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Classification of partial discharge sources in mica-epoxy-glass insulation sample using statistical analysis

Ramesh P Nair*, Sumangala B V** and Chandrashekhar D Keri***

Partial Discharge (PD) in rotating machine insulation system is deleterious. Even though the main insulation of rotating machine is Mica, which is highly PD resistant, the discharges taking place in slot region and end windings are highly deteriorating to insulation system. In this paper, PD measurements are taken in Mica-Epoxy-Glass insulation sample using cylindrical-plane electrode system. The sample contains a defined void on the surface. Distinguished Phase Resolved Partial Discharge (PRPD) patterns are obtained for different location of void. The different PRPD patterns obtained corresponds to internal void in the bulk of insulation, void between high voltage electrode and insulation surface, void between ground electrode and insulation surface; and surface discharge. The PRPD patterns obtained from void between high voltage electrode and insulation surface, in the actual scenario, indicates PD originating near the conductor surface inside the insulation system of rotating machines. The PRPD patterns obtained from void between ground electrode and insulation surface indicates PD originating on the surface of insulation such as slot discharge, end winding discharge in rotating machine insulation system. The variation of PD parameters like Charge magnitude (q) with respect to applied voltage is shown for different location of void. Further statistical parameters like skewness and kurtosis are calculated for charge distribution (n-q) and phase distribution (n-Φ) for different PRPD patterns. It is inferred that statistical analysis of PD parameters is a good tool to classify of partial discharge sources.

Keyword: *Stator Insulation, slot discharge, surface discharge, skewness and kurtosis.*

1.0 INTRODUCTION

Unexpected failure of rotating machines used by the utilities will result in production loss due to forced outages. It has a greater impact on national economy. These production losses can be sometime very high even compared to the machine cost. Thus it is important to avoid such unexpected failure of vital machines, which is possible through condition monitoring. By monitoring the healthiness of these machines, the utility personnel can arrange planned shutdown of in-service machine for maintenance purpose or to repair/replace the critical machines, if required.

Majority of the machine failures are the result of insulation breakdown, hence insulation is considered as the weakest link [1]. In high voltage rotating machines, stator insulation system is a composite type. The main insulation is Mica, which has very good electrical properties but due to poor mechanical strength a backing material is used like glass fibers. These two materials are bonded together using epoxy resin. Hence the composite insulation of rotating machine is made of mica-epoxy-glass. If the bonding is not adequate, voids may occur in insulation system which leads to partial discharge.

*Senior Research Fellow, Cables and Diagnostics Division, Central Power Research Institute, Bengaluru - 560080, India
**Professor Dr. Ambedkar Institute of Technology, Department of EEE, Bengaluru - 560056, India
***Scientific officer, Cables and Diagnostics Division, Central Power Research Institute, Bengaluru - 560080, India

Partial discharges (PD) are localized electrical discharge that only partially bridges the insulation between conductors and which can or cannot occur adjacent to a conductor [2]. Partial discharges are both a cause and a symptom of many deterioration processes. Mainly there are three types of PD occurring in stator insulation system - i) Internal discharges that occur in voids present in the bulk volume of the winding insulation. ii) Slot discharges that occur in the air gaps between the core laminations and adjacent coil sides in the slots. iii) End winding discharges that occur at the end winding portions due to degradation of stress grading material [3]. The internal discharges are considered less severe compared to slot and end winding discharges [4]. Many researches are still going on to discriminate different types of partial discharges. Some earlier researches have shown the possibility of correlating the aging process of insulation material with the frequency and shape of PD signals [5].

Each PD sources in rotating machine have distinct PD pattern. These patterns are referred to as Phase Resolved Partial Discharge (PRPD) pattern, where the PD pulses are superimposed on to the applied voltage cycle based on their occurrence at a particular phase angle of voltage cycle. Different PD sources in the insulation system have distinct PRPD pattern, which can be useful to classify the PD sources [6]. If the PD sources are known, depending on their severity of degradation to the insulation, necessary corrective measures can be taken to avoid in-future failures.

Many PD measurements have been carried out previously for different location of voids in the insulation sample and statistical parameters are analyzed to classify different sources [8-10]. However, they have not simulated surface discharges which are similar to that occurring in stator bars of rotating machines. Normally these discharges take place near the grounded core and insulation surface. These surface discharges along with other discharge sources in rotating machine are having distinct PRPD patterns. In this paper, distinct PRPD patterns are simulated for different location of voids in the insulation system, which are similar to the discharge locations in a Rotating Machine. Statistical analysis of PD parameter is done in order to classify different PD sources.

2.0 EXPERIMENTAL DETAILS

This section covers the details of experiment done, sample preparation, results and discussions.

2.1 Sample Preparation

Sample used for experiments is a muscovite mica-epoxy-glass insulation, commonly used insulation for rotating machines. It is available in the form of tape. The sample is prepared using a molding machine, where the insulation tape is hot pressed at 180°C for 30 min and cooled at room temperature. The sample thickness is 2 mm. Once the sample is prepared, a void/dent is introduced on the surface of sample. The sample used for experiment is shown in Figure 1.

2.2 PD Measurement Test Set-up

The PD measurements are taken using Omicron make MPD 540 digital PD detector. The source used is a 15 kV Phenix make PD free voltage source. PD free 1000 pF capacitor is used as a coupling device. The whole test arrangement is inside the Faradays' cage. The background noise was less than 5 pC. To conduct the PD measurement, a cylindrical-plane steel electrode arrangement is used. The test set-up is shown in Figure 2.

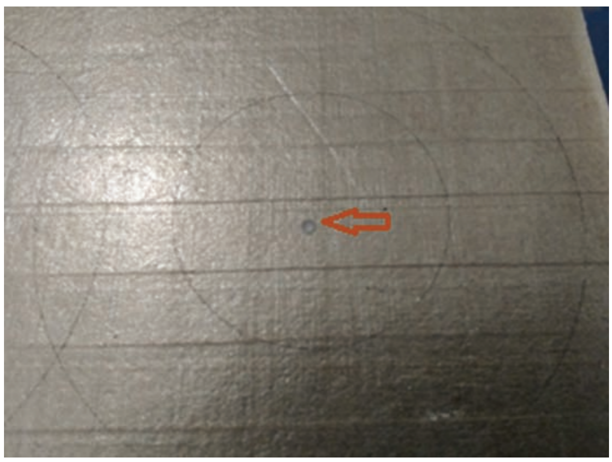

FIG. 1. SAMPLE USED FOR PD MEASUREMENT SHOWING VOID ON THE SURFACE

2.3 PD Measurements

The PD measurements are taken for different location of void in the insulation electrode arrangement. First measurement was taken in a similar aged insulation sample.

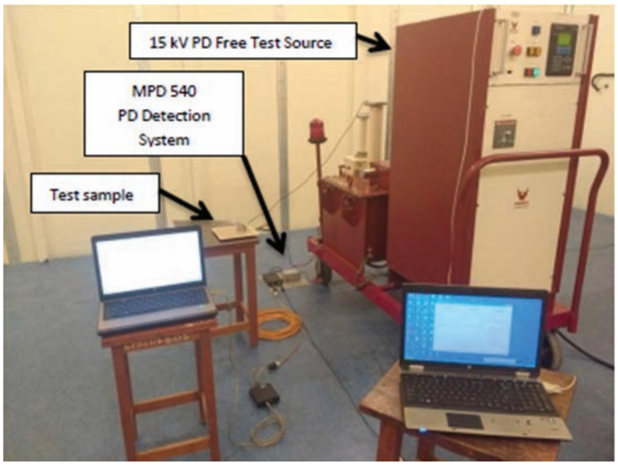

FIG. 2. PD MEASUREMENT TEST SET-UP

The discharge taking place in this sample corresponds to the internal discharge which is confirmed by the symmetric PRPD pattern obtained. Second measurement was taken, when the void in the surface of sample was facing the ground electrode. The discharge taking place in the void facing the grounded electrode is similar to the slot discharges taking place in the slot portion of rotating machines. Third measurement was taken, when the void in the surface of sample was facing the High Voltage (HV) electrode. The discharge taking place in the void facing the HV electrode is similar to the discharges in the stator bars, when there is a de-lamination of insulation layer near the copper conductor. Fourth measurement was taken for the surface discharges near the ground electrode.

3.0 STATISTICAL ANALYSIS OF PD PARAMETERS

To perform statistical analysis in-order to classify the discharge sources, a distribution is made using the PRPD pattern. To make a distribution, the voltage waveform is divided into several phase windows and the mean discharge magnitude as a function of corresponding phase angle $H_{qn}(\phi)$ is determined [8]. These distributions have distinct shapes that may vary with the discharge source and the shape of distribution in positive and negative half cycle of voltage waveform also may vary [9]. To describe the shape of distribution, two statistical operators are considered: skewness and kurtosis. Skewness represents asymmetry of distribution.

If distribution is symmetric, $S_k = 0$, if it is asymmetric to left, $S_k > 0$, and if asymmetric to the right, $S_k < 0$.

Skewness is given by,

$$S_k = \frac{\sum (x_i - \mu)^3 . p_i}{\sigma^3} \quad ...(1)$$

Where

x_i = Measured value;

p_i = Probability of frequency of appearance of that value of x_i = in window i;

μ = Mean Value;

σ = Variance

Kurtosis represents sharpness of distribution. If distribution has same sharpness as normal distribution, $K_u = 3$. If it is sharper than normal, $K_u > 3$ and if it is flatter than normal, $K_u < 3$. Kurtosis is given by,

$$K_u = \frac{\sum (x_i - \mu)^4 . p_i}{\sigma^4} \quad ...(2)$$

These operators are applied to the distributions $H^{+}_{qn}(\phi)$ for positive half cycle and $H^{-}_{qn}(\phi)$ for negative half cycle of voltage waveform, to classify different discharge sources [10].

4.0 RESULTS AND DISCUSSIONS

4.1 Internal Discharge

PD measurements are taken in an aged insulation sample. As the insulation ages the void content in the insulation increases, this gives rise to PD. The PRPD pattern for internal discharge is shown in Figure 3. Symmetric pattern indicates the presence of internal discharge [6]. The variation of average charge magnitude with rise in voltage is shown in the Figure 4.

It can be seen in the figure that the charge magnitude increases with increase in voltage, this shows that there are multiple voids in the bulk volume of sample.

4.2 Discharge in Void Facing Ground Electrode

PD measurement was taken, when the void in the surface of sample was facing the ground electrode. The PRPD pattern obtained is shown in Figure 5.

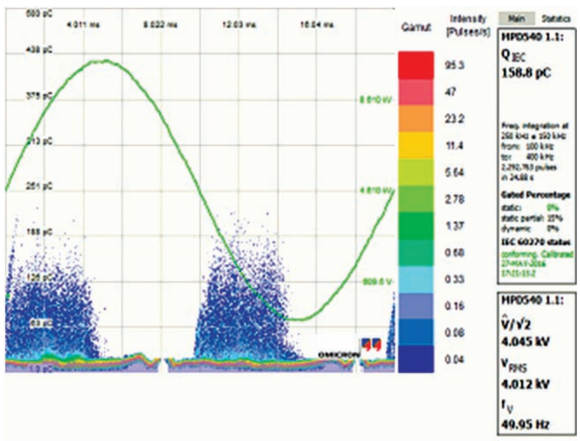

FIG. 3. PRPD PATTERN FOR INTERNAL DISCHARGE

The pattern is asymmetric for this type of discharge. Higher magnitude discharges can be seen in negative half cycle of voltage waveform [6-7]. These discharges are similar to slot

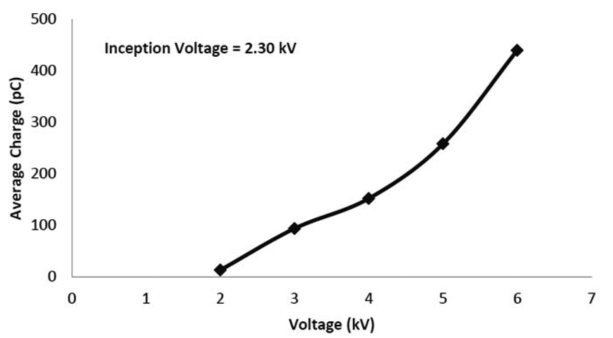

FIG. 4. VARIATION OF AVERAGE CHARGE MAGNITUDE WITH INCREASING VOLTAGE

discharges in rotating machine. The variation of average charge magnitude with rise in voltage in case of void in the surface of sample was facing the ground electrode is shown in the Figure 6.

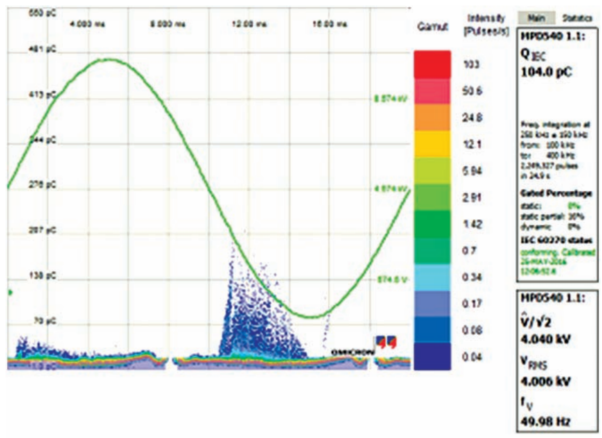

FIG. 5. PRPD PATTERN FOR DISCHARGE IN VOID FACING GROUNDED ELECTRODE

It can be seen in the Figure 6 that the charge magnitude does not vary with increase in voltage.

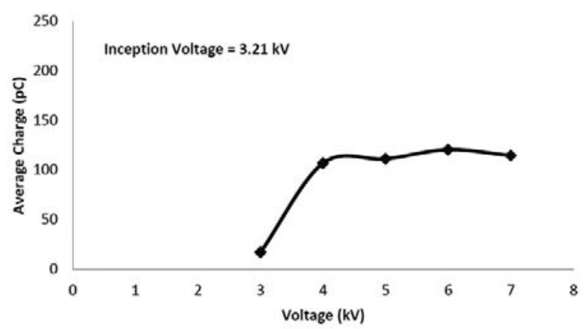

FIG. 6. VARIATION OF AVERAGE CHARGE MAGNITUDE WITH INCREASING VOLTAGE

4.3 Discharge in Void Facing HV electrode

PD measurement was taken, when the void in the surface of sample was facing the HV electrode. The PRPD pattern obtained is shown in Figure 7. The pattern is asymmetric. Higher magnitude discharges can be seen in positive half cycle of voltage waveform [6]. These discharges are similar to the discharges in the stator bars, when there is a de-lamination of insulation layer near the copper conductor.

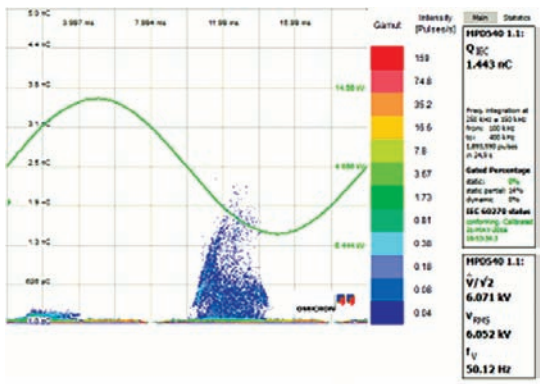

FIG. 7. PRPD PATTERN FOR DISCHARGE IN VOID FACING HV ELECTRODE

The variation of average charge magnitude with rise in voltage is shown in the Figure 8.

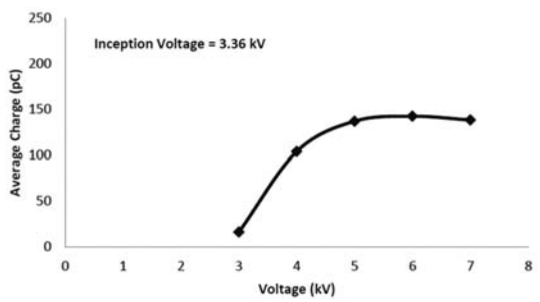

FIG. 8. VARIATION OF AVERAGE CHARGE MAGNITUDE WITH INCREASING VOLTAGE

It can be seen in the figure that in this case also, charge magnitude does not vary with increase in voltage.

4.4 Surface Discharge

PD measurement was taken for the surface discharges near the ground electrode. The PRPD pattern obtained is shown in Figure 9.

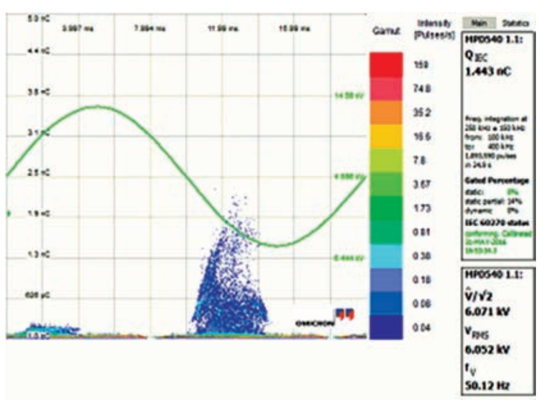

FIG 9. PRPD PATTERN FOR SURFACE DISCHARGE

The pattern is asymmetric for surface discharge. Higher magnitude discharges can be seen in negative half cycle of voltage waveform, compared to the positive half cycle [6]. These discharges are similar to surface discharges in rotating machine. The variation of average charge magnitude with rise in voltage is shown in the Figure 10.

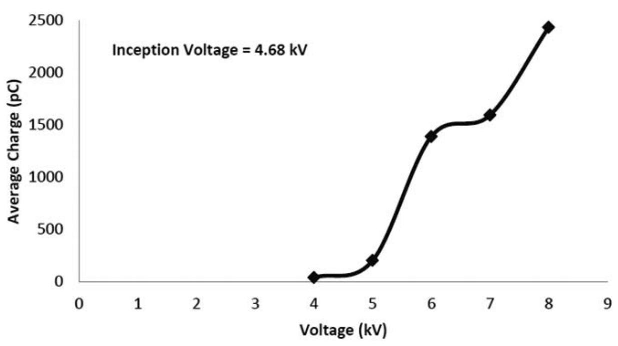

FIG. 10. VARIATION OF AVERAGE CHARGE MAGNITUDE WITH INCREASING VOLTAGE

It can be seen in the figure that the charge magnitude increases with increase in voltage.

4.5 Statistical Analysis

To classify different discharge sources, statistical analysis is used. The skewness and kurtosis of the mean charge height distribution $H_{qn}^{+}(\phi)$ in positive half cycle and $H_{qn}^{-}(\phi)$ in negative half cycle of voltage waveform are calculated. These parameters are shown in the Table 1.

TABLE 1
STATISTICAL ANALYSIS OF PD PARAMETERS

STATISTICAL PARAMETER		Discharge occurring at			
		Internal Void	Void facing Ground Electrode	void facing HV electrode	SURFACE
$H_{qn}^{-}(\phi)$	Skewness	5.3082	1.9132	3.8487	3.3130
	Kurtosis	70.7524	5.3291	38.9757	24.3541
$H_{qn}^{+}(\phi)$	Skewness	5.7409	3.3441	2.3454	28.4847
	Kurtosis	86.8745	36.3380	7.2326	1112.8

It can be observed from the results that the statistical parameters are different for different discharge sources. For internal discharges, the skewness of the distribution $H_{qn}^{-}(\phi)$ and $H_{qn}^{-}(\phi)$ are almost equal. For asymmetric discharges the skewness are different. Similarly, for internal discharge the kurtosis of distribution $H_{qn}^{+}(\phi)$ and $H_{qn}^{+}(\phi)$ are almost equal, while for asymmetric discharges the kurtosis values are different. For surface discharge, the kurtosis of distribution $H_{qn}^{-}(\phi)$ is very large due to the sharp increase in PD magnitude in negative half cycle.

5.0 CONCLUSION

In this paper an attempt is made to simulate partial discharge sources similar to the discharges in rotating machine. Distinct PRPD patterns are obtained for different discharge sources. The variation of discharge parameters with change in voltage magnitude is also distinct. These characteristics can be used for discharge source identification. Further a distribution was made using the PD patterns to classify the discharge sources. The statistical analysis of this distribution using operator skewness and kurtosis is a very good tool to classify the discharge source. These data can be used as a finger print to classify unknown discharge sources in the insulation system of rotating machines.

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REFERENCES

[1] G. C. Stone, “Condition monitoring and diagnostics of motor and stator windings-A review.” IEEE Trans. On Dielectrics and Electrical insulation, Vol. 20, No.6, pp. 2073-2080, 2013.

[2] High-voltage test techniques - Partial discharge measurements, International Standard, IEC 60270:2000(E), Third Edition, 2000-12

[3] K. Mallikarjunappa, S. N. Moorching, C. Viswanatha, “An overview on the estimation of life of high voltage AC machine insulation”. CBI&P 59th R&D Session, Calcutta, Feb. 1994.

[4] Mallikarjunappa, K.; Viswanatha, C.; Moorching, S.N., "Multi-factor ageing of stator coil insulation of HV machines and degree of correlation among non-destructive test parameters," Electrical Insulation and Dielectric Phenomena, 1993. Annual Report, Conference on, pp.562,567, 17-20 Oct 1993.

[5] S. Azizi-Ghannad, J. K. Nelson and M. Embrechts, "An investigation of chaotic behavior of PD activity in power generator insulation systems," Proceedings of 1995 Conference on Electrical Insulation and Dielectric Phenomena, Virginia Beach, VA, pp. 353-356, 1995.

[6] IEEE Guide for the Measurement of Partial Discharges in AC Electric Machinery," IEEE Std 1434-2014 (Revision of IEEE Std 1434-2000), pp.1-89, Dec. 4 2014.

[7] C. Hudon, M. Belec and M. Levesque, "Study of slot partial discharges in air-cooled generators," in IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 15, No. 6, pp. 1675-1690, December 2008.

[8] N. C. Sahoo, M. M. A. Salama and R. Bartnikas, "Trends in partial discharge pattern classification: a survey," in IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 12, No. 2, pp. 248-264, April 2005.

[9] F. H. Kreuger, E. Gulski and A. Krivda, "Classification of partial discharges," in IEEE Transactions on Electrical Insulation, Vol. 28, No. 6, pp. 917-931, Dec 1993.

[10] E. Gulski, ‘‘Discharge Pattern Recognition in High Voltage Equipment’’, IEE Proc.: Sci., Meas. Technol., Vol. 142, pp. 5161, 1995.