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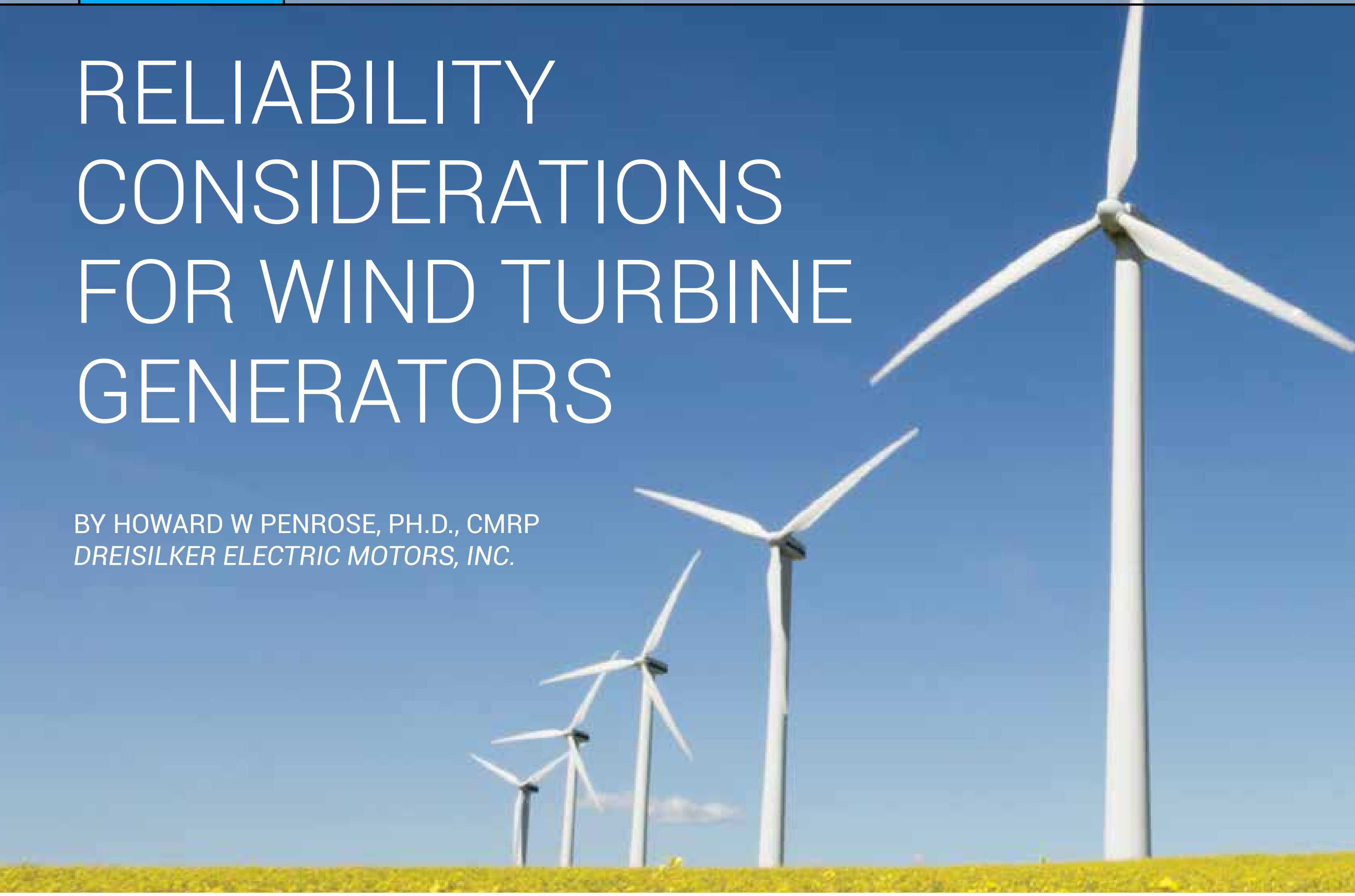

RELIABILITY CONSIDERATIONS FOR WIND TURBINE GENERATORS

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INTRODUCTION

The availability of wind generation systems has undergone significant changes over the past two decades. It was only five years ago that gearbox bearing issues remained in the top 5 of overall wind turbine system failure. Number one was and remains the large blades, while well down the list was the generator itself.

As recently as 2012, the Sandia National Labs CREW (Continuous Reliability Enhancement for Wind) program noted that the statistics have changed such that the generator is rated second behind the blades for failure and gearboxes have dropped significantly down the list. This is believed to be a combination of overall reliability improvements in gearbox manufacturing as well as improvements in bearings. The data, which is based upon a reporting from 37% of the wind fleet, identifies that generator bearings are the primary reason for failure, but that it is an assumption.[1]

At this time, there does not seem to be a significant amount of data on the number of electrical versus mechanical failures of the generator portion of the wind turbine system, nor is there specific information as to the failure rates based upon the type of generator – permanent magnet, DFIG (Doubly Fed Induction Generator) or induction system. However, a majority of the literature and work has been on the impact of the insulation system of the generator in this environment, which from an insulation system standpoint makes more sense.

In the systems that we have been exposed to both through the repair process as well as discussions and visits with other facilities, it appears that a significant number of failures actually relate to the insulation system. Exact statistics on this failure rate are not known at this time, but it has been noted that the types of failures are relatively similar and are more severe depending on climate. It is our belief that the insulation and related system failure is for a combination of reasons beginning with one primary assumption: the machines operate in a multi-dimensional movement space versus what is expected of most machines mounted in-place in a building or out of doors.

ELECTRICAL INSULATION SYSTEM PRIMARY OBSERVATION

One of the observations that has provided misleading root-cause-analysis of machines is the quick and easy identification of missing wedges in a slot and a failure that has occurred in that immediate area. Normally it will be a short to ground between the top edge of the stator winding and the core of the machine. This has also been noted in the literature [2],[3], with a great deal of effort being put into the manufacture and placement of magnetic wedges, primarily in induction and DFIG generator systems. However, as is usually the case, the obvious is not always the answer.

We performed as series of investigations across a number of manufacturers plus evaluated published results of generator failure investigations, which are rare. The primary reasons relate to the manufacturers keeping the failure information relatively close. The results are quite different than those published, when a full RCFA is performed.

PROCESS OF THE INVESTIGATION

Performed across induction and DFIG generators from several manufacturers, the first step was to throw all assumptions out the window. We started from scratch with a full PROACT®[4] analysis of the generators with our focus being on those machines which had stator insulation failures. We did note that there were a number of rotor failures in the DFIG machines, which is a separate topic.

Through the process we selected the failed coils to remove as well as the removal of coils in areas that were in relatively good shape. It was immediately identified that the machines, even at the points of failure, rarely had severe iron or winding damage. A majority of the failures to ground were almost pin-point faults with only a few showing any more significant damage. In machines that have a high level of energy, either in current or high voltage, the damage to the area around a ground fault tends to be fairly severe.

As Dreisilker does not use burnout ovens to remove coils but instead uses a warming method, it allows the forensics team to remove intact insulation systems from the electric machine for investigation. We pulled samples of several generators of different manufacture from both the failed coil and unfailed areas within the insulation system including areas that had missing wedges and others that did not. These samples were sectioned and put under a microscope as each layer of insulation was peeled back.

What we found in each system, regardless of voltage, was astounding, although somewhat expected. In large generators and electric motors, small pieces of iron or filings that enter into the machine as contamination will start to embed themselves into the insulation system. This effect is known as the 'magnetic termite' and is a direct result of a strange effect that occurs with magnetic materials in alternating current magnetic fields. The material will begin to spin and, in the case of small particles, will begin to burrow its way into the insulation system. Where this material gathers can be excess heating and, in the worst cases, a straight path between conductors and ground.

With standard electric machines of the sizes we see in large wind generators, from about 1400 kW to 2500 kW, failures between conductors tend to be more prevalent than the majority of failures we have found in wind generators, which are direct ground faults. These systems are also rated at above 480 Volts with 690 Volts being the most prevalent (systems to 12.4 kV are also present in the fleet), but carry higher current than standard electric machines.

As a result of the significant number of failures to ground where wedges have been forced out of the slot, there has been a general focus on the wedge materials and slot tightness. However, based upon the type of investigations we are performing, we approached the wedge failure as a symptom and not the root-cause. The end result of this string of the investigation was that the wedges came out of the slots and material collected in the slots of which some became magnetic termites. After some period of time, the termites would generate a path until the insulation system failed. In some instances, the wedge would wear against the insulation system until it became weak enough to short to ground.

As we are performing forensics, this information was valuable, but we needed to know why the wedges were coming out in some slots and not in others and, in some machines, would progress around the circumference of the machine.

During the stripping process a particular design had an insulation system with a very low ignition rate. Even though it was rated at 155oC, during the warming process it would ignite and generate significant smoke at 210oC, which is unusual as ignition normally does not happen in this type of insulation system until it approaches 340oC. As a result, the technicians 'cold stripped' it by warming the stator slightly in an oven and then removing the coils intact from the stator core. This should have been very difficult, but was instead relatively easy to perform.

A closer look was given to the coil insulation and varnishing systems used on the machines being investigated. It was quickly discovered that in a number of the designs the coils were relatively loose in the slots and relied upon a global vacuum pressure impregnation varnishing system to hold the coils in place with epoxy. The reason for this can be speculated as a method to install coils faster and then relying upon the epoxy system to 'glue' the coils in place. This method may work in a different environment, but the particular environment and forces that a wind generator is subject to are quite different.

FORCES AND CONDITIONS

A wind generator consists of a heavy module and blades mounted upon a tall tower. If the tower were rigid, it would snap or shatter during high gusts of wind. Therefore, they are made to be able to flex slightly and in high winds, the module at the top of the tower will see a significant amount of sway. This movement, much like that found on a seagoing vessel or mobile equipment, subjects the internal components to mechanical forces that far exceed those of a standard machine.

As an electric machine operates, the coils move towards and away from the center of the stator radially and there is a 'swaying' motion at the coil ends. The amount of radial force on the coil depends upon the loading of the machine and how tight the coils are in the slots. The force can be significant and blocking, wedges and side and wedge packing are used to hold the coil rigidly in the slots, limiting movement.

Thermal shock is of particular concern in a wind generator. While there are space heaters in the generator or system, they must be functioning and they must be sized correctly as the machine will come up to temperature relatively rapidly. As the machine changes temperature, the different components increase in size at different rates. This causes a shearing motion through the length of the slot and will eventually break down the bond between the coil, epoxy and generator core. In addition, the movement will eventually start to wear away the insulating materials and blocking, loosening the coil in the slot. The more severe the thermal swing, the less reliable the system will be.

CONCLUSIONS AND RECOMMENDATIONS

The overall mechanical system appears to be relatively sound in many DFIG and induction generator systems. However, based upon the thermo-mechanical dynamics of the system, additional work should still be performed in order to improve the reliability of these components, such as bearings.

In general, it was found that due to the operating conditions the winding systems in a wind generator, and the associated mechanical systems, must hold tighter tolerances. Insulation systems, including slot-packing systems, must be chosen in order to maintain tension between the coil and slot system regardless of the thermal changes. The overall mechanical system must be capable of withstanding the overall dynamic mechanical, electrical and thermal stresses inherent in the wind generation system.

[1] Peters, Valerie A., et.al., Continuous Reliability Enhancement for Wind (CREW) Database: Wind Plant Reliability Benchmark, Sandia National Laboratories, NM, 2012

[2] Alewine, K; Chen, W., "A Review of Electrical Winding Failures in Wind Turbine Generators," Proceedings of the 2011 Electrical Insulation Conference, pp. 392-397, Institute of Electrical and Electronics Engineers, Inc., 2011.

[3] Daneshi-Far, Z., et.al., "Review of Failures and Condition Monitoring in Wind Turbine Generators," Proceedings of the 2010 International Conference on Electric Machines, Institute of Electrical and Electronics Engineers, Inc., 2010

[4] PROACT®, Reliability Center, Inc., reliability.com, 2014.