenance.

On-line electrical testing can provide a large amount of useful information, but specialized equipment and training is critical and the parameters for use on wind turbine generators is not yet available as standard testing. Future editions of this standard should address that technology as it develops.

This guide will provide an introduction to several of these tests, but only the insulation resistance testing is recommended for use by non-specialized personnel. Always remember the dangers associated with any electrical testing and follow proper safety procedures. Qualified and accredited companies and technicians should be utilized in most cases. Reference NFPA 70B and NFPA 70E as well as the InterNational Electrical Testing Association (NETA)/ANSI testing protocols.

©American Wind Energy Association 2013

Generator Off-Line Electrical Testing

1. Common Test Methods

1.1. Insulation Resistance

Insulation resistance testing (sometimes referred to as IR testing, not to be confused with infrared testing) is one of the oldest maintenance procedures developed for the electrical industry and is covered in detail in IEEE Standard 43-2000. This test is fairly simple to perform and can provide information regarding the condition of the electrical insulation in the generator as well as contamination and moisture. This test is recommended before energizing a machine that has been out of service or where heating elements have failed to keep the winding temperature above the dew point which might have resulted in condensation on the windings. It is also useful whenever there is doubt as to the integrity of the windings and before any over voltage testing is performed. An accurate IR test requires a correction factor for the winding temperature to create useful data. The methods and expected result data for this test is listed in the standard document. While the test results from IR testing are not normally trended, it is possible to do so to show a gross degradation of the insulation systems. It is, however, very important that the duration of the test, the temperature of the windings and relative humidity be consistent for the trend data to be meaningful.

1.2 Polarization Index

Another test described in IEEE Standard 43-2000 is the polarization index (or P.I.) that is useful in some applications to identify contaminated and moist windings. In most modern machines, however, where the insulation resistance is above 5000 megohms, the test might not prove meaningful. There has also been a consideration of collecting de-polarization data. Refer to the standards document for additional applications and details.

1.3. Winding Resistance Testing

It is common to use a basic ohm meter in screening generator winding circuits, but the information gained is not a reliable diagnostic tool because of the many components in the circuit. The use of very low resistance test meters can provide good information, but these tests are very sensitive to temperature fluctuations and trending is difficult.

©American Wind Energy Association 2013

1.4. Ancillary Component Tests

Testing any auxiliary motors such as those in cooling systems or automated lubrication devices would follow the same basic procedures as the generator itself, but at the appropriate testing range. Other components such as resistance thermal devices (RTD), thermocouples, heater elements, micro switches, etc. are normally checked with an ohm meter. Consult the manufacturer’s literature for specifications.

2. High Voltage Tests

Although these tests are not commonly used in general maintenance procedures, it is useful to have a basic understanding of what tests are available for predictive maintenance trending, troubleshooting and failure analysis. These tests are generally considered to be non-destructive in nature, but a weakness in the insulation system could and probably should fail during these tests so care should be taken when determining when these tests are advisable. It is recommended that only properly trained generator electrical test technicians should perform these tests.

2.1. High Potential Testing

The high potential test (sometimes referred to as an over potential test) is designed to stress the electrical insulation beyond its normal operating voltages to expose potential failures at a more convenient time. Both AC and DC tests are available, but should only be performed by a generator testing expert. The DC test methods are described in IEEE Standard 95. Trending is possible with this testing, but care should be taken as insulation weaknesses (cracking, contamination, carbon tracking, etc.) can be advanced to failure.

2.2. Step Over-Voltage Test

Using the same equipment as the high potential test, the step over voltage test stresses the insulation at rising levels of voltage over a set time scale. This is a very useful trending test and is also commonly used in periodic predictive maintenance testing. The same concerns exist as for high potential testing.

©American Wind Energy Association 2013

2.3. Surge Comparison Test

This type of test is the most common analysis tool for testing turn to turn insulation in motors and generators. In this test, a short pulse of high voltage energy at an appropriate stress level is sent through the windings and the results captured on a recording oscilloscope. The patterns of two identical circuits are then compared and the overlaying waves will highlight any differences which represent a potential failure point. A trained test technician can often identify winding failure types by the oscilloscope wave forms. This test is normally used in conjunction with a high potential test. This type of test is described in IEEE Standard 522. Modern automated winding analysis equipment combines many of these tests into a concise report and is very useful for predictive maintenance practices. Again, these high voltage tests should only be performed by a trained generator test technician.

2.4. Partial Discharge Testing

Both periodic and continuous monitoring testing of partial discharge currents and/or corona are common for large high voltage machines for trending expected useful insulation life. Some techniques do exist for testing low voltage applications, but specialized equipment and training are necessary. It should be considered for long term predictive maintenance programs.

Summary

Good maintenance practice calls for the periodic evaluation of generator electrical conditions and should always be part of a basic maintenance plan. Use of the proper testing protocols can assure safe operation of the generator and can help highlight corrective opportunities before catastrophic failure. True predictive high voltage tests offer much useful data for analysis and maintenance scheduling to avoid unplanned outages, but should only be performed by trained technicians.

References

Electrical Apparatus Service Association Standard AR100-2010 Recommended Practice for the Repair of Rotating Electrical Apparatus www.easa.com/resources/booklet/ANSI-EASA-AR100-2015

Electrical Insulation for Rotating Machines: Design, Evaluation, Aging, Testing and Repair, Dr. Greg C. Stone, et.al. John Wiley & Sons, 2004 ISBN: 978-1-118-05706-3 www.wiley.com/WileyCDA/WileyTitle/productCd-1118057066.html

©American Wind Energy Association 2013

References
(continued)

IEEE Std. 4-1995 and Amendment 1-2001 Standard Techniques for High Voltage Testing ieeexplore.ieee.org/document/913838/

IEEE Std. 43-2000 Standard Techniques for Testing Insulation Resistance of Rotating Machinery ieeexplore.ieee.org/document/836297/

IEEE Std. 95-2002 Recommended Practice for Insulation Testing of AC Electric Machinery (2300 V and Above) with High Direct Voltage ieeexplore.ieee.org/document/996345/

IEEE Std. 112-2004 Standard Test Procedure for Polyphase Induction Motors and Generators ieeexplore.ieee.org/document/1353938/

IEEE Std. 115-2009 Guide for Test Procedures for Synchronous Machines ieeexplore.ieee.org/document/5464495/

IEEE Std. 522-2004 Guide for Testing Turn Insulation of Form Wound Stator Coils for Alternating Current Electrical Machines ieeexplore.ieee.org/document/1322822/

National Electric Manufacturer's Association NEMA MG-1-2009, R1-2010 Motors and Generators www.nema.org/Standards/ComplimentaryDocuments/Contents%20and%20Forward%20MG%201.pdf

NFPA 70B Recommended Practice for Electrical Equipment Maintenance www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards?mode=code&code=70B

NFPA 70E Standard for Electrical Safety in the Workplace www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards?mode=code&code=70e

©American Wind Energy Association 2013

RP 204 Converter Maintenance

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.

Committee Chair: Kevin Alewine, Shermco Industries
Principal Author: Aaron Lawson, PSI Repair Services
Contributing Author: Kevin Alewine, Shermco Industries

Safety Notice

The American Wind Energy Association (AWEA) cannot determine or prescribe how industry employers should evaluate their compliance obligation under the Occupational Safety and Health Administration's (OSHA) regulations. Each employer must make its own determinations depending on the condition of the worksite.

AWEA strongly encourages its members to develop their own written program to address worker safety and health procedures, programs, and hazard assessments, as well as, provide training for their workers in these areas. Elements to consider when creating a program:

1. Ensure workers utilize appropriate personal protective equipment (PPE) including but not limited to flame resistant (FR) rated clothing, Arc Flash suit and hood, and electrical gloves rated to the electrical hazard present.

2. Follow all electrical safety codes including but not limited to NFPA70E, OSHA, ANSI, etc.

3. Ensure proper Lock Out Tag Out (LOTO) procedures are followed.

4. Allow adequate time for capacitors to discharge before opening converter cabinets. Capacitor discharge times should be provided by the converter OEM. If unknown, wait a MINIMUM of 30 minutes!

5. Ensure there is no dangerous voltage present at the converter by measuring the voltage at the capacitor banks, input and/or output phase terminals.

©American Wind Energy Association 2017

Purpose and Scope

The scope of "Converter Maintenance" provides an introduction to the operation of converters commonly used in wind turbines. It also addresses basic maintenance and troubleshooting related to the converters. It is not machine specific; OEM documentation should be used where available. Variations to this recommended practice may be necessary in some instances.

Introduction

Converters are used to synchronize the output from a generator to the frequency of the grid. There are various topologies used in wind turbines such as doubly fed induction generators or full power conversion from permanent magnet generators. The converters used are similar and have the same basic components. The maintenance and troubleshooting for these converters are similar and can be applied with a basic knowledge of the converter being used.

Note: The terms converter and inverter are commonly used interchangeably. For the purpose of this document, the term converter will be used. Only qualified and properly trained personnel should be allowed to perform maintenance on converters.

Converter Maintenance Procedures

1. Filter

Inspect the filter for contamination and replace when necessary. The filter should be replaced every year or sooner depending on the dustiness of the environment. Clogged filters will cause cooling fans to work harder which shortens their lifetime and will also increase the temperature of the converter which will lead to a shorter converter lifetime.

2. Electrical Connections

Inspect terminals for loose connections, corrosion, and damage from high temperature. Inspect wiring for cracked insulation, abrasions, and discoloration. Inspect the condition of all wire crimps. Repair or replace any cables or terminals that show damage. Terminals on the phase connections as well as the DC link connections should be inspected. Ensure that no insulation is trapped under terminals. Verify all connections are tightened using the specified torque ratings. Improperly tightened electrical connections will heat up and eventually fail.

©American Wind Energy Association 2017

3. Fiber Optic Cables, If Equipped

When fiber optic cables are removed, care should be taken to ensure dust and debris are not allowed to come in contact with the cable or transceiver ports. Use clean and dry compressed air to blow off dust from the cables, connectors, and transceiver ports. Isopropyl alcohol and lens paper can be used to clean off cables and connectors. Never use dry lens paper as it is extremely abrasive when dry. Never insert any foreign object into a transceiver port. Install covers or plugs to prevent dust from contaminating cleaned fiber optics. Commercial optical cable cleaning kits are also available; follow their instructions for proper use.

4. Heat Sink

Inspect heat sink for dirt or debris. Heat sink fins will pick up dust and dirt from the cooling air. Dirty or clogged heat sinks will not allow heat to be efficiently removed from power electronic components and cause a shortened lifetime. Heat sinks should be inspected and cleaned at least annually but more often if the environment is excessively dusty. Cleaning can be accomplished by blowing clean and dry compressed air through the heat sink and capturing dust using a vacuum cleaner at the outlet. Care must be taken to prevent dust from entering adjoining equipment. Oil or grease contamination must also be removed from heat sink surfaces and fins.

5. Fans

Test for proper operation of the cooling fans. If the heat sink temperature gradually rises over time, this may be an indication of a failing fan. A handheld anemometer can be used to verify the proper airspeed. If the airspeed is low, the fan should be repaired or replaced. Increased noise or vibration from a fan is an indication of bearing failure and the fan should be repaired or replaced before complete failure. Clean the fan blades and guard of any accumulated dust and debris or other obstructions.

6. Liquid Cooling System, If Equipped

Inspect the heat exchanger for dust and debris and clean if necessary. The coolant pump should be tested for proper operation. Many pumps will have a pressure gauge that should indicate the pump is operating correctly. Excessive noise from the pump may be an indicator of a failing pump or motor. The entire coolant system should be inspected for leaks and repaired as necessary.

©American Wind Energy Association 2017

6. Liquid Cooling System, If Equipped
(continued)

Coolant should be tested for proper refractive index and adjusted as necessary. A refractometer should be used with the proper scale; an automotive hydrometer is not acceptable for converter coolant testing. Distilled water should be used with the specified antifreeze; potable water should never be used due to its mineral and chemical content variation. Coolant level and refractive index should be tested every 6 months unless otherwise specified by the manufacturer. Coolant should be completely replaced (to renew the corrosion inhibitors) every 5 years unless otherwise specified by the manufacturer.

7. Seals

Inspect enclosure and door seals for condition. Damage to seals will allow dirt and contamination to enter the enclosure. Proper airflow can also be affected by damaged seals. Replace if damaged. Cable glands should also be inspected for proper sealing or damage.

8. Enclosure

Inspect all enclosures and remove any loose hardware, insects, or any other foreign objects. Vacuum any accumulated dirt or debris that may be present inside the enclosure.

9. Converter Control Unit

Depending on the type of converter control unit, a memory backup battery may be used. This battery should be replaced as recommended by the manufacturer or at least every 5 years. Care should be taken when replacing this battery to prevent electrostatic discharge (ESD) damage to the electronics. Proper replacement procedures should be followed to prevent memory data loss.

10. Thermographic Inspection

Thermal cameras can be used to inspect converter equipment when under load for abnormal heating of components and electrical terminals. Proper training is required when using thermal cameras. Consulting with a certified and experienced thermographer is recommended. Proper PPE is required when accessing a converter cabinet under load as there is an extreme danger of arc flash and hazardous voltages are present.

©American Wind Energy Association 2017

10. Thermographic Inspection
(continued)

Baseline thermal images may be required to ensure abnormal conditions are properly identified. Areas to inspect include electrical terminals, Insulated Gate Bipolar Transistors (IGBTs), capacitors, control circuit boards, and heat sinks/ cooling systems. Loose terminals will show up hotter than properly torqued terminals. Failing IGBTs, capacitors, or components on circuit boards may appear hotter than other components in the system. Improperly functioning heat sinks or coolant lines may appear cooler than when they are properly operating.

11. DC Link Capacitors

Two main types of capacitors are used in converters, aluminum electrolytic and film capacitors. Aluminum electrolytic capacitors have a shorter lifetime than film capacitors. Many newer converters use film capacitors for this reason. The lifetimes of both types of capacitors are dependent on the ambient temperature, operating time, and loading of the converter. Testing DC link capacitors are difficult without the proper equipment. Standard equivalent series resistance (ESR) meters are not able to test high capacitance and voltage of DC link capacitors.

Visually inspect capacitors for bulges, dents, burns, or other abnormal marking and replace any that have damage. Large aluminum electrolytic capacitors commonly have a vent plug that will pop out in the case of an over voltage or over temperature event. Replace any capacitors that have a missing vent plug. Clean DC link capacitors and bus bars of any dust and debris as this can cause arcing across their terminals.

12. Insulated Gate Bipolar Transistors (IGBTs)

Inspect IGBTs for dust and debris. Clean any contamination on or near their terminals as this can cause arcing. A digital multimeter can be used to check IGBTs for shorts across their collector and emitter terminals.

Troubleshooting

Most wind turbine control systems deliver codes when a fault occurs. These codes give important information that can aid the troubleshooting process.

©American Wind Energy Association 2017

Troubleshooting
(continued)

Possible causes of common failures codes:

Over Temperature:
- Defective temperature sensor/switch or thermostat
- Dirty or clogged heat sink
- Dirty or clogged filters
- Failure of cooling fan
- Low coolant level
- Kinked coolant hoses
- Exceeding converters ambient operating temperature

Over Current:
- Phase to phase short
- Phase to ground short
- Shorted IGBT
- Faulty current transformer/transducer
- Faulty converter control unit
- Shorted generator
- Shorted cabling
- Faulty crowbar circuit, if equipped

Switching Frequency:
- Faulty rotor converter
- Loose or damaged rotor cables
- Faulty slip ring brushes

DC Overvoltage:
- Static or transient overvoltage on grid
- Failed converter
- Faulty line side converter contactor

DC Undervoltage:
- Open grid supply fuse
- Open DC fuse
- Faulty converter

©American Wind Energy Association 2017

RP 207 Wind Turbine Generator and Converter Types

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.

Committee Chair: Kevin Alewine, Shermco Industries
Principal Author: Kevin Alewine, Shermco Industries
Contributing Author: Aaron Lawson, PSI Repair Services

Purpose and Scope

The scope of "Wind Turbine Generator and Converter Types" provides an introduction for managers and technicians new to wind energy some of the most common generator and converter technologies utilized in wind turbines. These are not manufacturer specific and several variations are found, but these types make up the majority of the North American fleet. It is hoped that this can provide some common terms and nomenclature for use when addressing generic issues and solutions as well as design-specific concerns.

Introduction

As the wind energy industry continues to grow and the reliability of turbine fleets becomes more critical, manufacturers have focused on generator designs that have proven success in this severe application. While traditional generator designs have been used, there are several technologies utilized that are less common in utility or industrial applications. A typical engine driven generator, as an example, is designed using a salient pole generator where the frequency generated is dependent on the rotating speed and drive torque is managed to match the load. Constant speed is a real problem in wind generation, so more innovative solutions are required. The variability inherent with the wind has led to the development of complex control systems and high power electronics. These devices work in conjunction with the generator to maximize the power output and the useful wind speed range. They also stabilize the output frequency and power factor regardless of mechanical input.

©American Wind Energy Association 2017

Wind Turbine Overview

The two basic types of drivetrains used in current designs are the traditional rotor/gearbox/generator style or the direct drive design where the rotor is directly connected to a relatively large diameter generator. In the traditional design, the gearbox increases the relatively low input speed, typically 17-20 RPM, to a high-speed output shaft connected to a 4 or 6 pole generator. Newer designs developed for large off-shore machines will probably use a simpler, more robust gearbox with a medium speed output to an 8 pole generator.

The early versions of the direct drive turbines used generators with many pole pieces (often nearly 100) much like a hydro turbine. Although some of these models are still in production, other configurations are more popular as output ranges increase. Newer direct drive turbines typically utilize permanent magnets rather than individual pole pieces.

With rare exception, wind turbines generate electricity at 690VAC and utilize internal or external step-up transformers to match project distribution requirements. This low voltage, high amperage configuration has proven to be reliable and cost-effective in nearly all wind turbines, regardless of manufacturer. One reason for this specific voltage level has been the limits to the maximum operating voltage of power electronic devices used in wind converters. Insulated gate bipolar transistors (IGBTs) have been limited to maximum voltages of 1200v-1700v in the past. Currently, device manufacturers have IGBTs with maximum voltage ratings of 3.3kv-6.5kv [1]. These higher voltage IGBTs have the downside of being much more expensive than the more common IGBTs in the 1200v-1700v range.

In addition to these higher voltage IGBTs, converter manufacturers are developing multilevel converters which further expand the possible output voltage for wind generator applications. For example, a medium-voltage converter can be designed with modern 6.5kv IGBTs in a seven-level topology with maximum voltages up to 11kv [2]. One downside to multilevel converters is the high number of IGBTs requires a very complex control system.

Fully Converted Generator Design Types

Most modern wind generators utilize one of three basic induction generator types – asynchronous induction (squirrel cage), permanent magnet rotor, and doubly-fed induction (DFIG). In this overview, these types of generators are briefly described, the benefits and shortcomings of each are explained as well as the types of electronic controls necessary for excitation, frequency conversion, and synchronization with the grid.

©American Wind Energy Association 2017

Traditional Synchronous Generators

The traditional salient-pole generators common to general industrial and commercial applications have been used in just a few designs of wind turbines. The output compared to their weight and complexity has not proven popular. Their need to run at a constant speed to synchronize with the grid also complicates their use. One of the few successful designs required the use of not only a gear box but also a fluid drive to maintain generating frequency making the weight, cost, and maintenance complexity of the entire drivetrain generally undesirable.

Asynchronous Induction Generators

This design was one of the earliest used in wind generation where all of the output was converted to DC and used to charge batteries, similar to automotive applications. As the size of turbines grew dramatically and the cost of large power converter components fell, these machines have been scaled to operate in the 2-3MW range. In this design, power is supplied to the stator windings to induce current in the already rotating squirrel-cage rotor. This excitation current supplies the rotating magnetic field that generates AC current from those same windings. This is a very simple generator, but not-so-simple power conversion equipment. Effectively an AC/DC-DC/AC convertor is used on the output current with the frequency matched to the grid by high power semiconductor inverters that maintain the synchronization necessary.

Most of the generators used in this application generate 690VAC over a wide speed and current range. The converter is the key to grid stabilization, power factor, and reliability. The benefit of this design is that up-tower maintenance is simplified but the risk is that it can be very expensive to replace failed electronic components even if they are easier to access.

Permanent Magnet Generators

These generator designs were once thought to be the solution for many of the maintenance costs and they are, in fact, proving to be very reliable machines in general. However, the costs associated with manufacturing these units can negatively impact the financial strategy of developers, so they remain less popular in many areas. In these designs, the excitation is supplied by the magnets on the rotating element. Like the standard induction generators, the AC output is fully converted by the electronics, which are simpler in design than either the induction generators or the doubly-fed induction generators discussed below.

©American Wind Energy Association 2017

Permanent Magnet Generators
(continued)

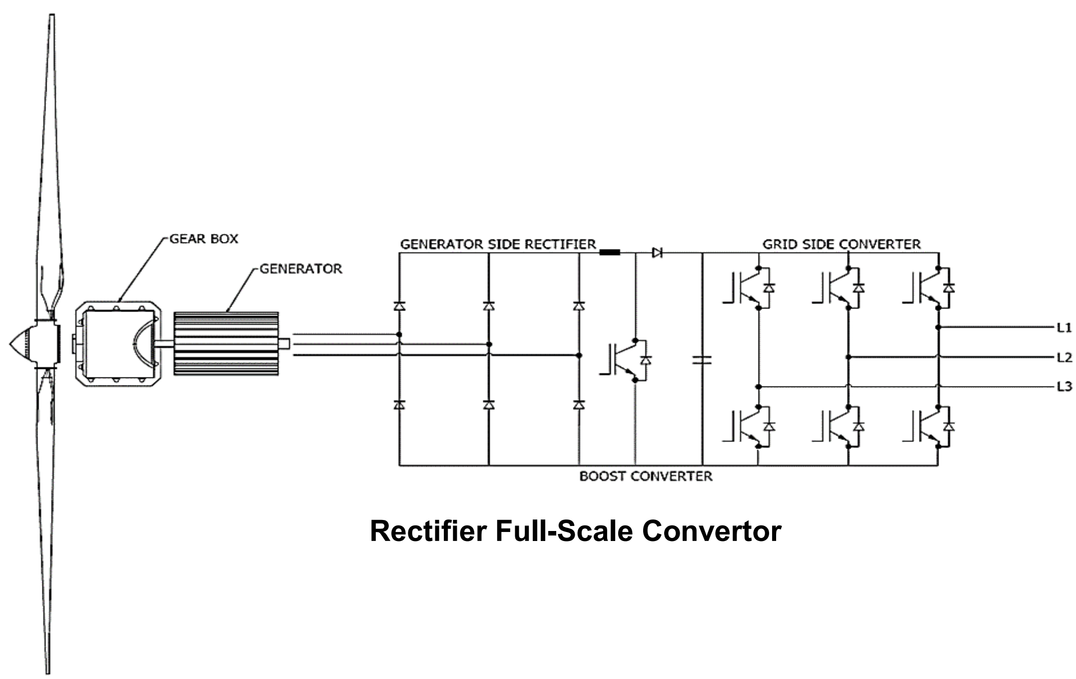
Maintenance is minimal on these machines and they may continue to be popular where long term operating costs are taken into consideration when planning the wind project, as they are in Asia and Europe. Most of the current designs utilizing permanent magnet generators are direct drive machines where an outer ring housing the magnets rotates around a would core which greatly improves the reliability of the windings. The ring is connected directly to the rotor and hub assembly and supported, typically, on a single very large main bearing.

Full-Scale Converters (FSC)

Synchronous, asynchronous, and permanent magnet generators can all be used with full-scale converters (FSC). There are two major types of FSCs used today, Rectifier Full-Scale Converters and Back to Back Full-Scale Converters.

Rectifier Full-Scale Converters (FSC)

Rectifier FSCs use simple rectifiers on the generator stator output which reduces the number of IGBT modules and corresponding control units required. This leads to a reasonably priced and efficient converter. Some disadvantages are increased losses due to the need for induction current and harmonics caused by the uncontrolled rectifier.

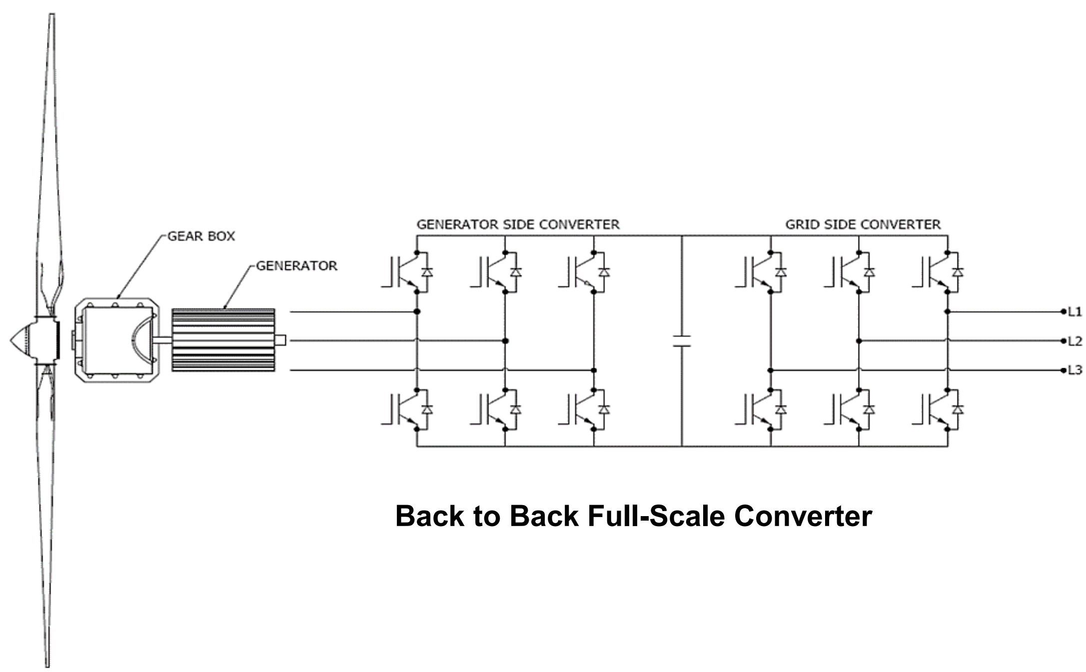


Rectifier Full-Scale Convertor

Back to Back Full-Scale Converters (FSCs)

Back to Back FSCs are becoming the most widespread topology used in the wind turbine field. These consist of two identical converters connected back to back to the grid side and generator side. This design is able to achieve minimum machine losses and the maximum range of control. The generator can be utilized efficiently over a wide range of speeds and the full reactive power can be made available during low wind conditions [3]. A major downside of this type of converter is the high cost due to the requirement of two identical converters using expensive power electronics.

Power can be produced at a lower cost if a wind turbine can operate within a wider range of wind speeds. This increases the profitability for the wind farm. Both types of full-scale converters allow a wide range of wind speed using modern generators and convert the full output power.



Back to Back Full-Scale Converter

©American Wind Energy Association 2017

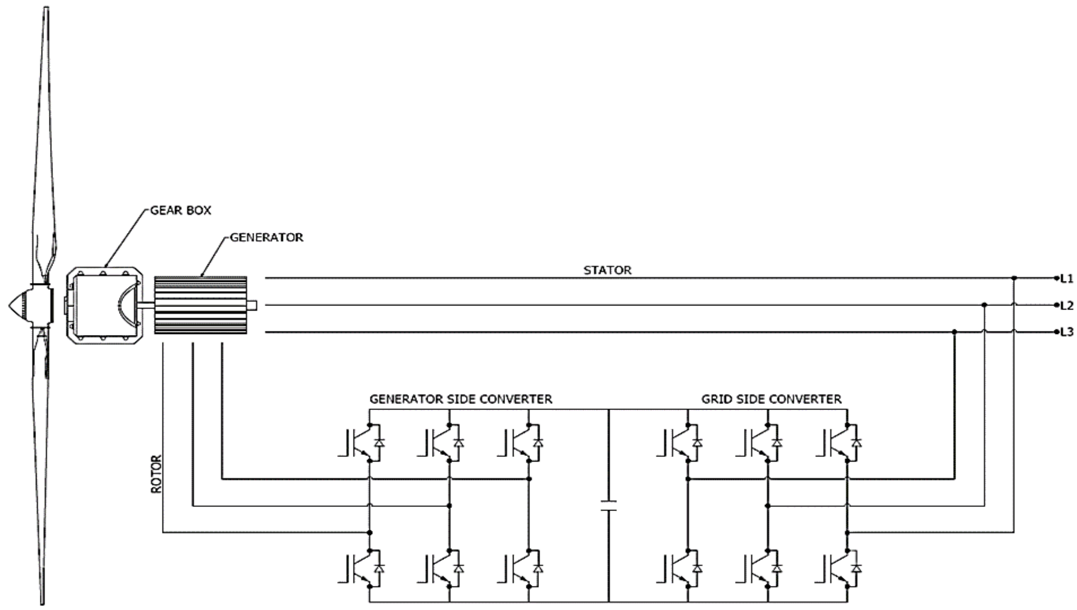
Doubly-Fed Induction Generators (DFIG)

This type of generator is relatively rare outside of the wind industry, but they have been well accepted by many turbine OEMs as their standard design. With a fairly high power output to weight ratio, these offer a good value for the initial cost of a wind project. This design utilizes a wound, three-phase rotor with excitation power provided through a slip ring assembly. Unlike a traditional generator, where the rotor provides the rotating magnetic field and all power is generated by the stator, if these machines are operated above the synchronous speed, then a positive current flow also comes from the rotor. This allows for a much smaller machine.

Converters for doubly –fed induction generators control the slip of the generator. They supply excitation current to the rotor when the generator is below synchronous speed. When the generator is above synchronous speed, the converter will take excess current from the rotor and supply it to the grid. This increases the amount of power the generator can create at high speeds and also increases the wind speed range capable of useful power generation.

An advantage of DFIG designs is the majority of the power generated is supplied directly to the grid. The converter used is only required to convert 30% of the power from the generator. The IGBTs and other power electronic components necessary are substantially smaller and less expensive than those used in full-scale converters. These converters maximize the tradeoffs between cost and range of useful wind speed when compared with full-scale converters. One of the main disadvantages discussed above is the requirement for slip rings which require regular maintenance. A second disadvantage is the IGBTs must be able to cope with high peaks in current and voltage during grid faults.

©American Wind Energy Association 2017



Doubly-Fed Induction Generator

More About Convertors

In all applications, regardless of generator type, the basic construction and function of the converter are the same. They consist of IGBTs to switch the power, DC Link Capacitors to store energy and decouple back to back converters, Snubber Capacitors to lessen voltage spikes during switching, a Bus Structure with low inductance to connect the power electronics, Drive Electronics to provide IGBTs with the proper turn-on and turn-off signals, and Control Electronics to control the converter frequency and switching signals. A water or air cooled heat sink is also used to remove excess heat generated by the IGBTs during switching. The converter switches at 1200-4500Hz in a Pulse Width Modulated (PWM) waveform. PWM is a modulation technique used by converters to generate a sine wave from a DC voltage. The converter creates a square wave with a varied duty cycle. Duty cycle is the on-time over the period of the square wave. The overall average of the PWM waveform is equivalent to an alternating current sine wave. The output is then filtered using a line reactor and power factor correction (PFC) capacitors prior to being fed into the pad mount transformer and ultimately to the grid.

©American Wind Energy Association 2017

References

[1] IGBT Modules www.infineon.com/cms/en/product/power/igbt/igbt-module/channel.html?channel=ff80808112ab681d0112ab69e66f0362

[2] *Power converters for wind turbines: Current and future development*, Md Rabiul Islam, Youguang Guo, and Jianguo Zhu, Centre for Electrical Machines and Power Electronics, University of Technology Sydney, FORMATEX 2013 formatex.info/energymaterialsbook/book/559-571.pdf

[3] SEMIKRON IGBT modules www.semikron.com/applications/wind-energy/application-examples.html

All images courtesy of PSI Repair Services.

©American Wind Energy Association 2017

RP 208 Shaft Current Management

The following recommended practice (RP) is subject to the disclaimer at the front of this manual. It is important that users read the disclaimer before considering adoption of any portion of this recommended practice.

This recommended practice was prepared by a committee of the AWEA Operations and Maintenance (O&M) Committee.

Committee Chair: Kevin Alewine, Shermco Industries
Principal Author: Rob Hefner, Schunk Graphite
Contributing Author: Roland Roberge, Morgan AM&T
Reviewing Committee: Benoit White, Mersen

Purpose and Scope

The scope of "Shaft Current Management" addresses the common maintenance issues related to the grounding systems for generator and drive train shafts in various wind turbine designs. It is not machine specific and some adaptation may be required based on specific designs.

Introduction

A wind turbine generator shaft is usually protected by a grounding system to prevent currents from passing onto the generator and/or drive train bearings. The use of carbon brushes contacting the shaft rotating area and tied into the unit's grounding is the most popular way of managing unwanted shaft currents. These brushes are wear items and should be included in any regularly scheduled maintenance inspection or process. The normal recommendation is to inspect and clean the brush and assembly at least bi-annually, but longer maintenance cycles may be possible with improved materials and designs. Brush life is affected by carbon grade, shaft speed, ambient temperature and humidity as well as other operating environmental conditions. During maintenance, a careful visual inspection should be performed and any abnormal conditions should be documented, preferably including photographs.

Understanding the Need for Shaft Grounding

Shaft voltages can be caused by:

- Asymmetry in the magnetic circuit of rotating electrical machines
- Build-up of static charges within the shaft
- Capacitative coupling of voltages into static exciting systems

©American Wind Energy Association 2013

Introduction
(continued)

If current does pass via the bearings of an electrical machine, high current densities may occur on the small contact points within the bearing, which can result in a local melting of the metal surfaces. The consequence is the formation of small craters and serrations. This typically increases the internal friction of the bearing and worsens over time causing increased temperature, contaminated lubrication and ultimately bearing failure.

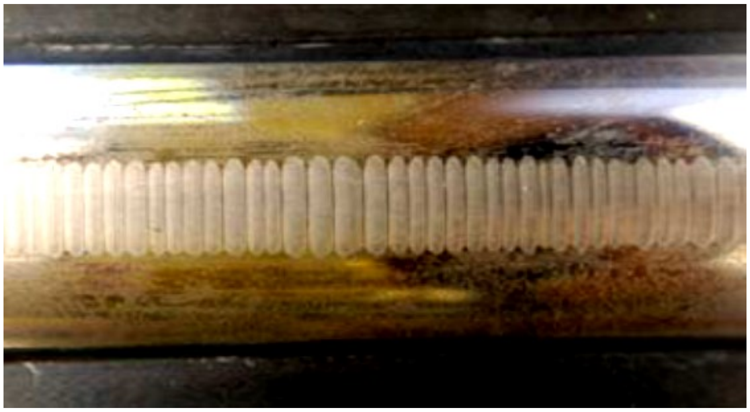


Figure A: Ripple formation on bearing race caused by voltage passing through bearing (fluting)

Electrical insulation of the bearings is a common practice, but is not always sufficient. Shaft grounding with carbon brushes helps to protect components by grounding out the majority of the voltage/current before making contact. This grounding is typically achieved by two brushes being mounted in a 90° angle on the shaft as seen in the images below. Varying grades may be recommended based on the operating conditions and the turbine manufacturer or a trusted carbon brush manufacturer can help with choosing the proper grade for the conditions.

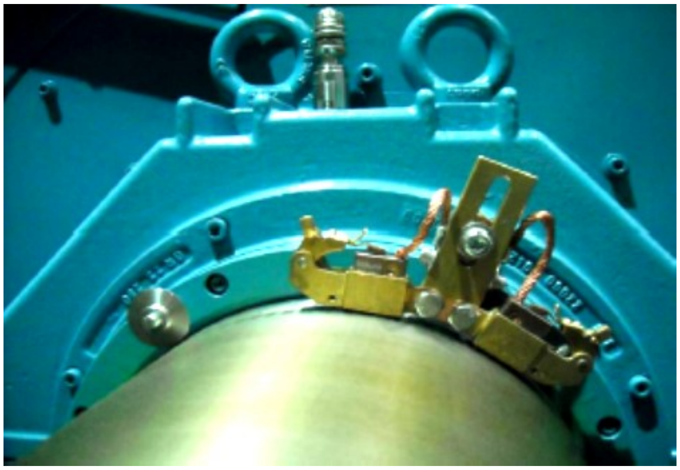


Figure B: Example of Main Shaft Grounding

©American Wind Energy Association 2013

Introduction
(continued)

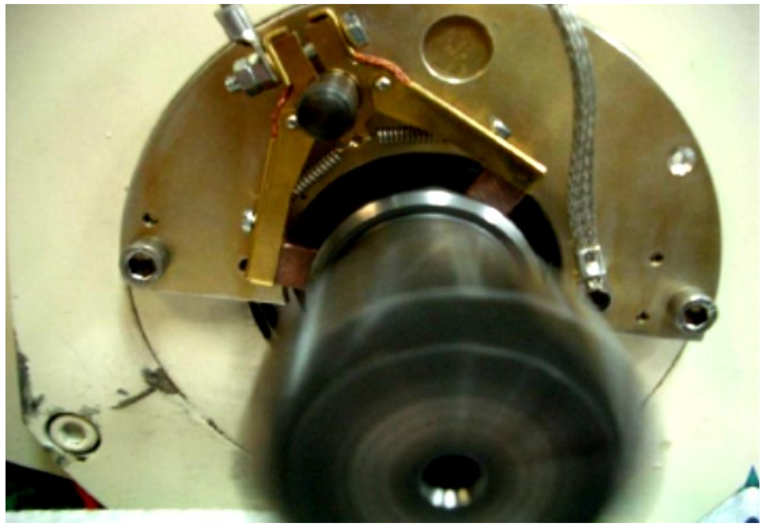


Figure C: Example of Generator Shaft Grounding

Shaft Grounding Maintenance Procedures

1. Inspecting The Assembly

Remove the shaft cover if one exists. View the general condition of the assembly. Note any build-up of residue, leaking gaskets, broken or missing components, etc. It is always good to document the “as found” condition of the brush and assembly with an image.

1.1. Brushes

1.1.1. Removal

To remove the brush from most designs, pull back the spring loaded holder arm and loosen any connections to the holder assembly. Other styles of tension devices may in use. Consult the manufacturer’s specifications for a specific generator design. Pull the brush out of its holder by its cables without disconnecting it. Note the orientation of the brush to the holder to ensure the brush will properly be reinstalled if it is not to be replaced.

©American Wind Energy Association 2013

1.1.2. Brush Body

Inspect the brush for minimum length requirement, any unusual wear-marks and free movement of the brush in the holder noting any restriction that maybe a sign of material swelling.

NOTE: This should also be a regular test for lightning protection brushes.

Inspect for chipping or cracking. Assure that the terminals are secure and that shunts, micro switch tabs, etc. and rivet connection, if applicable, are in good working order and properly mounted and connected.

1.1.3. Shunt Wires

Discolored shunt wires can indicate overheating or extreme current discharges. It is recommended to replace the complete brush set, because single brushes can already be damaged. If the shunts are damaged or frayed by vibration or mechanical problems they should also be replaced and the condition corrected. Note any abnormal wear indicators. Verify terminal connections are secure on all brushes. Additionally, shunt wires should still be pliable when moving, if the shunt wires are rigid they are susceptible to damage causing reduction in conductivity and the brushes should be changed.

1.1.4. Brush Surface

Rough brush face surfaces may be cause by brush sparking from electrical or mechanical problems.

Rule of thumb: If one of the brushes has to be replaced and the set is worn more than 25%, all the brushes should be re placed. If all brushes are to be replaced, disconnect them and re move them from the assembly. Loosen the terminal bolts until the brush terminal can be slid out from under it. If possible, do not fully remove the bolt to avoid dropping it and other hardware into the assembly.

1.2. Brush Holder

1.2.1. Holder Box

Inspect entire holder for any indications of arching or burning damage. Verify that all hardware and electrical connections are secure. Note any abnormal wear indicators.

©American Wind Energy Association 2013

1.2.2. Springs

Inspect tension devices for any indications of arching, burning or discoloration. The spring force should be checked every year with an appropriate spring scale device and springs should be replaced every 3 to 5 years depending on type of application. Springs with a deviation of more than 10% from the set value should be replaced.

1.2.3. Holder Distance

For a safe guidance of the brushes in the brush holder it is normally suggested that the distance between holder and shaft surface is no more than 3mm (0.125”).

1.3. Counter Surface

Inspect the shaft surface where the brush makes contact. There should be a film (or patina) of on the shaft. LEAVE THE FILM AS IS! This helps with the wear and connectivity of the brush to shaft surface. If oil or grease comes into contact with the counter surface, an insulating film can be formed which hampers the current transfer. Increased brush wear could be the consequence. The brushes are porous and, in case of oil contamination, all brushes should be replaced after the shaft surface is cleaned.

2. Cleaning and Reassembly

2.1. Cleaning the Shaft Surface

Typically the generator shaft is clean area of a generator, but carbon dust may build up over time in this area. For these cleaning procedures, it is suggested that appropriate personal protection devices be worn, including a dust mask.

Use a small vacuum, preferably with a HEPA type filtration system, and a synthetic brush to remove all accumulated dust and other contaminants from the shaft, the brush holder assemblies, and any areas where the dust may have collected below the shaft. Contact cleaner or other solvents should not be used directly on the brushes or the shaft surface. If it is necessary to use a solvent, spray the solvent on a disposable towel or cloth and use the cloth to wipe the solvent on the unclean area. Do not use solvents on carbon brushes because they could affect the carbon material. The surface film (or patina) should not be cleaned with a solvent. Always clean from the top down to avoid re-contaminating components.

©American Wind Energy Association 2013

2.2. Installing Brushes

To install new brushes or to reinstall brushes after inspection, insert the brush into the holder ensuring the proper orientation, then affix the brush back to its operating position. Connect new brushes and check that the connection is tight and the terminal is located correctly under the spring washer. As a final check to assure that the brush is free to move up and down in the brush holder and that the spring is correctly fitted, pull on the brush leads and lift the brush approximately 12mm (0.5") and then lower it back onto the shaft a few times. Assure that the bushes are oriented 90° to the shaft and that as much surface as possible is in contact with the shaft surface to avoid premature wear.

2.3. Seating New Brushes

In the event new brushes are manufactured with a bottom radius, seating may be needed to ensure the proper electrical continuity.

Garnet paper or any non-metal bearing abrasive paper is recommended and cloth backed abrasives are often easier to use in many circumstances. The abrasive size should be 80 to 120 grit. Fine sandpaper, such as 400 grit, will easily fill with carbon making the sanding process more difficult. It is important not to leave abrasive particles under the brushes when completed as these could damage the counter surface.

Seat one brush at a time while all the other brushes are still connected but out of their holders.

Lift the brush by its shunts and slide a strip of the abrasive cloth under it with the abrasive side of the paper facing the brush. Lower the brush down onto the abrasive cloth and place the spring in its normal engaged position. The spring should apply the pressure to the brush. Slide the garnet paper back and forth under the brush in line with the brush path. After several of passes back and forth, remove the brush from its holder and check the face of the brush. The seating is complete when at least 80% of the brush face is abraded. Vacuum out all the accumulated carbon dust and sanding debris and reinstall the brush

Once properly assembled, assure that all bolts are tightened and the brushes are properly connected.

©American Wind Energy Association 2013

2.3. Seating New Brushes
(continued)

Again, as a final check that the brush is free to move up and down in the brush holder and that the spring is correctly fitted, pull on the brush leads and lift the brush approximately 12mm (0.500”) and then lower it back on to the shaft a few times.

Also, make sure that all tools and cleaning materials are removed from the area and that any cover gaskets are functioning properly before re placing the cove if applicable.

Summary

This recommended practice is designed to identify basic procedures and techniques for maintaining the collector ring assemblies in double fed induction generators. Careful cleaning, maintenance and proper brush replacement, when required, will assure long, trouble fee service life for these critical components.

©American Wind Energy Association 2013

Operations and Maintenance Recommended Practices
Full Table of Contents

©American Wind Energy Association

Operations and Maintenance Recommended Practices
Full Table of Contents

American Wind Energy Association
1501 M St. NW, Suite 900
Washington, DC 20005
www.awea.org