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Onset Voltage of Corona in SF_6-N_2 Mixtures

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Abstract

The onset voltages of positive and negative coronas are theoretically predicted for SF_6 - N_2 mixtures. For positive onset, the method of calculation is based on the condition necessary for the onset streamer to propagate. For negative onset, the method of calculation is based on the criterion developed for the formation of repetitive negative corona pulses. The analysis is applied for rod-plane and sphere-sphere gaps. The calculated onset voltages obtained in both positive and negative coronas agree well with those measured values within ± 10 %.

Introduction

Sulfurhexafluoride (SF_6) is the most commonly used insulating gas in electrical systems [1]. Also, SF_6-N_2 mixtures are already used by the power industry as an insulating gas in extremely cold climates where pure SF_6 deviates from ideal gas behavior [2]. These mixtures containing 40-50 % of SF_6 have a dielectric strength of up to about 80-90 % that of pure SF_6 [3]. Under quasi uniform field conditions, e.g. for cylindrically concentric electrodes, an SF_6-N_2 mixture that contains 10 % of SF_6 by volume ratio has nearly the same breakdown voltage as 100 % SF_6 if the total pressure for the mixture is twice that for SF_6 [4]. Therefore, these mixtures have been considered for possible applications in compressed gas insulated transmission (CGIT) systems [3]. It is thus of considerable interest to understand the non-uniform field pre-breakdown characteristics of these mixtures.

Several approaches have been reported for computing the discharge inception voltages in SF_6. Nitta's criterion [5] assumed that the transition from single avalanche to streamer is attained when the avalanche size reaches a critical value of 10^8. Pederson's concept [6] states that when the rate of growth of an avalanche in a "slightly" non-uniform field reaches a value equal to that in a uniform one, a streamer is formed leading to complete breakdown. Khalifa and M. Abdel Salam [7] developed a method for computing the discharge inception voltage in compressed SF_6 and in its mixtures[8]. The method is based upon the condition of streamer growth or propagation.

This paper presents a theoretical prediction of the onset voltage of corona in SF_6-N_2 mixtures. For positive onset the method of calculation is based on the condition necessary for the onset streamer to propagate; this method is applied for rod-plane and sphere-sphere gaps. For negative onset, the method of calculation is based on the criterion developed for the formation of repetitive negative corona pulses, this method is also applied for rod - plane gaps. .

Method of Analysis

Positive onset criterion

Assume an electron exists at the border of the ionization zone $(\alpha - \eta)_m = 0$ surrounding the stressed electrode, where α and η are the ionization and attachment coefficients, respectively, and m refers to the gas mixture. This electron generates a primary avalanche by electron collision with gas molecules. The size of the primary avalanche N_{+1} is calculated. Due to photoionization process, photons produced from the avalanche head ionize the gas molecules in the ionization zone. Due to this process, photoelectrons are produced, and as a result, successor avalanches are produced in the ionization zone, Fig. [1]. Then, the size of the successor avalanches N_{+2} is calculated. At the onset voltage, N_{+2} just exceeds N_{+1} and the discharge process becomes self sustained[9,10]

$$N_{+2} \geq N_{+1} \qquad (1)$$

$$N_{+1} = \exp[\int_{Z_i}^{H} (\alpha(\bar{z}) - \eta(\bar{z}))_m d\bar{z} \qquad (2)$$

$$N_{+2} = \int_{r_i}^{R_i} g_1(f_1 f_2)_m N_{+1} \mu_m \exp[-\mu_m \rho + \int_{\rho}^{r*} (\alpha(z,\bar{\rho}) - \eta(z,\bar{\rho}))_m \, d\bar{\rho}] \, d\bar{\rho} \qquad (3)$$

$$r_1 = \sqrt{6\int_{Z_i}^{H} D_{em}\frac{dz}{V_{em}}} \qquad (4)$$

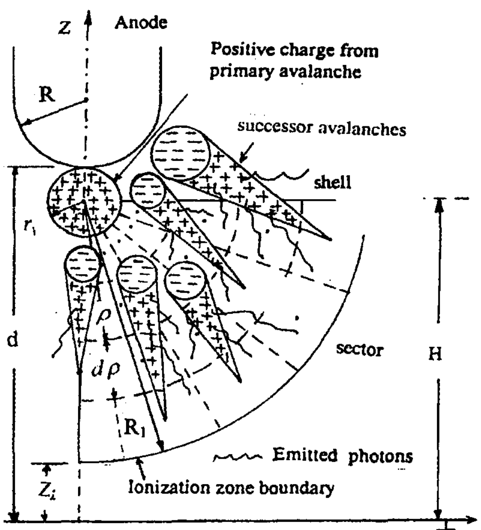

Fig. (1) Growth of successor avalanches starting from the centers of sectors and ending at the positive space charge sphere or the rod tip surface.

where, r* equals the anode radius R or the radius r_1 of the positive ions sphere left from the primary avalanche at ($Z = d - r_1$) being started at the border of the ionization zone Z_i. The parameters g_1, $(f_1f_2)_m$, μ_m, D_{em}, and V_{em} are, respectively, the geometry factor, photo-efficiency release, absorption coefficient, electron diffusion coefficient, and electron drift velocity of the gas mixture. The field along the gap axis due to the applied voltage is obtained by the charge simulation method in rod-plane gaps [11] and by the method of successive imaging in sphere-sphere gaps[12].

Negative onset criterion

Fig. (2) shows the development of an avalanche in the vicinity of the rod tip. With the growth of the avalanche $N_e(z)$, starting from the rod tip and growing toward the grounded plane, more electrons are developed at its head, more photons are emitted in all directions and more positive ions are left in the avalanche wake. For a successor avalanche to be started, the preceding avalanche should provide an initiating electron at the rod by photo emission[9,13]. The condition for a new successor avalanche to develop is that the number of photoelectrons N_{eph} should be

$$N_{eph} \geq 1 \qquad (5)$$

$$N_{eph} = \gamma_{phm}\int_{d}^{z_i} \alpha(z)_m N_e(z) g_2(z)\exp(-\mu_m z)dz \qquad (6)$$

where, γ_{phm} is the photoelectric efficiency of the cathode in the mixture, $g_2(z)$ is a geometry factor to account for the fact that some photons are not received by the stressed rod. This factor is function of pressure p , and absorption coefficient μ [13].

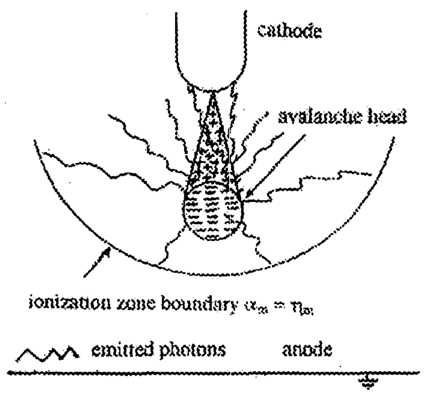

Fig. (2) Growth of the primary avalanche and emission of photons in negative corona.

Results and Discussion

The present analysis aims at obtaining the onset voltages for rod-plane gaps in SF_6-N_2 mixtures (positive and negative), and the breakdown voltages (BDVs) for sphere-sphere gaps which corresponds to the positive

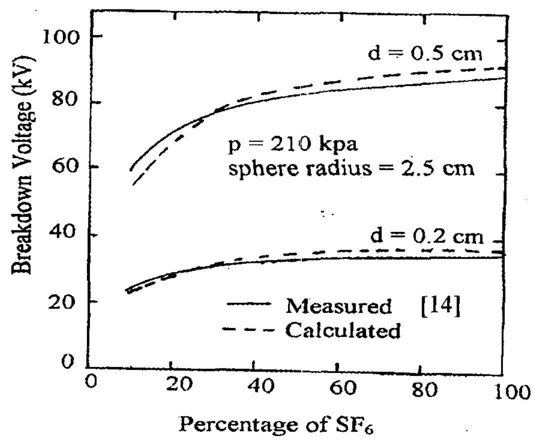

Fig (3) Calculated and measured [14] BDVs for sphere-sphere gaps insulated with SF_6 –N_2 mixtures.

onset voltage. The numerical data employed in the analysis are given in Appendix A.

Fig. (3) shows the calculated and the measured[14] BDVs for sphere-sphere electrode system in SF_6-N_2 mixtures in pressure 210 kpa. SF_6 content lies between 10%, and 100%. The electrode system uses 2.5 cm radius spheres and gaps of 0.2, and 0.5 cms.
Fig.(4) shows the calculated and the measured BDVs [15], for SF_6-N_2 mixtures having 1% and 100% SF_6 in a sphere- sphere electrode system. The system uses 3.75 cms radius spheres, and 0.5 cm gap spacing in the pressure range of 100 to 400 kpa. The calculated values in Figs. (3) and (4) agree well with those measured experimentally within ± 8%.

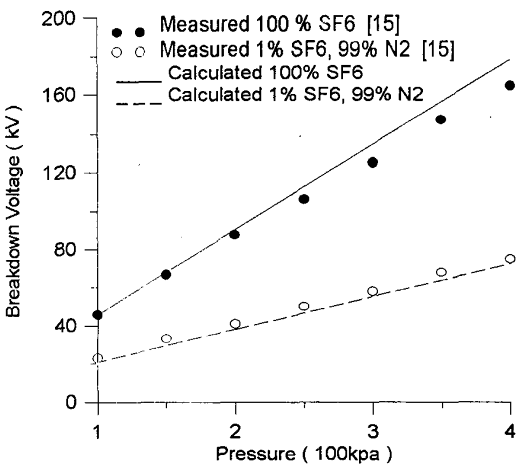

Fig.(4) Calculated and measured[15] values of BDVs for sphere-sphere gaps insulated with SF_6-N_2 mixture having 1%, and 100%SF_6.

Fig. (5) shows the calculated and the measured [16] positive onset voltages in a hemispherical rod-plane gap for SF_6-N_2 mixtures having 10%, 50%, and 100 % SF_6. The deviation between the measured and the calculated values does not exceed 10 %.

Fig. (6) shows the calculated and the measured [14] negative onset voltages in 40 mm hemispherical rod-plane gaps at different rod radii, for SF_6-N_2 mixtures having 10 %, and 50% SF_6 . Fig.(7) shows the calculated and the measured [14] negative onset voltage in 10, and 40 mm rod-plane gaps for SF_6-N_2 mixtures having 50 % SF_6 at different rod radii in the pressure range of 50 to 500 kpa. For gaps with rod radii of 3.125, and 6.3 mms, no corona activity had been observed prior to BDVs [14], and the reported measured values are BDVs . As can be seen in Figs (6 and 7), the calculated values are in good agreement with the experimental measurements.

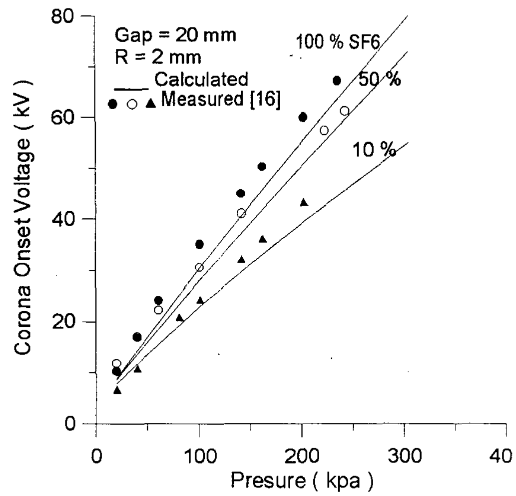

Fig. (5) Calculated and measured [16] positive onset voltage in a 20 mm rod-plane gap using a 2 mm radius, for 10%, 50%, and 100% SF6 against gas pressure.

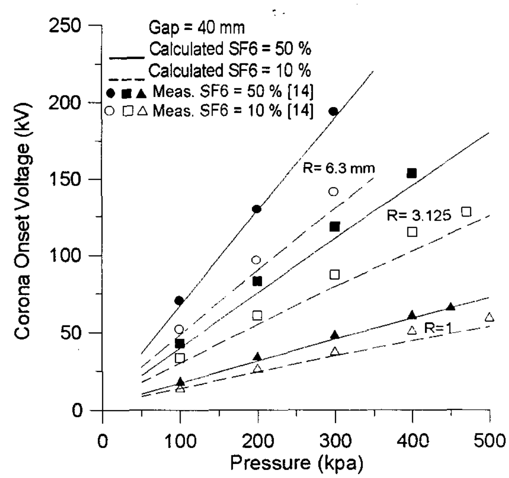

Fig. (6) Calculated and measured[14] negative onset voltage for 10 mm rod-plane gap at different rod radii in 10%, and 50%, SF_6 as a function of gas pressure .

The maximum percentage deviation between the calculated and the measured values is 10%.

Conclusions

1-A method is developed for computing the positive and the negative corona onset voltages in a gas mixture of SF_6-N_2. The method is applied to sphere-sphere gaps and rod-plane gaps.
2-The onset voltage decreases with the decrease of SF_6 percentage in the mixture.

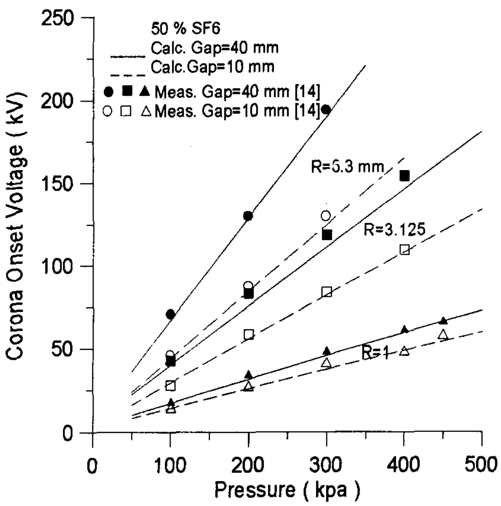

Fig.(7) Calculated and measured[14] negative onset voltage in 10, and 20 mm rod-plane gaps at different rod radii for SF_6-N_2 mixture having 50% SF_6.

3- The onset voltage decreases with the decrease of gap spacing for the same rod radius.

4- The onset voltage decreases with the decrease of rod radius for the same gap spacing

5-The computed results are in satisfactory agreement with those measured experimentally for both positive and negative coronas in rod-plane gaps at different gap spacings, and different rod radii.

Appendix A

Accurate values of the physical parameters involved in the discharge phenomena are required. α and η are expressed in [17] for SF_6, and α for N_2 is expressed in [14]. The describing equations for $(\alpha - \eta)_m$, μ_m, $(f_1 f_2)_m$, and D_{em} are expressed in [8]. γ_{phm} is also expressed in the same way as $(f_1 f_2)_m$. Calculation is performed using the following data: g_1=0.25[10], $(f_1 f_2)_{SF6} = 6\times10^{-6}$ [10], $(f_1 f_2)_{N2} = 3.1\times10^{-4}$ [18], $(\gamma_{ph})_{SF6} = 8\times10^{-6}$ [19], $(\gamma_{ph})_{N2} = 4.5\times10^{-4}$ [18], μ_{SF6}=600 p/101.3 m^{-1}, μ_{N2}=250 p / 101.3 m^{-1}[20].

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