

# Measurement of Small PD'S in Compressed SF<sub>6</sub> (10%) - N<sub>2</sub>(90%) Gas Mixture

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**Abstract**—Partial Discharge measurement is a very important means of assessing the integrity of insulation systems in a High Voltage apparatus. In compressed gas insulation systems, floating particles can initiate partial discharge activities which adversely affect the working of insulation. Partial Discharges below the inception voltage also plays a crucial in damaging the integrity of insulation over a period of time. This paper discusses the effect of loose and fixed Copper and Nichrome wire particles on the PD characteristics in SF<sub>6</sub>-N<sub>2</sub> (10:90) gas mixtures at a pressure of 0.4MPa. The Partial Discharge statistical parameters and their correlation to the observed results are discussed.

**Keywords**—Gas Insulated transmission Line, Sulphur Hexa Fluoride, metallic Particles, Partial Discharge (PD), Inception Voltage (Vi), Extinction Voltage (Ve), PD Statistical parameters.

## I. INTRODUCTION

THE insulation properties of Gas Insulated Systems (GIS) are actually not only determined by their design, but also by the manufacturing quality. They are mainly influenced by the presence of metallic particles. Hence the effects of free moving particles have to be investigated through experiments by many researchers in order to understand the basics of the breakdown processes. It is a known fact that the insulation degradation occurs due to the partial discharges in the system [1-3]. But PD phenomena even below the so called inception voltage have serious implications on the performance of insulating systems and are attributed to the sudden breaking down in service [4]. It has also been indicated that below inception, there is a current that caused cavities in the polymer surface. The chemical changes similar to those that occur when the polymer insulation fails at or above PD inception levels [5]. The sudden failures of insulating systems have been explained to a certain extent by some authors. It is reported that random discharges occur below the inception [6].

In this paper, PD results of SF<sub>6</sub>-N<sub>2</sub> (10:90) gas mixtures and the corresponding statistical parameters around the inception level of clean duct and duct with loose wire particles are presented and discussed.

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## II. EXPERIMENTAL DETAILS

### A. Experimental Set-up

The test equipment consists of Model Advanced Partial Discharge Measuring and Analysis System MPD 540 of M/s Omicron Instruments. The dedicated software provided the necessary statistical parameters at any point of measurement. It is also possible to get the 2D and 3D histogram of the acquired PD data.

### B. Test Configuration

The experimental set-up consists of a high pressure test chamber of 3.5 litre volume. The co-axial duct was fixed inside the chamber and it was pressurized with the gas mixture. Copper wire of 0.6 mm diameter and Nichrome wire of 0.3 mm diameter were used in the study. No special tip geometry was used. The particles were free or attached to either the central conductor or the duct.

### C. Experimental Procedure

The PD measuring system is first calibrated by the usual method using a standard pulse generator. The calibrator is then disconnected and the sample is connected to a PD free HVAC source across the test object, through a RC divider. The PD measuring system is calibrated for voltage measurement by applying a certain known voltage much less than the inception voltage across the test object. The voltage is then increased gradually and maintained at the desired level for a duration ranging from 30 minutes to one hour. The final voltage step was 20% above the discharge inception level and the voltage was reduced gradually to zero to record the extinction voltage. For all the measurements, the discharge inception threshold was fixed at 5 pC. The PD statistical results with loose and fixed copper and Nichrome wires introduced in the duct at 0.4 MPa are discussed and compared with the results of the clean duct.

## III. RESULTS AND DISCUSSIONS

The results and discussions presented in this paper refer to the discharges of very low magnitudes which in the long run would result in ageing of the insulation system. The objective of the study is to understand the PD characteristics below the inception level. Hence the inception threshold level selected was 5 pC. The results discussed will be applicable to the experimental conditions described here, in the low PD regime.

In Fig. 1 is shown the variation of statistical parameters namely  $Q_{iec}$  (weighted Charge in pC),  $Q_{peak}$  (Q Maximum in pC),  $Q_{ave}$  (Average charge in pC),  $n$  (no. of PD's/sec) and  $D$

(quadratic rate in  $\text{aC}^2/\text{s}$ ) with the applied voltage obtained during the measurement and recording of PD around the inception voltage in a clean co-axial duct at 0.4 MPa. The PD inception voltage at a threshold of 5 pC is 1.18 kV for a clean duct. The 3-D histogram obtained in this case at a voltage level of 20% above the inception level is shown in Fig. 2.

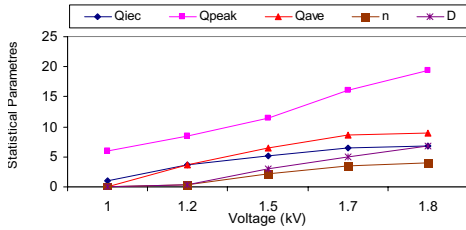


Fig. 1 Variation of statistical parameters with the change in voltage at 0.4 MPa in a clean duct

From Fig. 1 it is clear that both  $Q_{iec}$  and  $Q_{ave}$  vary in a similar pattern with voltage and saturate beyond inception voltage. But  $Q_{peak}$  increases rapidly. The number of PD events per second ( $n$ ) also increases at a though at a slower rate with voltage. The variation of quadratic rate  $D$  with voltage is not significant. The 3D histogram of the acquired PD data is shown in Fig. 2. It is clear that characteristic is symmetric though the PD activity is slightly higher during the +ve half cycle. In terms of phase, the discharge activity is confined to  $36^\circ$  to  $130^\circ$  and  $216^\circ$  to  $320^\circ$  respectively. The surface discharge activity is not seen in this case.

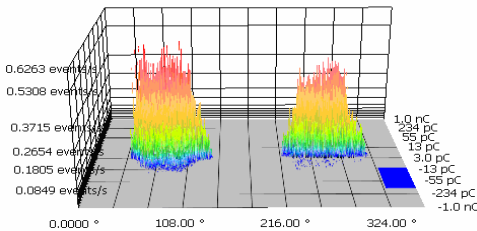


Fig. 2 Three dimensional histogram of PD for a clean co-axial duct

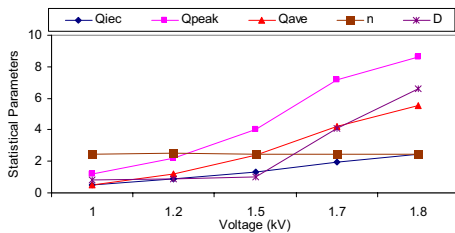


Fig. 3 Variation of statistical parameters with change in voltage at 0.4 MPa in a duct with loose copper wires

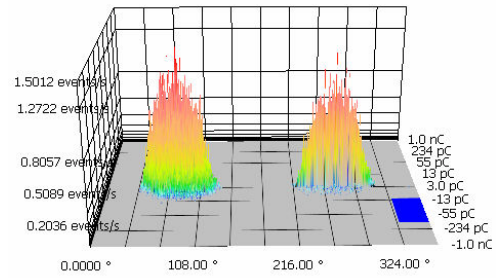


Fig. 4 Three dimensional histogram of PD for a duct with Copper wires

With unattached copper particles inside the co-axial duct, the PD inception voltage is 1.677 kV when compared to 1.18 kV of clean duct. The inception level of the clean case is lower because of the very low threshold level selected. Here the rate of increase in the  $Q_{ave}$  and  $Q_{peak}$  is significant especially at inception voltage. However,  $Q_{iec}$  does not increase significantly as compared to  $Q_{ave}$ . The corresponding histogram, shown in Fig. 4, is identical to the previous case. It is clear that the particle does not affect the inception level but the statistical parameters are significantly influenced by the presence of particle.

With the Nichrome wires introduced in to the duct the inception voltage is 1.727 kV. From the results of Nichrome wire given in Fig. 5, it is significant to observe that the rate of increase in the number of PD's/sec ( $n$ ) is rapid at 1.5 kV. This may be attributed to the increase in field non-uniformity of field due to lower diameter of Nichrome wire. All other statistical parameters show similar pattern of variation as in the previous case. The histogram appears to be less symmetrical over the two ac half cycles and this can be clearly seen from the 3 D histogram shown in Fig. 6.

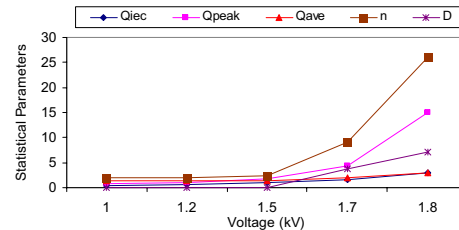


Fig. 5 Variation of statistical parameters with change in voltage at 0.4 MPa in a duct with loose Nichrome wires

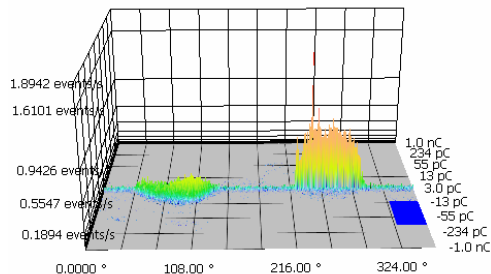


Fig. 6 Three dimensional histogram of PD for a duct with free Nichrome wires

The results in Fig. 6 clearly establish that corona is dominant and hence the discharge activity is more pronounced in the -ve half cycle. It may be remembered that the wire particle is unattached and is on the outer duct. The variation of statistical parameters like  $Q_{peak}$ ,  $n$  and  $D$  give us information about the role of particles and the sensitivity of PD measurements to the presence of loosely bound metallic particles on the duct.

The results of copper particle fixed vertically to the central conductor are shown in Figs. 7 and 8. It is interesting to note that all the statistical parameters show variation with voltage. The most significant increase is seen in case of  $Q_{peak}$ ,  $Q_{avg}$  and  $D$ . The 3D histogram shows that the discharge activity is more on the -ve half cycle but it is also present in the +ve half cycle. Since the discharges are in gas gap, the results look different from the Nichrome wire particle on the duct. The voltage inception occurs at 1.584 kV in this case.

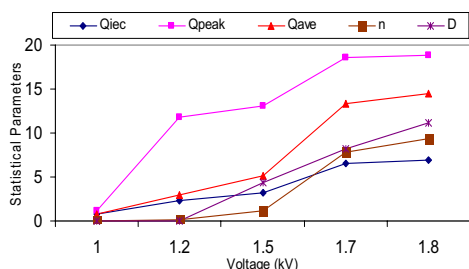


Fig. 7 Variation of statistical parameters with change in voltage at 0.4 MPa in a duct with fixed copper wire

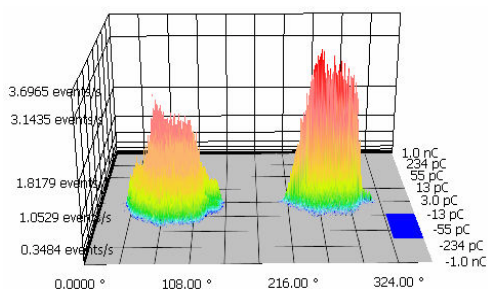


Fig. 8 Three dimensional histogram of PD for a duct with fixed copper wire

The results PD with Nichrome wire fixed to the central conductor are shown in Fig. 9. In this case, the voltage inception occurs at 1.031 kV. The results are similar to that of fixed copper wire. Even the 3 D histogram looks similar as can be seen from Fig. 10. The number of PD's/sec 'n' is higher in the case of a fixed Nichrome wire (nearly 3.7) obviously due to the higher field non-uniformity arising due to lower diameter of Nichrome wire.

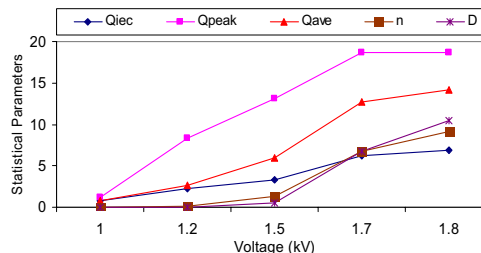


Fig. 9 Variation of statistical parameters with change in voltage at 0.4 MPa in a duct with fixed Nichrome wires

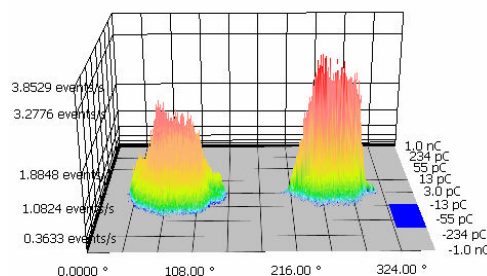


Fig. 10 Three dimensional histogram of PD for a duct with Fixed Nichrome wire

The 3-D histograms have clearly highlighted the differences observed in PD characteristics with particle size and position. With unattached particle on the duct, the corona effect and the gas discharge processes manifest in such a way that the discharge activity during the +ve half cycle are prominent. With decrease in wire diameter or increase in sharpness of tip of the wire particle, there is reversal of trend and activity is more during the negative half cycle. With the particle fixed vertically to the central conductor, the 3D results look identical but there is increase in  $n$ , the number of PD's/sec with increase in sharpness of wire.

#### IV. CONCLUSION

1. In case of low PD's, the discharge inception voltage does not vary much for clean duct and duct with unattached particles in the gas mixture studied.
2. The PD Histogram is not influenced by wires of larger diameters when the field enhancement is not significant. But with thin wire particles, there is a significant change and PD activity in the -ve half cycle is significant.
3. The  $Q_{iec}$ ,  $Q_{peak}$  and  $Q_{ave}$  for a clean duct is always higher than the duct with loose particles at a given voltage, in case of low PD's.
4. The number of PD events per second  $n$  in kPD's/s, is higher for the duct with particles than the clean duct for a given voltage.
5. Statistical parameters in the low PD regime show significant increase with incremental voltage and variation in the number of PD's/sec alone would depend on the wire tip radius.

6. In case of thin wire particles, the statistical parameters do not show much variation up to the inception level but show significant increase there after.
7. Statistical parameters  $Q_p$ ,  $Q_{avg}$  and  $n$  show stepped increase with voltage whereas  $D$  and  $Q_{iec}$  show linear increase with voltage when the particle is attached to the central conductor or when heavier unattached particle is present on the duct.
8. Analysis of 2D/3D histograms of acquired PD data and the variation of statistical parameters with voltage and time are useful tools for understanding the gas discharge processes and the behavior of gas mixtures in the low PD regime.

transformers, gas mixtures for high voltage applications, partial discharges in solid-gas and solid liquid composites and measurement of small partial discharges in these insulation systems. He has more than 60 publications to his credit. In addition to his official responsibilities at CPRI, he is also guiding students for PhD.

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