CHARACTERISTICS OF PARTIAL DISCHARGES ON A DIELECTRIC SURFACE IN SF_6-N_2 MIXTURES

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INTRODUCTION

An important tool for improving the reliability of HV-insulation systems relies on partial discharge (PD) measurements. The assessment of the insulation failure of HV equipment using PD measurements requires an interpretation of the PD measurements themselves. The statistical characterization of pulsating PD signals has been shown[1-3] to play an important role in understanding PD phenomena. The development of diagnostic systems which utilize statistical data on partial discharges for pattern recognition is important for the identification of types of defects in electrical insulation.

This paper presents the results of a recent investigation of pulsating PD phenomena occurring in point-dielectric gaps under an alternating voltage in SF_6-N_2 mixtures. The dielectric is a cast epoxy resin with Al_2O_3 filler. A computer-based PD recording system has been utilized which captures the amplitudes and time of occurrences of "all" pulsating PD events above a certain amplitude within an arbitrary time period. The data have been collected over sufficiently long time periods to make stochastic analysis possible. From the analysis of the stochastic behavior, the differences of the time-resolved histograms of PD in SF_6-N_2 mixtures and air have been obtained. Due to the strong electronegative character of SF_6 and its tendency to decompose during a discharge, the PD patterns in SF_6-N_2 mixtures are notably different from those in air. The measured PD pulse rate and average current show that partial discharges in SF_6-N_2 mixtures in the presence of an epoxy surface are non-stationary, that is they vary with time. Measurements made over a twenty-four-hour period show that there are different stages of the partial discharge behavior. These results are presented and briefly discussed.

EXPERIMENTAL CONDITIONS

The schematic diagram of the experiment is shown in Fig. 1. A zero-crossing detector is utilized to obtain the time of occurrences of the partial discharges, and digitized data are collected by the computer. The PD was generated between the point and the dielectric epoxy by applying a continuous sinusoidal alternating voltage at 60 Hz to a point

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stainless steel electrode. The tip radius is about 50 μm and the gap distance is 0.5 mm ±0.01 mm. The insulating gas mixture consists of $10\%SF_6+90\%N_2$ at a pressure of 100 kPa.

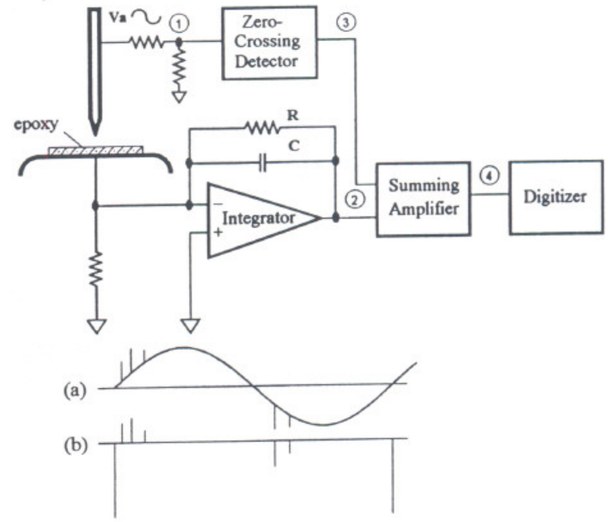

Fig. 1. Experimental arrangement for the study of PD characteristics and the measurement of the time-resolved pulse amplitudes.

(a). A typical waveform superimposed by the voltages from test point ① and ②.

(b). A waveform seen at test point ④ which is the sum of the voltages from test point ② and ③.

EXPERIMENTAL RESULTS AND DISCUSSION

Non-stationary Behavior

Figure 2(a) shows the measured 24-hour PD average current at a voltage of 2.30 kV, and Fig. 2(b) shows the measured relative PD pulse rate over the same time period. Over this time period, both the PD average current and the pulse rate show distinct patterns of behavior. According to the International Electrotechnical Commission (IEC) Standard 270,[4] the average current I is given by

$$I = \frac{1}{T_{ref}}(|q_1| + |q_2| + \ldots + |q_i|)$$

which is the sum of the absolute values of the individual PD amplitudes q_i during a certain time interval T_{ref}, divided by this time interval. In this paper the time interval used for the average current is one second. Figure 3 shows individual PD (positive and negative) amplitude distributions. All data were recorded after an initial 10-hour conditioning period during which no measurements were made because the inception voltage varied randomly by several thousand volts. The data shown in Figs. 2 and 3 were taken at a rate of one point per second for the first 2 minutes of each consecutive 10-minute period. Pulses with amplitudes lower than 3.0 pC (positive) and 3.6 pC (negative) were not recorded.

The PD (positive and negative) pulse amplitude distributions in Fig. 3 at stages 1, 3, and 5 are quite different from those at stages 2 and 4. The former is characterized by a widely scattered pulse-amplitude distribution while the latter is characterized by a narrow pulse amplitude distribution. It is clear that the PD patterns of stages 2 and 4 are different

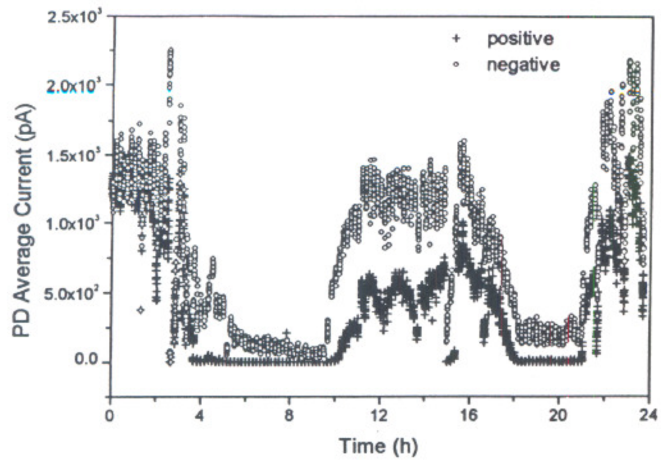

Fig. 2(a). PD average current measured for 24 hours with a gap distance of 0.5 mm ±0.01 mm, a frequency of 60 Hz, and a voltage of 2.30 kV.

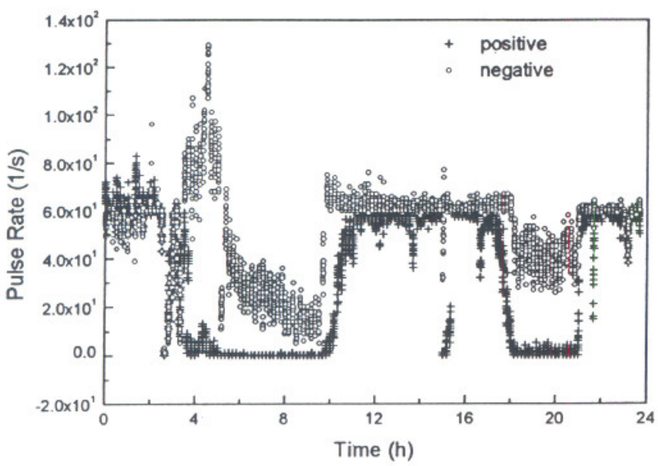

Fig. 2(b). PD pulse rate measured for 24 hours with a gap distance of 0.5 mm ±0.01 mm, a frequency of 60 Hz, and a voltage of 2.30 kV.

from those of stages 1, 3 and 5. According to the charge distributions in Fig. 3, the positive partial discharges cease to exist after about 4 hours and the negative partial discharges shift to lower values. A similar cessation of positive discharge has been observed in air exposed to PD for 2.9 hours by Van Brunt et al. by applying an alternating voltage to a point electrode touching a dielectric surface.[3] For the data in Fig. 3, the partial discharges are observed to appear again after about 10 hours (stage 3). The pattern in stage 3 is similar to stage 1, but after about 18 hours the pattern shifts to that of stage 2. The data in Figs. 2 and 3 show that the partial discharges on the epoxy surface exhibit correspondingly non-stationary behavior manifested by different stages which reoccur upon the continuous recording of the PD pulses.

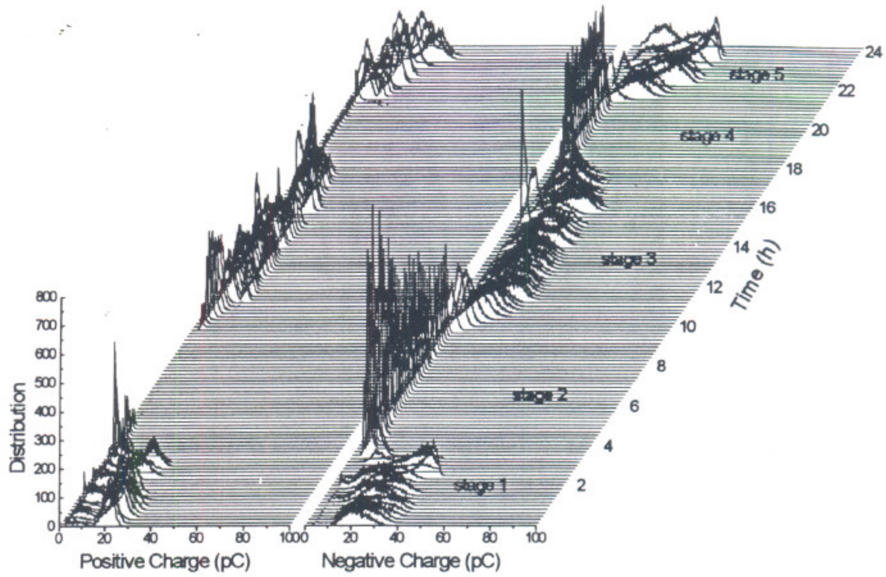

Fig. 3. Progression of individual PD (positive and negative) amplitude distributions measured for 24 hours with a gap distance of 0.5 mm ±0.01 mm, a frequency of 60 Hz, and a voltage of 2.30 kV.

Surface Condition

In Fig. 4(a) is shown the concave profile of the epoxy surface after exposure to partial discharges for 36 hours in a $10\%SF_6$+$90\%N_2$ mixture. Interestingly, within the concave are seen protrusions (shown as a and b in the figure) of about 1 μm to 3 μm high and about 10 μm wide. In Fig. 4(b) is shown the condition of the epoxy surface, amplified by a factor of 1000. Evidently, there is a clustering of crystalline-like structure on the epoxy surface.

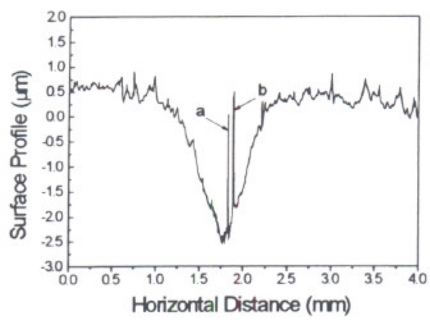

Fig. 4(a). Profile of the epoxy surface after exposure to partial discharges for 36 hours in a mixture of $10\%SF_6$+$90\%N_2$. The protrusions, indicated in the figure by *a* and *b*, are about 1 μm to 3 μm high and about 10 μm wide.

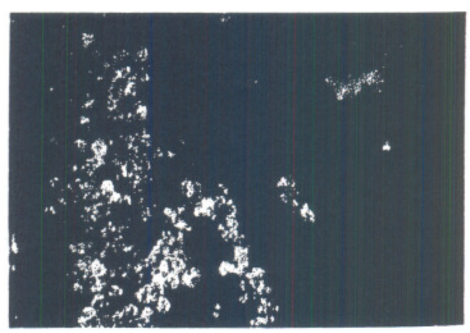

Fig. 4(b). Condition of the epoxy surface, corresponding to a small area in the profile of Fig. 4(a), magnified 1000 times, after exposure to partial discharges for 36 hours in $10\%SF_6$+$90\%N_2$. The white color shows the crystalline-like structure formed.

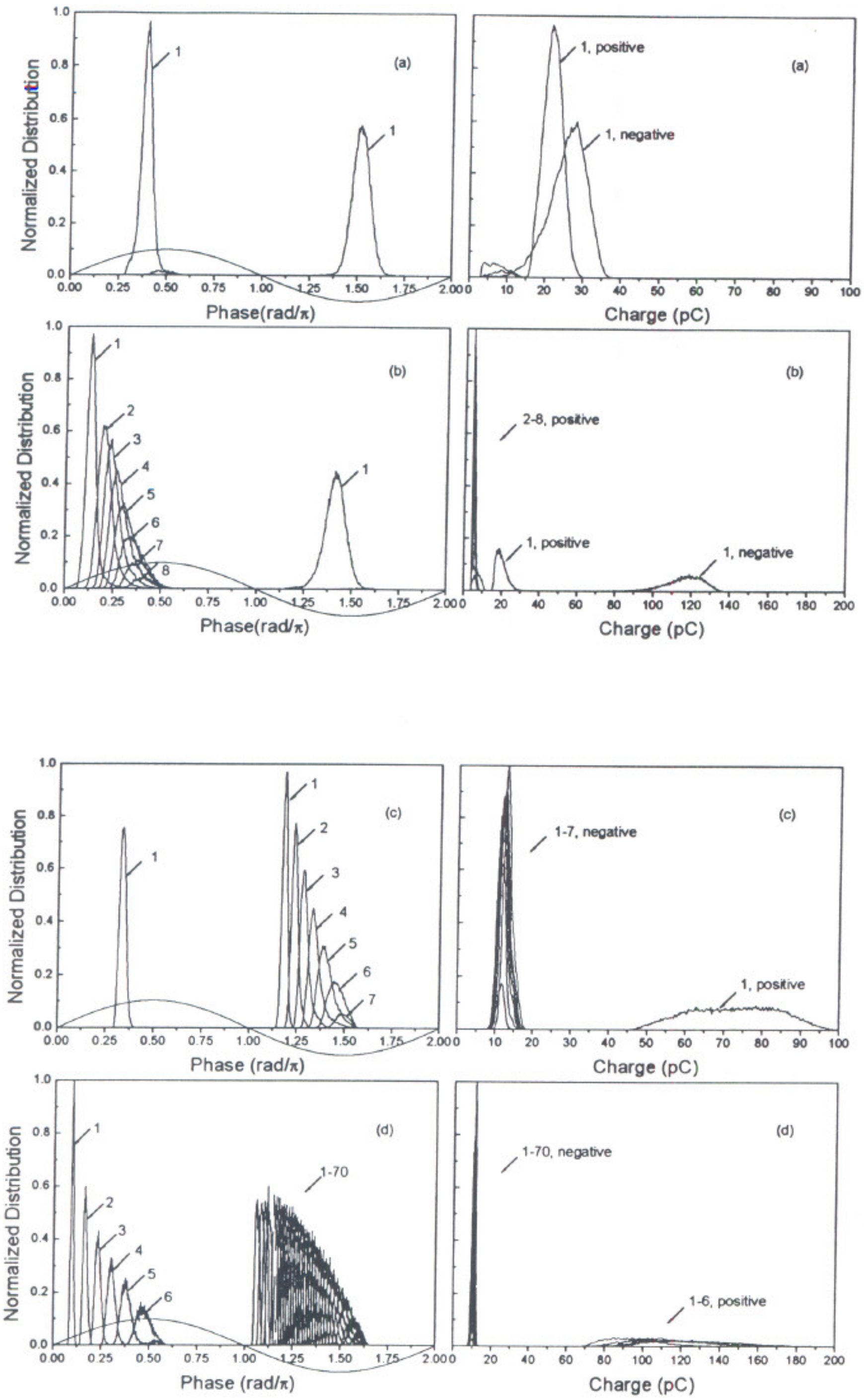

Fig. 5. Individual PD phase and amplitude distributions (gap distance = 0.5 mm ±0.01 mm, frequency 60 Hz). (a)10%SF_6+90%N_2 mixture, voltage = 2.28 kV; (b) 10%SF_6+90%N_2 mixture, voltage = 3.18 kV; (c) air, voltage = 1.79 kV; (d) air, voltage = 3.00 kV. Numbers (*1, 2, 3, …*) indicate pulse sequence within the positive half cycle or negative half cycle of the sinusoidal alternating voltage.

Voltage Dependence of Statistical Distribution

In Figs. 5(a) and 5(b) are shown representative PD phase and charge distributions for the 10%SF_6+90%N_2 mixture at two values of the applied voltage. Similar data are shown in Figs. 5(c) and 5(d) for air. Although for the long periods the partial discharges exhibit non-stationary behavior, for relatively short time intervals, stable signals can be obtained which allow the study of the voltage dependence of the statistical distributions. The data presented here were taken after one-hour conditioning exposure to partial discharges. For the 10%SF_6+90%N_2 mixture, the number of pulses increases in the positive cycle and stays the same in the negative cycle when the voltage is increased. While the same behavior in the positive cycle is exhibited by the PD in air,[5] the number of pulses in the negative cycle increases for air as well. For both gaseous dielectrics, the larger the difference is in the number of pulses between the positive and negative cycles, the larger is the observed difference in the amplitudes of the individual pulses between positive and negative cycles. These types of behavior and the differences between the SF_6-N_2 mixture and air are likely to be due to the different electron attachment and detachment processes in these two gases. In this regard, it is interesting to note that when the PD reappears in the SF_6-N_2 mixtures after a few cycles with no pulses, a PD always first occurs in the negative cycle followed by a PD in the positive cycle. This suggests that the second discharge is triggered by electrons detached from negative ions formed during the preceding pulse.

CONCLUSIONS

Changes of the dielectric surface induced by partial discharges modify the statistical behavior of the partial discharges themselves. Positive partial discharges reappear even after they have been extinguished for hours. Consideration of the time development of partial discharges is thus necessary for defining the PD patterns for PD pattern recognition and detection.

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REFERENCES

1. R. J. Van Brunt, Stochastic properties of partial-discharge phenomena, *IEEE Transactions on Electrical Insulation*. 26:902(1991).
2. R. J. Van Brunt, P. von Glahn, and T. Las, Anomalous stochastic behavior of partial discharge on aluminum oxide surface, *Journals of Applied Physics*. 81:840(1997).
3. R. J. Van Brunt, P. von Glahn, *and T. Las*, Non-stationary behavior of partial discharge during discharge induced ageing of dielectrics, *IEE Proceedings of Science Measurement Technology*. 142:37(1995).
4. *Partial Discharge Measurement*, International Electrotechnical Commission, IEC Standard, Publication 270, 47(1981).
5. Y. Wang, X. Han, and R. J. Van Brunt, Digital recording and analysis of partial discharges in point-dielectric gaps, in: *1998 IEEE International Symposium on Electrical Insulation*, Washington, D.C., USA (1998).

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