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Effect of Electrode Surface Roughness and Coating on the AC breakdown Voltage of SF_6-N_2 Gas Mixtures

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Abstract-- **In recent decades many researches were focused on SF_6 gas mixtures, especially SF_6-N_2 mixtures which are suitable for slightly non-uniform electric fields. This paper experimentally studies effect of electrode surface roughness on breakdown voltage of SF_6-N_2 gas mixtures under weakly non-uniform electric field. Consequently, the effect of silver and chrome coating on the improvement of dielectric strength of SF_6-N_2 gas mixtures was investigated.**

***Index Terms*—Coatings, Electric breakdown, Gas insulation, Rough surfaces, SF_6.**

I. Introduction

USING SF_6 instead of other gaseous dielectrics reduced the size of enclosures and substation components in GIS systems. In addition, SF_6 because of its better dielectric strength than other gases provides more safety for the operator [1]. But in search of improved properties, low cost to achieve economy, reduced sensitivity to surface roughness and conducting particles, low toxicity of decomposed by-products, compatibility with solid dielectrics and other desired properties, a considerable amount of works has been performed to investigate the behavior of mixtures of other gases with SF_6. The other main gases considered so far are air, nitrogen, carbon dioxide and helium. In practice, mixture of SF_6 with N_2 have so far found a limited application in gas insulated power cables, also known as 'compressed gas insulated transmission lines' (CGIT)[2].

There are so many parameters that affecting the breakdown voltage of SF_6 and SF_6 gas mixtures, for example ratio of SF_6 to the other gas in the mixture, electrode material [3], etc. one of the most important factors which affected the breakdown voltage of these insulating gases is surface roughness of electrodes which are used in that gas insulated apparatus. Sharp protrusions are checked and remove from the inner surfaces of the enclosures for use in GIS. Also to obtain a desirable surface finish and reduce the effect of electrode surface roughness on the breakdown voltage of these insulating mediums, it's possible to use various coatings on the surface of electrodes to decrease local enhancement of electric field deduced of surface roughness.

So we have been used coating of rough electrodes as a varying parameter of our experiments to investigate the effect of that on the breakdown voltage of SF_6 gas mixtures.

The most creditable equation for estimating theoretically the breakdown voltage is the streamer inception criterion [4]:

$$\int_0^{X_{cr}} \bar{\alpha}\, dx = K \tag{1}$$

The distance X_{cr} from the electrode tip is where the net ionization is zero. Malik and Qureshi assumed that K has a value between 5 and 25 for the different SF_6 gas mixtures [5]. K can be called streamer constant which is a dimensionless parameter [6]. $\bar{\alpha}$ is effective ionization coefficient which introduced the ionization by electron collision and is equal to:

$$\bar{\alpha} = \alpha - \eta \tag{2}$$

α is ionization coefficient and η is attachment coefficient. In order that breakdown takes place, $\bar{\alpha}$ must be greater than zero.

The resulting functions of pressure reduced effective ionization coefficients (α/p) are linear in the region of interest around the pressure reduced critical field $(E/p)_{cr}$ for SF_6 contents above 5% which permits the approximation [7]:

$$\bar{\alpha} = k.\left[E - \left(\frac{E}{p}\right)_{cr}.p\right] \tag{3}$$

k and $(E/p)_{cr}$ achieved via experimental tests and researches by Malik and Qureshi [5]. According to (1) and (3) streamer inception will happen when the equation (4) is met:

$$\int_0^{Z_{cr}} (E - E_{cr})dz = K/_k \tag{4}$$

Field enhancement by surface roughness of electrodes cannot be taken into account by field calculations and just have to be estimated. If roughness modeled by a sphere with radius R, field distribution can approximated by [7]:

$$E(Z) = E_m.(1 - 2H_z) \tag{5}$$

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E_m is maximum field and H_z is spherical curvature factor.

According (4) and (5) streamer criterion can be rewrites as:

$$\frac{E_{cr}}{E_i} + \frac{E_i}{E_{cr}} = 4.\frac{K}{k.(E/p)_{cr}}.\frac{H}{p} + 2 \quad (6)$$

E_i is inception electric field. Applying the intrinsic dielectric strength E_{cr} and corresponding voltage U_{cr} the curvature factor gets [7]:

$$m_R = \frac{E_i}{E_{cr}} = \frac{U_i}{U_{cr}} \quad (7)$$

Taking into account the influence of the electrode curvature by m_c the streamer inception will happen at:

$$U_i = m_c.U_{cr} \quad (8)$$

Electrode configuration of gas insulated systems (GIS) falls into the category of slightly non-uniform fields. For simulating slightly non-uniform fields in laboratorial researches, we have utilized sphere-sphere construction for electrodes.

The main purpose of this paper is to study the breakdown strength of different N_2/SF_6 gas mixtures under smooth and rough electrode surfaces and so different electrodes coatings condition which are Silver and Chrome in a slightly non-uniform and locally enhanced electric field.

II. Experimental Procedure

The experiments were conducted under AC (50 Hz) voltage from a 220 V/100 kV, 5 kVA transformer. The voltage was applied to the test chamber through a 10MΩ resistor. The test chamber used in this study has 6 dm^3 volume and enables to support pressures up to 5bar. All of the experimental apparatus were calibrated according to IEC 6052 standard.

Experiments were carried out by using one pair of polished sphere-sphere electrodes of 20 mm diameter and were made of yellow brass. A sphere electrode of 20 mm diameter with a spherical protrusion at the tip which radius equals to 200 µm. Likewise one pair of rough electrodes were prepared and coated with Silver and Chrome of 10 µm thicknesses. The rough electrodes selected as cathode.

The Cathode electrode was fixed to the chamber and the anode electrode could move vertically. Before electrodes being mounted in the test chamber, were thoroughly washed with acetone. The air gap was fixed to 4 mm.

After mounting the electrodes in the test chamber, the chamber was pumped down to -86 kPa and then filled up to 300 kPa with desired gas mixture. Pressure of chamber reduced 40 kPa after each series of test at constant pressure.

Purity of SF_6 and N_2 was respectively equal to 99.9 and 99.999.

Voltage was approximately increased by 2 kV/Sec. For recording the mean value of breakdown voltage, each series of tests at constant pressure were repeated eight times, whereas standard deviation was accepted a measure of scatter of the results round the mean. The experimental setup is shown in Fig. 1.

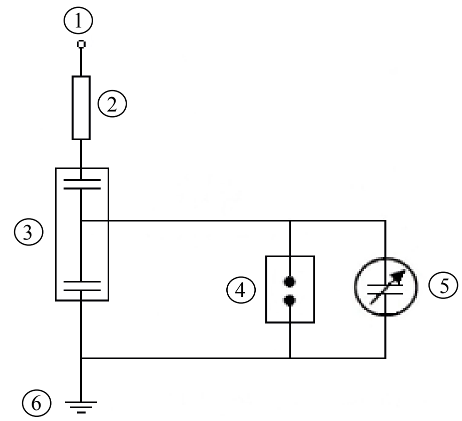

Fig 1. Experimental setup, 1- High voltage terminal; 2- Resistor (10MΩ); 3- Capacitor (100 pF); 4- Test vessel; 5- Electrostatic voltmeter; 6- Ground connection

III. Experimental Results and Discussion

The breakdown voltage of different mixtures with various electrode conditions was measured at the pressure up to 300 kPa, in sphere-sphere electrode construction.

The mean breakdown voltage value of N_2(95%)/SF_6(5%), N_2(90%)/SF_6(10%) and N_2(85%)/SF_6(15%) insulation system with fixed air gap 4 mm was measured at different pressures of gas mixtures, by utilizing one pair of polished electrodes (Fig.1). these peak AC breakdown voltage were measured for increasing volume percentage of SF_6 in the mixture at different constant gas pressures.

As seen from these curves, at 15% of SF_6 in the mixture at 300 kPa, more than 7.4% and 22.2% of the electric strength properties of 10% of SF_6 and 5% of SF_6 in the mixture are achieved respectively. The reason is that, the electric strength of SF_6 is superior to that of N_2.

Using rough electrode as cathode cause to reduction in breakdown voltage of gas mixtures (Fig. 2). Reason of this decreasing in breakdown voltage is enhancement of locally field that cause to earlier happening of partial discharges in the air gap between electrodes.

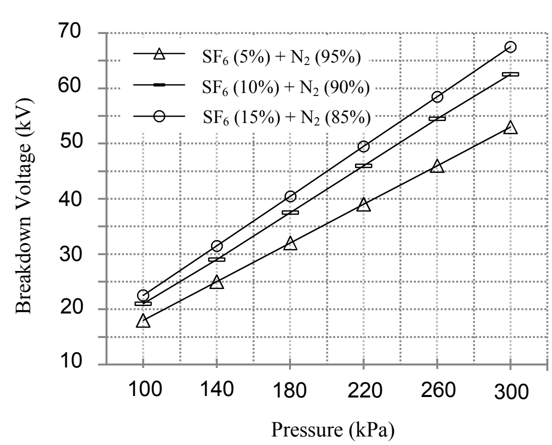

Fig 1. Breakdown voltage of SF_6 (15%) + N_2 (85%), SF_6 (10%) + N_2 (90%) and SF_6 (5%) + N_2 (95%) at different pressure values and polished electrodes

To reduce the effect of electrode surface roughness, coated electrodes utilized as cathode and experiments at similar way repeated for silver and chrome coated electrodes. Figures (3), (4) and (5) show the breakdown voltage of coated electrodes for different gas mixtures.

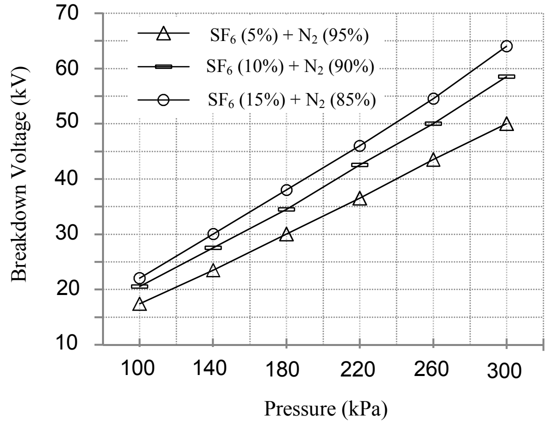

Fig 2. Breakdown voltage of SF_6 (15%) + N_2 (85%), SF_6 (10%) + N_2 (90%) and SF_6 (5%) + N_2 (95%) at different pressure values and rough cathode electrode

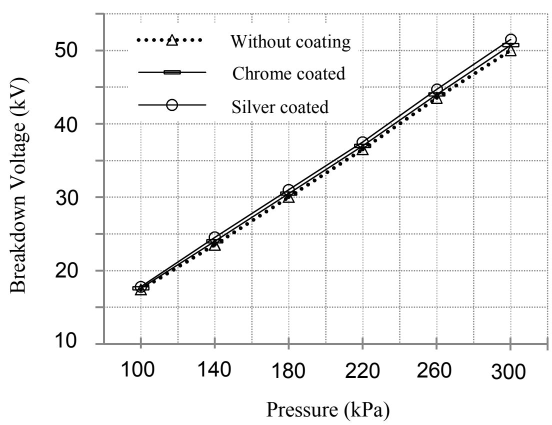

Fig 3. Breakdown voltage of SF_6 (5%) + N_2 (95%) at different pressure values and electrodes without coating and with silver and chrome coating

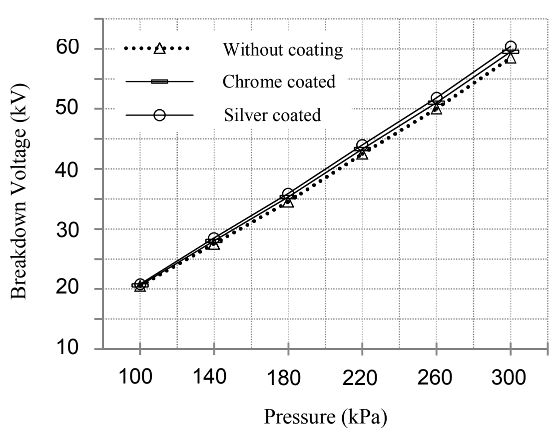

Fig 4. Breakdown voltage of SF_6 (10%) + N_2 (90%) at different pressure values and electrodes without coating and with silver and chrome coating

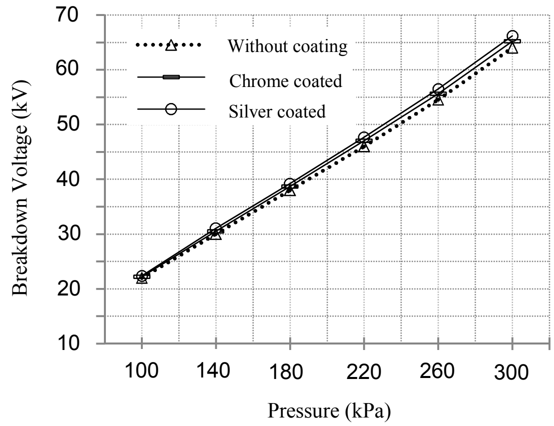

Fig 5. Breakdown voltage of SF_6 (15%) + N_2 (85%) at different pressure values and electrodes without coating and with silver and chrome coating

As illustrated in these figures a thin layer of coating increased the breakdown voltage of each gas mixture. It's obvious that Silver has more effect on improving the breakdown voltage of insulation system than chrome. There are two reasons for this phenomenon, one of that is the ability of silver to make a more uniform layer on the electrode surface than chrome, which reduced the microscopic protrusions and locally fields more than Chrome layer. The other reason is greater first ionization potential of silver than chrome. For example, the breakdown voltage of 15% of SF_6 in the mixture at 300 kPa with silver coated electrode is 1.5% more than chrome coated electrode and 3% more than rough electrode without coating. At 300 kPa pressure, the breakdown voltage of 15% of SF_6 in the mixture with silver coated electrode is about 9.8% and 15.5% more than of 10% of SF_6 and 5% of SF_6 in the mixture respectively.

The first ionization potential of silver and chrome are equal to 7.576 V and 6.766 V respectively. Therefore an electron of silver atom needs more energy than electrons of chrome atoms to enables to departures the surface of metal and move to a point outside the solid surface. Also, effect of coating material on the breakdown voltage, depends on the thermal conduction, melting point and mechanical strength of the material [8], [9].

In spite of these facts, the discrepancy between impressions of various electrode coating materials on the breakdown voltage is not considerable.

The effect of pressure on the breakdown voltage needs to be discussed because the operating pressure for GIS enclosures, which pressurized with SF_6 gas, varies from 100 kPa to 800 kPa [1]. At high pressures, experiments have been performed on the spatial growth of ionization. As seen from Figures (1) to (5), an increase in pressure will cause a raise in the breakdown voltage. . For example, the breakdown voltage of 15% of SF_6 in the mixture at 300 kPa silver coated electrode is 14.65% more than breakdown voltage at 260 kPa.

IV. CONCLUSION

Experimental results show that, material of electrode coatings affects the breakdown voltage of a gas insulated system. By increasing the amount of first ionization potential of the electrode coating material, the breakdown voltage will be increased consequently.

As investigated, a thin layer of coating on the surface of electrodes cause to improvement of breakdown voltage. A common point in experimental results of these mixtures is the little difference between breakdown voltage of silver coated and chrome coated electrodes and considerable different of polished and rough electrodes. Electrode surface roughness cause to reduction of breakdown voltage.

Also it is obvious that by increasing the percentage of SF_6 in the gas mixtures the breakdown voltage will be increased considerably.

V. References

[1] Baharat heavy electrical limited, *Handbook of Switchgears*. New Delhi, India: Tata McGraw-Hill, 2006.

[2] R. Arora, W. Mosch, *High Voltage Insulation Engineering*. New Delhi, India, New age international publishers, 2005.

[3] H. Sharifpanah, A. Gholami, S. Jamali, "Effect of electrode material on the breakdown voltage of SF_6-N_2 and SF_6-CO_2 mixtures in a weakly non-uniform electric field," *in Proc. 2_{nd} IEEE Int. conf. on Power and Energy,* Johor Baharu, Malaysia, Dec. 2008, pp. 1532-1534.

[4] A. Pedersen, “Criteria for spark breakdown in sulfur hexafluoride,” IEEE *Trans. Power Apparatus and Systems*, vol. PAS-89, pp. 2043-2048, Nov./Dec. 1970.

[5] N. Malik, A. Qureshi, "Breakdown gradients in SF_6-N_2, SF_6-Air, SF_6-CO_2 mixtures," *IEEE Trans. Electrical Insulation*, vol. EI-15, pp. 413-418, Oct. 1980.

[6] A. Gholami, H. Sharifpanah, A. Mohammadi, "Effect of surface roughness and curvature on streamer inception and breakdown of SF_6-N_2 mixtures," In *Proc. 3rdTPE int. conf. Technical and Physical Problems in Power Engineering*, Ankara, Turkey, May 2006, pp. 844-846.

[7] w. Boeck, R. Graf, M. Finkel, "Effect of surface roughness and electrode's shape on the breakdown voltage of SF_6," In *Proc.7th Int. conf. on Properties and Applications of Dielectric Materials,* Nagoya, June 2003, pp. 543-546.

[8] W. Opydo, J. Mila, "Effect of coating electrodes with an aluminum oxide layer on the electric strength of unconditioned vacuum insulation systems," in *Proc. 17th IEEE Int. Symp. Discharges and Electrical Insulation in Vacuum,* Berkeley 1996, pp. 541-543.

[9] W. Opydo, J.Opydo, "Comparative analysis of vacuum and SF_6 as high voltage insulations," in *Proc. 3rd IEEE Int. conf. on Properties and Applications of Dielectric Materials*, Tokyo, Japan, July 1991, pp. 396-399.

VI. Biographies

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