WHAT CAN GO WRONG DURING STATOR COIL PARTIAL DISCHARGE MEASUREMENTS ACCORDING TO IEC 60270?

Paper No. AM-33

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Abstract - The available literature on partial discharge (PD) analysis suggests that measurements should be performed at higher frequency bandwidth than the conventional IEC 60270 methods, to enhance capability for detection of stator coil defects. In an energized test object, electrical disturbances or noise can strongly influence the observed PD magnitude. Spurious PD could be due to proximate sparking of imperfectly earthed objects, loose connections in the area of the high voltage, electromagnetic radiation, contact noise, broadband noise or loosely applied slot simulating earthing fixtures. Various international standards recommend adjustment of frequency bandwidth to acquire genuine PD signals by enhancing the signal-to-noise ratio. IEEE Std. 1434-2000, suggests an acquisition frequency of 2 MHz with adjustable bandwidth.

Once an appropriate data acquisition bandwidth is established, the recommended approach to determine expectations for PD magnitudes on new factory windings is to compare PD magnitudes with the machine manufacturer's historical distribution, developed for windings with similar geometry, voltage rating and insulation system construction. This will be more meaningful than attempting to establish an absolute limit based on voltage rating.

Index Terms — Partial discharge, frequency bandwidth, noise, stator coil, insulation system.

I. INTRODUCTION

Partial discharge (PD) measuring technique has been used for many years to assess or monitor the condition of insulation systems used in medium to high voltage rotating machines. In recent years, PD testing is rapidly becoming an industry practice to acquire quality assurance (QA) data for newly installed stator winding insulation systems. Majority of OEMs establish their own database for benchmarking and to determine performance of their normal production range using PD technique. PD, which is also known as corona discharge occurs in air or gap are small electrical sparks. These discharges are initiated in degraded or poorly manufactured motor stator-winding insulation, typically of rated 3300 V and above [1-2].

Partial discharges (PDs) are well defined in IEEE & IEC standards. As an example PDs are defined in IEC 60270 as: "localized electrical discharges that only partially bridges the insulation between conductors and which can or cannot occur adjacent to a conductor. PDs are in general a consequence of local electrical stress concentrations in the insulation or on the surface of the insulation. Generally, such discharges appear as pulses having a duration of much less than 1 μs" [3].

Review of literature recommend that for PD test method, a higher frequency range than the conventional 30 kHz to 400 kHz is more appropriate for detection of groundwall defects such as internal voids [4-5]. The advantage of high frequency measurements over lower frequency (<1 MHz) is that the response to external discharges on the end arms is reduced, rendering the system preferentially sensitive to PD in internal voids and de-laminations [6].

The other benefit of using higher frequency measurements is to ensure that the noise level produced by the complete test circuit does not influence the measurement of PD. Depending on the environment; the maximum allowable noise level at the test voltage can be as high as 100 pC [7]. When the test object is energized, the sources of disturbances or noise could be due to sparking of imperfectly earthed objects in the vicinity, by loose connection in the area of the high voltage, electromagnetic radiations, contact noise, broadband noise [3][8] or loosely applied slot simulating dummy plates. To avoid this disturbance adjustment of frequency band is recommended to acquire true PD signals.

According to IEEE Std. 1434, for 100–10,000 pF coupling capacitor and appropriate inductive matching unit, the recommended frequency range is 10–300 kHz; however, due to sensitivity of PD to the external noise a choice to use 2 MHz adjustable bandwidth [9] or as recommended in [10] the range can be extended up to 3 MHz. This will increase the signal to noise ratio (SNR) and assist the acquisition of actual PD signals using various instrumentations.

As there is no recommended PD magnitude in any IEEE or IEC standards; therefore, vast majority of OEMs establish their own database for benchmarking and to determine their normal production range [9-10]. The absolute limits on the PD magnitudes are not possible for new windings due to settling-in period. Therefore, the winding manufacturer can compare a new winding's Qm with other similar windings that they have made in the past [10]. If the mean and standard deviation of these other similar windings has been calculated, it is reasonable for an end user to request that a new machine to fall within the historical distribution.

II. PD MEASUREMENT TEST SETUP AND CONDITIONS

A. *Instrumentation for PD Measurements*

The Instrumentation used for PD measurements was in accordance to IEC 60270 [3]. The frequency bandwidth or range used for measurements was 40 kHz to 800 kHz. Both the largest repeatedly occurring PD magnitude and the apparent charge with repetition rate of 10 pulses per second (pps) were recorded. Prior to perform PD measurements in different environment, PD instrument was calibrated for each case identified in Section C. The calibration impulse generator allowed the calibration of the PD measurement according to IEC 60270 [3]. The coupling capacitor used with the PD instrumentation was 1 nF.

B. Selection of Sample Coil

To complete the PD measurements under various environments, form-wound coils with a voltage rating of 13.8-kV were manufactured using epoxy coated mica paper. The slot sections were press-cured after forming the coils and the endwinding insulation was cured later in an oven. All coils had identical conductor, turn, and main insulations. A layer of semi-conducting tape with a specific lapping was applied to the straight section of each coil leg. A layer of a grading tape was then applied to the overhang portion of each coil and overlapped onto the semi-conducting tape for a specific length. Dummy slot platens, to simulate the stator core slot section, were attached to the straight section of each leg of the test coils. Fig. 1 shows a sample coil.

PD measurements were performed both at V(L-G) and 120%V(L-G). To understand the effect of samples conditioning, measurements were done before and after exposing the coils to 120%V(L-G) for a certain period.

Fig. 1: A sample coil.

C. Influence of Environment

To understand the influence of environment, PD measurements were compared on sample coils under various conditions. The main objective was to impose different sources of electrical noise. Following test conditions were used during the measurement process:

1) Noise Free Environment (Inside Faraday Cage):

a) Standard baseline data was collected by performing PD measurements inside a Faraday cage. By using appropriate torque force, the grounding plates applied on the sample coils were then rested on the top of insulating blocks. The main purpose was to keep the coil overhang sections away from the surface of the test bench (see Fig. 1) or from any other ground reference in the vicinity.

b) To simulate the effect of sharp points, copper wire protruding at the coil leads was demonstrated. This was achieved by partially unraveling the ends of the copper wire that can be used to connect the coil leads. Fig. 2 shows an example of wire protruding at the coil leads.

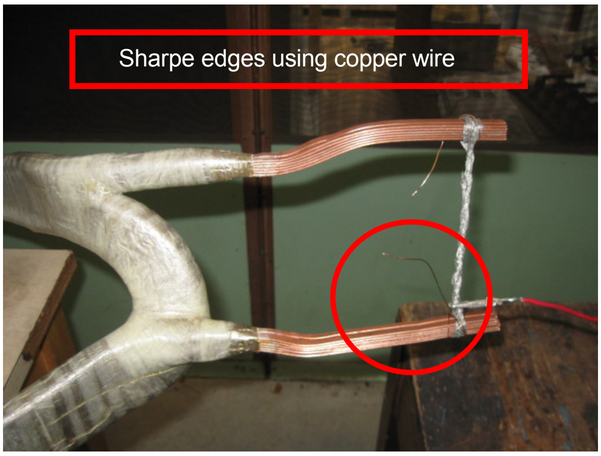

Fig. 2: Wire protruding at the sample coil leads.

c) As mentioned in Section (a), the inappropriate location of insulating blocks may affect the PD measurements. To demonstrate the influence of insulating blocks, they were moved from the bottom of the aluminum plates to underneath the coil grading section, as demonstrated in Fig. 4.

d) To reduce the clearance between test bench and coil endarms, the support blocks were removed from underneath the grounding plates. This setup can be found in Fig. 3.

Fig 3: PD test setup without insulating blocks.

e) Effect of higher torque force on grounding plates may result variation in PD measurements. The sample coils were lifted up to their original position using same insulating blocks. The torque value on the grounding plate bolts was increased to 25 lb-in and the PD measurements were then performed.

f) Effect of loose grounding plates was also studied. The sample coils while placed on top of the insulating blocks, had the torque on the grounding plate bolts reduced to 5 lb-in prior to perform PD measurements.

2) Effect of External Noise (PD Measurements Outside Faraday Cage):

a) In laboratory environment the fluorescent lights were turned off close to the test location and PD data was taken. The lights were then turned on to repeat the PD measurements for comparison.

Fig 4: Insulating blocks under stress grading region.

b) In this step, with lights on, the power resistor used for the thermal cycling test was energized and the PD measurements were performed. Thermal cycling test samples can be heated by circulating direct current through its turns. Electric machine stator coils are commonly low impedance components. To increase the total impedance of the thermal cycling test object, the sample coils are connected in series, which consequently lower the current source required to heat it up during the test. For some specific designs, connecting the coil in series does not result in sufficient increase of the test object impedance. To further increase the impedance, a power resistor can be connected in series with the stator coils. The cooling system of the power resistor used in this experiment contains a fan which may be a potential source of external noise for the PD measurements.

c) After turning off the power resistor and maintaining the lights on, the surge tester used for stator coil inter-turn testing was energized and PD measurements were completed. The surge testing produces steep-front voltage waveforms having a rise time of 0.1 to 0.2 µs as defined in IEEE Std. 522, and IEC 60034-15 [12-13]. A sample waveform is shown in Fig. 6.

d) Finally, the laboratory environment control system was studied with reference to its influence on low range frequency PD measurements.

II. RESULTS AND DISCUSSION

A. PD Measurements in a Noise Free Environment (Inside Faraday Cage):

All PD measurements performed inside the Faraday cage did not show much variation and the results were comparable to the baseline. Additional tests inside the noise free environment are planned and will be published somewhere else. Voltage levels higher than the120%V(L-G) will be considered for future trials to observe any changes in the measurements.

In a noise free environment the effect of loose grounding plates was studied by reducing the torque on the bolts to 5 lb-in prior to perform any PD measurements. The loose plate didn't show any influence on the measured low frequency PD. This suggest that the sample coil slot corona suppression system had a sufficient contact with the grounding plates, which did not show any variation in the PD measurements up to 120%V(L-G) voltages.

B. Positioning of Insulating Blocks

The inappropriate location of insulating blocks can somewhat affects the PD measurements. To demonstrate the influence of insulating blocks they were moved from the bottom of the aluminum plates to underneath the coil stress grading section. PD data was compared to the baseline that was taken inside the Faraday cage to determine any change. Considerable change in the PD magnitude was observed. Peak PD magnitude increased from pC to several hundred (nC). The presence of insulating blocks in the stress grading region initiated discharge activities with higher magnitudes. Fig. 7 shows peak magnitude for PD in the range of 2.4 nC.

Fig 5: Thermal cycling cell power resistor for controlling current.

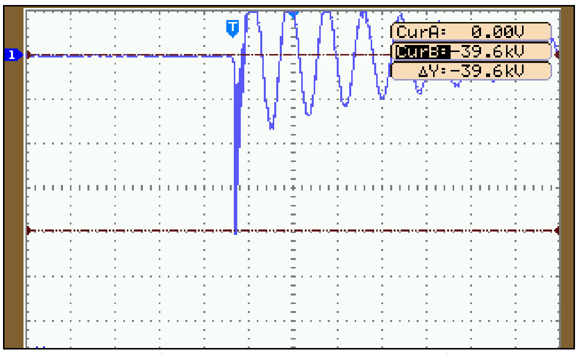

Fig. 6: Sample surge voltage waveform.

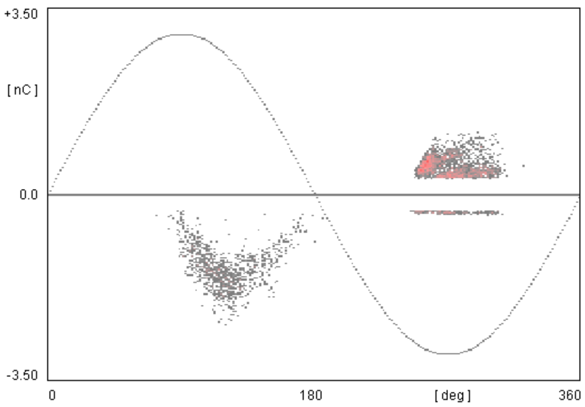

Fig. 7: PD plot with insulating block under stress control region.

C. PD Measurements Outside in the Presence of Fluorescent Lights

Outside the Faraday cage, the preliminary PD measurements acquired with the fluorescent lights turned on in the vicinity of the test setup exhibited similar pattern to those obtained with the lights off. These measurements were also compared with the PD data acquired inside the Faraday cage. All results were found to be comparable.

D. Effect of Transient Voltages (Surge Tester)

After PD instrument calibration, the surge tester was energized at high peak voltages. A dummy coil was connected to the tester to demonstrate turn-to-turn testing using a single shot mode. A very high magnitude of PD was recorded prior to even energizing the test sample. The switching operation of surge tester developed high level of noise due to which the low frequency PD measurements were not possible. The maximum PD magnitude observed was up to 27.6 nC (see Fig. 8). Due to presence of such high level noise the PD measurements on a sample coil was aborted.

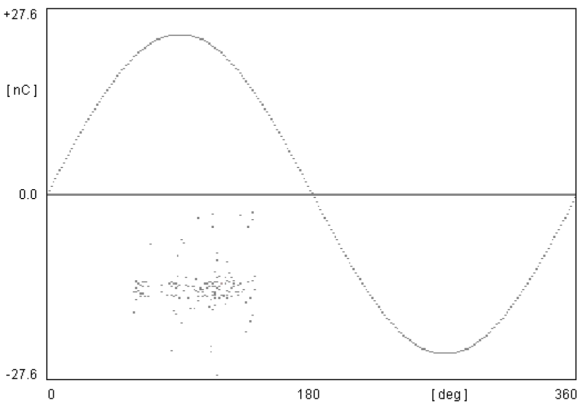

Fig. 8: PD plot with energized surge tester.

E. Thermal Cycling Power Resistor

The power resistor used for the thermal cycling test was energized and the PD measurements were performed at V(L-G) and 120%V(L-G) with and without conditioning. In the presence of power resistor the PD magnitude at 10 pps was not possible to extract from the two-dimensional plot; however, the peak PD magnitude was comparable with the baseline data.

F. Influence of Environmental Control System

A manufacturing test facility where typical environmental control system that periodically exchanges the air inside the building was selected. Several PD measurements were performed while the system was either on or off. The maximum PD magnitudes and the recorded apparent charge at 10 pps were observed to be almost doubled compared to the baseline data. Repeatable PD data was recorded in the absence or during the presence of noise produced by the air exchanger. Such influence was not noticed when the measurements were completed in a higher frequency bandwidth. This suggests that the noise produced were in the range of kHz.

PD measurements completed under various conditions are also summarized in Table 1.

TABLE I
SUMMARY OF PD MEASUREMENTS

Test #	Condition Present	PD Data Comparison
1	Noise Free – In Faraday Cage (IFC), standard test	Baseline
2	Sharpe edges (IFC)	Comparable with baseline
3	Insulating blocks under stress grading region (IFC)	Very high activity
4	Fluorescent lights ON – outside Faraday cage (OFC)	Comparable with baseline
5	Fluorescent lights OFF – OFC	Comparable with baseline
6	Surge tester transient voltage – OFC	Very High activity
7	TC power resistor	Comparable with baseline
8	Air exchange system	Activity doubled compared to baseline

III. CONCLUSIONS

From the results presented in the previous sections on 13.8-kV stator coils, the following conclusions can be made:

- Comparable PD results were achieved when tests were completed in a noise free environment.
- Large variation in PD data was noticed in the presence of surge tester, air exchanger or due to inappropriate location of insulating blocks.
- As some of the environmental conditions can influence the PD measurements; therefore, it will be difficult to recommend an absolute value for PD magnitude. As an alternative, the best approach will be to establish a database for benchmarking and to determine their normal production range.
- Additionally, the absolute limits on the PD magnitudes are not possible for new insulation due to their settling-in period. Therefore, the motor manufacturer can compare the associated Qm level for new insulation system with other similar systems that they have made in the past.
- Based on the analysis, it is reasonable for an end user to request that a new machine stator coils or winding to fall within the historical distribution.

IV. ACKNOWLEDGEMENTS

The authors would like to thank GE Peterborough Engineering Laboratory team for performing offline PD measurements under various conditions. Thanks are also due to customer witness for their valuable comments.

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V. VITA

Saeed Ul Haq (M’00) received his B.Sc. degree in Electrical Engineering from UET, Peshawar, Pakistan, in 1991, M.A.Sc. degree from the University of Windsor, Windsor, ON, Canada, in 2001, and his Ph.D. degree from the University of Waterloo, Waterloo, ON, in 2007. During his Ph.D. program, his main research interest was to study the insulation problems in drive-fed medium-voltage motors. Dr. Haq is a registered Professional Engineer in the Province of Ontario, Canada. In the past, he was involved in extensive volunteer work for the IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP) and International Symposium on Electrical Insulation. In 2007, he joined the GE Large Motors & Generators Technology team at Peterborough, Ontario, Canada, as an Insulation Engineer. His area of interest is in the development of insulation systems for large rotating electric machine.

Luis H. A. Teran received his Electrical Engineering degree from State University of Campinas (UNICAMP), São Paulo, Brazil, in 2008. He joined General Electric (GE) motors in Campinas, São Paulo, Brazil in 2007, through the company’s internship program, and the following year was recruited as a Technology Project Engineer. In 2012, Luis joined the Global Technology team for GE Power Conversion as an Insulation Engineer, focusing on electrical insulation system improvements and development of new materials for rotating electric machines. Luis has co-authored papers for IEEE-PCIC and PCIC Brazil.

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