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EFFECT OF MACROSCOPIC ELECTRODE SURFACE ROUGHNESS ON BREAKDOWN AND CORONA INCEPTION VOLTAGES IN $SF_6 + N_2$ GAS MIXTURES

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ABSTRACT

In this paper, breakdown and corona inception voltages of rod-plane electrode configuration with different sizes of electrode surface roughness in compressed $SF_6 + N_2$ gas mixtures under 50 Hz, ac voltages and dc voltages with different polarities have been studied. For 50 Hz, ac voltages, with reduction gas pressure, under different sizes electrode surface roughness, breakdown voltages of gas mixtures with lower percent (%20 SF_6) and higher percent (%80 SF_6) SF_6, approximately remain equal. Moreover, for ac voltages, with reduction electrode surface roughness, breakdown voltages of gas mixtures with different percent of SF_6 and N_2, are increasing for gas pressures less than 2 bar. For negative polarity dc voltages with reduction radius of electrode surface roughness, breakdown voltages of gas mixtures with higher and lower percent SF_6 are approached to each other for gas pressures smaller than 2 bar. For negative polarity dc voltages , with different radius of electrode surface roughness, critical pressure of gas mixtures are higher than 4 bar. In general, with different sizes electrode surface roughness, under compressed SF_6+N_2 gas mixtures, breakdown voltages for negative polarity are higher than positive polarity dc voltages.

I. INTRODUCTION

Global warming problem of SF_6 has lately attracted a considerable attention in the field of high voltage engineering. As an electrical insulation medium for power equipment, SF_6 has excellent properties, but it is potent greenhouse gas. To reduce the total amount of SF_6 usage emission, N_2/SF_6 mixture is becoming one of the most promising candidates to replace pure SF_6 [1].

There have been many investigations of the possible use of gas mixtures in high-voltage apparatus, but from a practical point of view only very few SF_6 gas mixtures have prospects for industrial application. The SF_6/N_2 gas mixture is probably the most promising one because nitrogen is a cheap inert gas, which does not cause any environmental problem and the relative electric strength of SF_6/N_2 in a uniform field is higher than that of SF_6 gas mixtures with most common gases [2-4]. In the last decade for the arc quenching the SF_6/N_2 gas mixture has been used successfully in circuit breakers designed for extremely cold area [3].

According to above facts, The aim of the present work is to investigate the macroscopic surface roughness effect of rod–plane electrode configuration on breakdown and corona inception voltages of SF_6/N_2 gas mixtures.

II. EXPERIMENTAL PROCEDURES

Experiments are carried out with 50 Hz ac and dc voltages up to the peak value of 280 kV in both polarities, using rod-plane electrode system. To examine the effect of different sizes macroscopic electrode surface roughness, we used hemispherical artificial protrusion on the center of plane electrode with radius r_p = 3 mm and r_p = 6 mm respectively. The electrodes are mounted in a pressure vessel. All electrodes and artificial protrusions are made of brass covered with chromium. The lower electrode is a plane electrode with an overall diameter of 75 mm and its edges are rounded with a radius of curvature of 3 mm, the upper electrode is a rode electrode with radius of 1mm. The gap distance between upper and lower electrode in all measurements is always 20 mm. The gases used were of commercial purity and were always filtered and dried prior to their admission in to the pressure vessel. No external irradiation was used in any of these measurements. Several measurements of the breakdown and corona inception voltages were made at each pressure, and for each case the lowest recorded value was used for the plots given in this paper. The lowest rather than average breakdown was used because it provides a better indication of withstand level and is therefore of considerable interest from a practical point of view [5]. Before starting any experiments, electrodes are treated with a metal polish and clean washed carefully with ethyl alcohol.

III. RESULTS AND DISCUSSION

(a) POSITIVE ROD-PLANE GAP

Figure 1 shows the breakdown and corona inception voltages of different percent SF_6+N_2 gas mixtures, in rod-plane electrode configuration with protrusion height equal to 3 mm, under positive and negative polarity dc voltages. In different percent SF_6+N_2 gas mixtures, under positive polarity dc voltages, with macroscopic sizes electrode surface roughness, between 0.5 and 2.5 bar gas pressures, before breakdown in the system, we measured corona inception voltages.

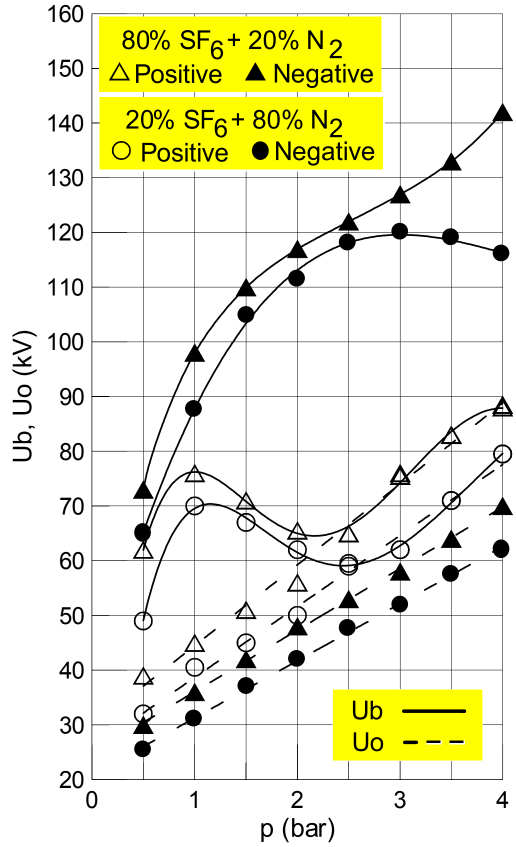

Figure 1. Positive and negative polarity breakdown and corona inception dc voltages with protrusion height equal to 3 mm

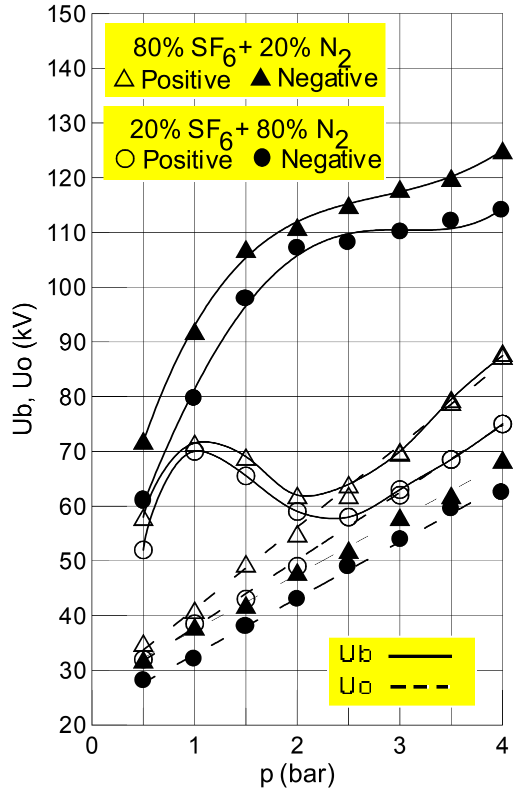

Figure 2. Positive and negative polarity breakdown and corona inception dc voltages with protrusion height equal to 6 mm

In this and subsequent figures, the breakdown voltages (U_d) are shown by solid curves while the corona onset voltages (U_o) are represented by broken curves. Figure 2 also shows the breakdown and corona inception voltages of different percent SF_6+N_2 gas mixtures, in rod-plane electrode configuration with protrusion height equal to 6 mm, under positive and negative polarity dc voltages.

The results of figs. 1 and 2 show that in positive polarity dc voltages, with reduction electrode surface roughness, the critical pressure p_{cr} at which transition from corona stabilized to direct breakdown is completed, has been increased slightly. Under positive polarity dc voltages, in corona stabilized region, breakdown voltages are always greater than corona inception voltages in different percent gas mixtures, with different sizes electrode surface roughness. In this region also the curve $U_d = f(p)$, under positive polarity dc voltages, with different sizes electrode protrusion height, in different percent gas mixtures, has maximum and minimum values respectively.

In pressure region that breakdown is said to be "corona stabilized", it is believed that the space charges produced by corona discharges stabilizes the field at and near the rod tip and thus enhances the threshold voltage level for complete breakdown of the gap [5]. However, above a certain pressure known as the "critical pressure", stable corona cannot occur and the discharge onset leads to a direct breakdown.

In positive polarity dc voltages, with different sizes electrode surface roughness, in SF_6+N_2 gas mixtures with different percentage of SF_6 and N_2, the amount of maximum pressure (p_{max}) remains constant. In this research work, for all different conditions maximum pressure has been obtained equal to 1 bar (p_{max} = 1 bar). In corona stabilization region, breakdown voltage of SF_6+N_2 gas mixture at p_{max} reaches to its maximum value. In non-uniform fields, we can obtain maximum pressure always in corona stabilization region. From the results of figure 1 and 2 we can say that, with increasing the radius of surface roughness, For gas pressures below 1.5 bar, corona inception voltages in %80SF_6+%20N_2 and %20SF_6+%80N_2 are approximately equal.

In general, with increasing percentage of SF_6 in gas mixture, according to electronegative property of this gas, effective ionization coefficient of the gas mixture decreases thereby increases the inherent dielectric strength of the mixture [6]. The corona inception voltages shown in Figs 1 and 2 increase with pressure due to an increase in the gas number density. The most interesting feature of these inception curve is the fact that inception voltages for SF_6+N_2 gas mixtures generally increase linearly with increasing pressure over a wider pressure range, in rod-plane gap with different sizes on plane electrode. The results for negative polarity dc voltages and 50 Hz AC voltages, to be discussed later also show a similar tendency.

(b) NEGATIVE ROD-PLANE GAP

The previous results indicate that the corona stabilization processes are more effective when the rod is cathode rather than when it is anode [7]. Generally the breakdown and corona inception voltage-pressure curves for both polarities show similar features with different radius hemispherical artificial protrusion on plane electrode. The values of critical pressure are higher for the negative rode under dc and impulse voltages [8-10]. Malik, has been reported that, for cathode of 1.59 mm in diameter, critical pressure in SF_6 is in excess of 5 bar [5]. Figs 1 and 2 show that, also for a rod cathode of 2 mm in diameter, critical pressure in SF_6+N_2 gas mixtures, with different sizes electrode surface roughness, excess of 4 bar. Thus in the present study, negative polarity dc breakdown in gas mixtures with different percentage of SF_6 and nitrogen, is corona stabilized over the entire pressure range of 0.5 to 5 bar as shown in figure 1 and figure 2 respectively. Generally the breakdown voltages increase linearly for low pressures and tend to saturate at higher pressures. This tendency was least evident in small size surface roughness as shown in figure 1.

At higher pressures, negative breakdown voltages are significantly higher than positive ones as is clear from figs 1 and 2. In negative polarity dc voltages, for pressures below 2 bar, with different sizes electrode surface roughness, breakdown voltages of SF_6+N_2 gas mixtures with different percentage of SF_6 an N_2 are approached to each other. Similar to the case of positive polarity, the corona inception voltages for rod-plane gap with different sizes electrode surface roughness on plane electrode, increase with increasing SF_6 percentage of the mixture. However, the inception voltages for negative polarity are lower than the corresponding values for positive polarity with protrusion radius of r_p = 3 mm and r_p = 6 mm respectively. This type of behavior is well documented in the literature for rod-plane electrode systems without surface roughness also [9-10]. The reason for this difference of inception voltages under positive and negative polarity are related to the different mechanisms of corona inception and statistical time lag effect, as discussed in detail by Van Brunt and Misakian [9].

(c) 50 Hz AC VOLTAGES

Under 50 Hz ac, breakdown voltage-pressure and corona inception voltage-pressure curves for rod-plane electrode configuration with compressed SF_6+N_2 gas mixtures, with macroscopic sizes electrode surface roughness on plane electrode, have been obtained.

In 50 Hz ac voltages, corona pulses appeared at first on the negative half-cycle, perhaps conforming an earlier observation under dc voltages. When we increase ac voltages more than previous values corona pulses appeared over the positive half-cycle. At the end with increasing ac voltages further, corona pulses split into two population on both sides of the peak of ac voltages. The similar phenomenon also have been observed in the same configuration without electrode surface roughness on plane electrode, with compressed SF_6+N_2 gas mixture with different percentage of SF_6 and N_2 [11].

Figure 3 shows breakdown and corona inception voltages of SF_6+N_2 gas mixture with different percentage of SF_6 and N_2, versus gas pressures, under 50 Hz ac voltages, with artificial protrusion height of 3 mm on plane electrode in rod-plane electrode configuration.

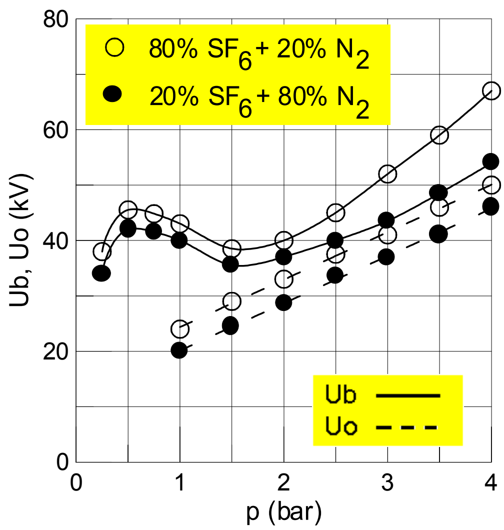

Figure 3. 50 Hz ac breakdown and corona inception voltages with protrusion height equal to 3 mm

Figure 3 indicate that, under 50 Hz ac voltages, with protrusion height equal to 3 mm, for gas pressures less than 2 bar, corona inception voltages of %80SF_6+%20N_2 and %20SF_6+%80N_2 are approached to each other. Figure 4 also shows breakdown and corona inception voltages of SF_6+N_2 gas mixture with low and high percentage of SF_6 and nitrogen, versus gas pressures, under 50 Hz ac voltages, with artificial protrusion height of 6 mm on plane electrode in rod-plane electrode configuration.

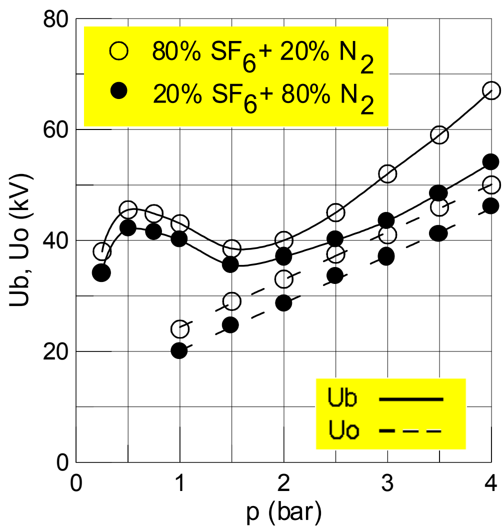

Figure 4. 50 Hz ac breakdown and corona inception voltages with protrusion height equal to 6 mm

In 50 Hz ac voltages between 0.5 and 4 bar gas pressures, with increasing pressure, corona inception voltages approximately increase linearly for different sizes of electrode surface roughness. The results further show that, corona stabilization region for the different configurations, under 50 Hz ac voltages are greater than 4 bar. Therefore, we can say that the critical pressure of the systems will be greater than 4 bar (p_{cr} > 4bar).

In 50 Hz ac voltages, with decreasing the height of electrode surface roughness, minimum and maximum pressures of the system are increased. For example in rod-plane electrode configuration, for 6mm protrusion height, p_{min} = 1.75 bar and p_{max} = 0.5 bar and for 3 mm protrusion height, p_{min} = 2.25 bar and p_{max} = 1 bar for compressed SF_6+N_2 gas mixture with low and high percentage of SF_6 and nitrogen. In decreasing region of the breakdown voltage-pressure curves $U_d = f(p)$, from p_{max} to p_{min}, with decreasing the radius of electrode surface roughness, the slope of curves has been increased. In Figs 3 and 4 p_{min} and p_{max} are the pressures that are obtained in minimum and maximum breakdown voltages respectively. The results of figs 3 and 4 show that under different sizes electrode surface roughness, for gas pressures smaller than p_{min}, breakdown voltages of the different systems are approached to each other. In 50 Hz ac voltages, over the pressure range of p_{min} to 4 bar, breakdown voltages of SF_6+N_2 gas mixtures with different percentage of SF_6 and N_2, under different sizes electrode surface roughness, are approximately equal. Moreover, for gas pressures below p_{min}, breakdown voltages of the systems are increased with decreasing artificial protrusion height.

IV. CONCLUSION

We investigated the ac and dc breakdown and corona inception voltages for rod-plane electrode system with different sizes electrode surface roughness in SF_6+N_2 gas mixture with different percentage of SF_6 and nitrogen. The main results obtained are

(1) In positive polarity dc voltages, with reduction electrode surface roughness, the critical pressure (p_{cr}) has been increased slightly.

(2) In positive polarity dc voltages, with different sizes electrode surface roughness, in SF_6+N_2 gas mixtures with different percentage of SF_6 and N_2, the amount of maximum pressure (p_{max}) remains constant.

(3) In 50 Hz ac and dc voltages, inception voltages for rod-plane electrode system with different sizes electrode surface roughness in SF_6+N_2 gas mixture, generally increase linearly with increasing pressure over a wider pressure range.

(4) In negative polarity dc voltages, critical pressure in SF_6+N_2 gas mixtures, with different sizes electrode surface roughness, excess of 4 bar.

(5) In general, with different sizes electrode surface roughness, under compressed SF_6+N_2 gas mixtures, breakdown voltages for negative polarity are higher than positive polarity dc voltages.

(6) In 50 Hz ac voltages, corona stabilization region for the different configurations are greater than 4 bar.

(7) In 50 Hz ac voltages, with decreasing the height of electrode surface roughness, minimum and maximum pressures of the system are increased.

(8) In 50 Hz ac voltages, over the pressure range of p_{min} to 4 bar, breakdown voltages of SF_6+N_2 gas mixtures with different percentage of SF_6 and N_2, under different sizes electrode surface roughness, are approximately equal.

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