PARTIAL DISCHARGE AS A CONCERN ON TURBINE-GENERATORS

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ABSTRACT

Partial discharge (PD) has been a concern on generators since engineers first began designing stator windings above about 4000 Vac shortly after the turn of the twentieth century. Efforts apparently have been made during this entire period to monitor and assess PD activity and damage to windings. However, during the last 25 years or so, the rate of assessment and monitoring activity has greatly accelerated.

This paper will consider several key topics relating to impact of electrical deterioration mechanisms on turbine-generator stator windings: Monitoring and Assessment of PD, Manifestations in the Slot and Endwindings, Inspection for electrical deterioration, Deterioration from PD, Deterioration from "Vibration Sparking", and Repair Options for Partial Discharge and Vibration Sparking.

MONITORING AND ASSESSMENT OF PARTIAL DISCHARGE

Many papers have been written both explaining the phenomenon of PD, and also documenting progress in monitoring and assessing signals generated by PD in generators.[1] All testing companies participating in the EPRI PD project have been able to make useful recommendations on the condition of generator stator windings.[2]

One company in the EPRI project has focused on reading the higher frequency ranges and has provided users with a relatively non-complex, user-friendly assessment package based partially on a very large data bank. At the other end of the spectrum, another company works in the lower, broader frequency ranges and is providing a system to display general condition of a generator stator winding as: normal, warning and alarm. If the warning light becomes lit, the PD outputs are collected and the owner is provided recommendations from the testing company headquarters engineering staff. Other PD testing companies are providing useful information using systems approaches lying in between these two companies. One additional company uses electromagnetic interference (EMI) measurement to assess PD in the stator winding and associated electrical components, including the excitation system.

Although not a perfect evaluation tool, PD/EMI monitoring/analysis is proving to be a valuable generator assessment tool. Of course, there are no perfect generator assessment tools. For example:

- Megohmmeter test is performed at low voltage.
- Power factor test gives highly questionable data on stator windings.
- Generator condition monitors (core monitor) have tended to give spurious signals.
- Stator winding hipot applies the same voltage to all bars in the phase and may fail a winding without warning.
- Visual inspection is limited to those areas that can actually be seen by the naked eye or with mirrors and scopes.
- Robot inspection is expensive and is likely to find problems that result in field removal, thus nulling its advantage.

It is important to keep in mind that PD alone cannot be relied upon to identify a problem/ solution on an operating generator. All available tools should be used in making any maintenance decision – inspection, test, unit history analysis, performance of similar generators, original equipment manufacturer (OEM) recommendations.

In the following section, several photographs of PD indications are shown. All of these indications would be expected to generate major signals on PD/EMI measuring systems. In some cases, an experienced individual looking at the signal output data would be able to suggest where the PD locations are likely to be.

MANIFESTATIONS OF PARTIAL DISCHARGE

Hydrogen-Cooled Generators.

Damaging PD activity does not seem to occur on hydrogen cooled generators – the inert, oxygen-free atmosphere significantly dampens the influence of PD on the insulating materials. Deposits may be seen at the line-to-line phase breaks in the endwinding, and on connection rings, but these deposits tend to be minor in nature. Also, it is not unusual to see local whitish deposits on the slot portion of bars removed from generators during rewind. But the impact on the groundwall appears to be negligible. (The hydrogen atmosphere also considerably reduces thermal and ambient deterioration rates on the groundwall insulation materials.)

Air-Cooled Generators – Endwindings

PD indications are common on air-cooled generator endwindings. PD is seen as extensive surface erosion, usually whitish in color. Photos 1, 2 & 3.

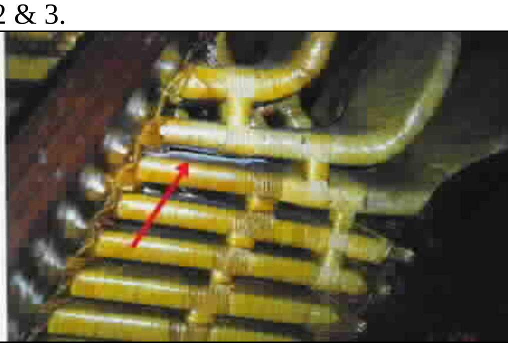

Photo 1. Damage to the Bar Surfaces due to PD at a Line-to-Line Phase Break.

Photo 2. Minor PD Indications at a Physically Very Close Line-to-Line Phase Break.

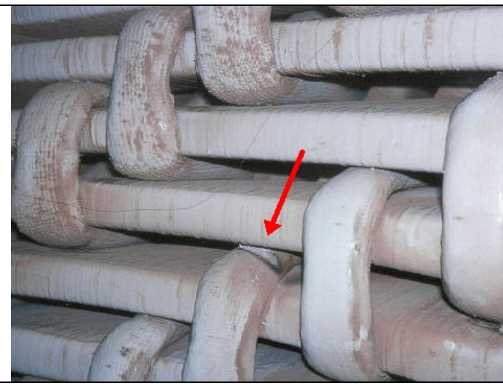

Photo 3. PD Indications Due to a Bar Tie Bridging a Line-to-Line Phase Spacing.

The actions of PD may also precipitate considerable amounts of a black semi-solid on oily generators; these deposits seem to be formed from bearing oil mist being transformed into a heavy, viscous state in the presence of a PD field. Photo 4.

Photo 4. Tar-like Substance Produced by Oil Mist in a PD Field.

PD may also attack the junction point between the endwinding voltage grading and the slot grounding system. Photo 5.

Photo 5. Arc Damage Due to Inadequate Contact Between End Arm Grading and Slot Grounding Paint/Tape.

On generators with non-mica insulation on the series and phase joints, PD may severely attack the non-mica materials at the high-voltage phase breaks. Photo 6.

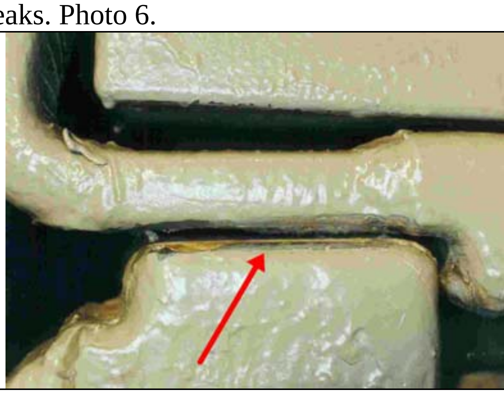

Photo 6. PD Indications on Non-Mica Insulation (Non-Mica Spacer Removed.)

A particularly difficult inspection point is the cross-over gap between top and bottom bars that are located in higher voltage portions of different phase belts. Photo 7.

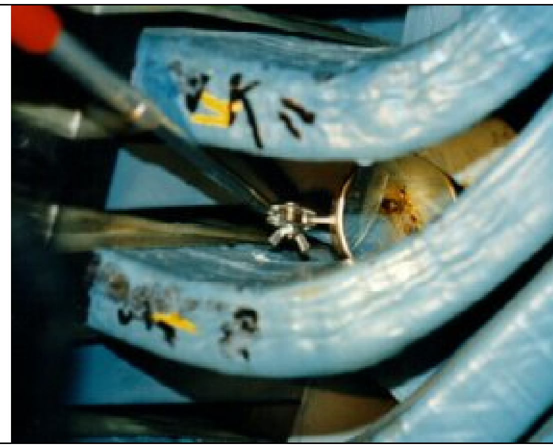

Photo 7. PD Indications Between Top and Bottom Bars Seen Through a Mirror

<u>Air-Cooled Generators – Slots</u>

The slot portion of the stator winding is difficult to inspect on all generators. On generators with ventilation spacer ducts, some access is available through these ducts. The PD on the bars in Photo 8 was found by inspection via borescope. These PD indications are obvious on the removed bars; however, while still in the slot the indications were difficult to detect through the distorted view of a borescope.

Photo 8. Bars After Removal from Slots Showing Significant PD Indications.

PD may also be observed at the ends of the slots, with strong suggestion that the PD carries on into the slot. Photo 9.

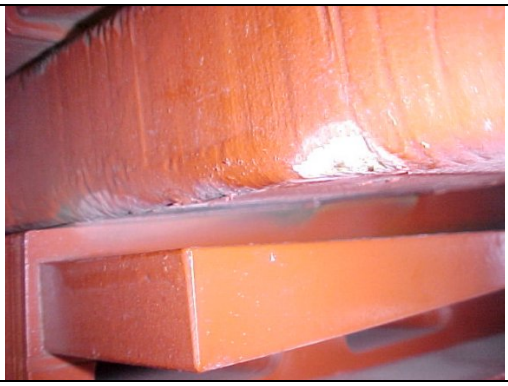

Photo 9 Significant PD Indications at Bar Exit from Slot.

On units with heavy step-back of the core iron at the ends of the core, wedges may be omitted in the last several inches of the slot. This design feature may expose the top bar surfaces and allow inspection for PD activity. Photo 10.

Photo 10. PD Indications on a Generator with large Step-back in the Core Iron.

Where PD is severe in the slots, the wedges may be attacked on those slots with top bars at the high-voltage portion of the phases. Photo 11.

Photo 11. Severe PD Attack of Stator Slot Wedges.

INSPECTION FOR PD

The photographs in the previous section, Manifestations of Partial Discharge, may suggest that PD is rather easily seen, although this is not always true. Without careful, thorough inspection, significant indications may easily be missed. Inspection for PD in the endwindings would focus on those areas of high electrical stress. Specific locations of interest on endwindings include:

- Line-to-line high-voltage phase breaks, Photos 1-3.
- Junction between end arm grading and slot grounding paint/tape, Photo 5.
- Non-mica insulation on phase breaks, Photo 6.
- Cross-over locations between higher-voltage top and bottom bars several inches outside the slot, Photo 7.
- Bar circumference at the slot exit, Photo 9.

The slot portion of the winding, because of access limitations, is more difficult to inspect than the endwinding. Unless the PD is sufficiently severe as to be eating the wedges away, Photo 11, or the ends of the slots do not have wedges, Photo 10, inspection is very difficult. On designs with core vent ducts, inspection can be made in the ducts with the use of a borescope. But great care must be taken to allow for borescope color, texture and dimension distortions. Furthermore, contaminants including vibration-generated dusts and grease, can seriously impact visibility. The PD shown in Photo 8 is clearly visible with the bars removed from the slot, but while still in place, the condition was not readily apparent except to someone who was patient and had considerable experience using a borescope.

If the inspection reveals a condition of PD at the end of the slot, Photo 9, PD in the slot may be suspected. But only removal of the bar can confirm the actual bar condition.

PARTIAL DISCHARGE vs. VIBRATION SPARKING

Partial Discharge

Partial discharge has been extensively studied for many, many years and is basically well understood. The phenomenon, which has been called “vibration sparking”, came into existence when hard stator bar insulation systems began to be used starting in the 1950s. The vibration-sparking phenomenon has apparently received little laboratory evaluation and is not at all well understood.

PD will occur only on the bars in the higher voltage portions of the winding – about the top 1/3rd of the phase. The source of energy is the voltage stress across the groundwall insulation. PD damages mica insulation at a very slow rate, and in the author’s experience, PD has not resulted in winding failure on a mica groundwall. PD will, however, cut rapidly through non-mica insulation systems in a few months or years, and has resulted in service failures.

Vibration Sparking

Vibration sparking has been mistaken for PD and the surface appearances may be difficult to distinguish. But vibration sparking can occur in the slots at random anywhere in the phase belt. Thus vibration sparking can occur in locations where there can be no PD energy, e.g., the neutral bars, whereas PD can only occur on higher voltage bars.

It is suspected that some reported cases of PD cutting into the groundwall insulation were actually the actions of vibration sparking. The activity shown in Photo 12 was found to be occurring independent of the location of the bars in the phase belt, and therefore could not be PD.

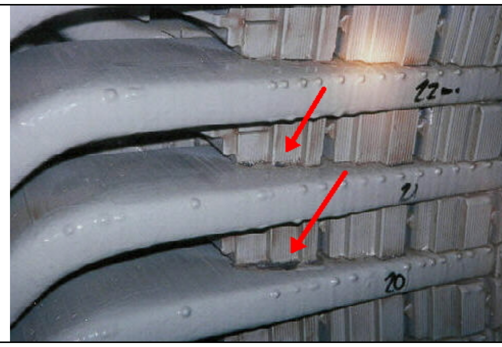

Photo 12. Random Attack of Stator Bar Insulation in the Slots.

The energy source for vibration sparking appears to be the voltage of the air-gap flux. The flux that generates the voltage in the bar copper (typically about 50 volts/foot of slot length) also generates the same voltage in the bar surface grounding paint/tape. This voltage then generates a small current flow in the circuit consisting of the bar grounding paint/tape and the stator core iron. If the bar is allowed to vibrate, the normal current flowing in this electrical circuit is interrupted at 120 Hz (60 Hz generators). The resulting spark energy can mechanically cut (etch) the groundwall insulation at an unacceptable high rate, and has failed mica insulation systems in less than three years of service.

SIGNIFICANCE OF OBSERVED DETERIORATION

PD can look very serious on the bar outer surface, the bare bar, and in delamination locations within the groundwall. But regardless of how serious the activity may appear, PD in the author’s experience has not cut deeper than partially through the first layer of mica tape. This is not to say that PD is not harmful to a mica insulation system, but even high energy PD may not cut through mica insulation even after 50 years of service. Vibration sparking, on the other hand, can cause service failure in a very few years of operation.

REPAIRS

Partial Discharge

Complete repair is probably not possible on significant PD that is occurring in the slots. Even on machines with radial ventilation ducts, only a portion of the surfaces can be coated. It is not possible to access all surface areas, and thus there will remain locations that have not been treated.

In the end winding access is much better, although many areas cannot be reached and treated. Perhaps light sanding and careful scraping can clean off some of the indications and the surfaces may be repainted, with semi-conducting paints as appropriate. Where PD is occurring on non-mica insulation at phase breaks, the non-mica insulation should be removed and replaced with mica tape/sheet.

Vibration Sparking (in the Slots)

On stators with core ventilation ducts, semi-conductive bonding resin can be injected alongside the bar, or a bead of semi-conducting silicone adhesive can be applied in the ducts to improve electrical contact between the bar surface and the core. Both approaches will tend to bond the bar to the core and stop vibration sparking. There is the concern that if bonded sufficiently well, the system may not adequately allow for differential expansions between the bars and the core. However, this is thought by some OEM engineers to not be a problem, and machines that have been bonded by either process have run satisfactorily for many years after the applications.

CONCLUSIONS

Partial discharge has been and continues to be a major concern on high voltage generator stators, and particularly so on those generators that are air-cooled. Every reasonable precaution should be made by OEMs and users to minimize the extent of PD within the generator.

It is highly desirable to monitor stator PD levels for two reasons:

- First, as a method of directly assessing the amount of PD activity in a stator winding, and
- Second, as a way to detect other forms of winding deterioration that result in increased PD levels.

In the latter category are deterioration mechanisms such as bar vibration, certain failing connections, contamination, and over-heating damage.

But in diagnosing generator deterioration and failure, it is important to recognize that there are two mechanisms that may give similar physical manifestations, i.e., partial discharge and vibration sparking. The appropriate corrective actions may be very different for the two different mechanisms.

This paper has considered several key topics relating to PD on turbine-generator stator windings. Successful generator operation and maintenance is related to how well owner and service personnel recognize and allow for the degradation mechanisms of PD and vibration sparking.

REFERENCES

1. Nelson, J. Keith. "Assessment of Partial Discharge and Electromagnetic Interference On-Line Testing of Turbine-Driven Generator Stator Winding Insulation Systems". EPRI Report #1007742, August 2003.

2. Maughan, Clyde V. "Partial Discharge On-Line Testing of Turbine-Driven Generator Stator Windings – A Guide for the use of Partial Discharge in Assessing the Condition of Generator Stator Windings". EPRI Report #1001209, December 2000.