International Journal of Scientific & Engineering Research, Volume 14, Issue 11, November-2023
ISSN 2229-5518

Experimental Results for Breakdown Voltage around Various Contaminating Particles with Presence of Spacers under D.C Voltage

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Abstract— The combination of metallic particle contamination and spacers has shown to be the most critical dielectric design factor in the case of gas-insulated transmission lines (GITL) and gas-insulated substations (GIS) systems. In this paper, the breakdown voltage experiments are carried out in a test chamber measuring 12 cm in diameter and 50 cm in length and capable of withstanding pressures of up to 5 bars. The electrode system is mounted in a room-temperature chamber filled with SF_6 gas or air. The electrode system utilized in this experiment consists of two parallel plane electrodes connected by an Epoxy Resin spacer within the test tank. The epoxy resin material is utilized in the production of spacers. Epoxy resin is made up of two components: Bisphenol-A and an anhydride hardener. In this paper, we create different concentrations of Bisphenol and hardener, which are subsequently combined to generate an epoxy resin substance. The optimal concentration of these materials is then chosen to form various spacer forms such as disc and conical spacers. The influence of single and multiple contaminants, such as spherical and wire particles, on breakdown voltage values is investigated. The influence of different spacer forms, such as disc and conical spacers, as well as the presence of various contaminating particles, on recorded breakdown voltage values is also investigated. A comparison of measured and calculated breakdown voltage values is performed.

Index Terms— Breakdown Voltage, Disc Spacer, Conical Spacer, Single Contaminating Particles, Multi-Contaminating Particles

1 Introduction

The insulation performance of fluid insulating media (liquids and gases) is adversely affected by the presence of spacers, unless special design precautions are taken. Both metallic and insulating particles may be present in practical systems. The metallic particle may be due to moving parts, manufacturing debris, and arcing by-products…etc [1-6]. Insulating particles, on the other hand may arise from spacer material or from protective coatings on conducting parts. The influence of conducting particles on the insulation performance of a system is a complex phenomenon, and is dependent on a variety of factors, for example, the shape, size, and material of particles, the electrostatic charge on a particle, and the proximity to spacers [7-11]. In gas-insulated power equipment, solid insulators play an important role in electrical insulation. To increase the insulation performance of solid insulators, two technical issues were considered: the first is insulation performance improvement, and the second is regulation of the electric field distribution in and around the solid insulating spacers. These procedures result in a more intricate equipment structure and higher manufacturing costs. As a result, a new concept for solid spacers with a simple structure and arrangement was proposed. Previous research offered a functionally graded material (FGM) to decrease the electric field distribution around the spacer, particularly at the triple junction point, which was one of the main aspects governing a solid dielectric's long-term insulating characteristic [12-13]. A particle-in-cell approach was used to explore the breakdown features of C_4F_7N/CO_2 mixtures under DC conditions. Elastic, excitation, ionization, and attachment collisions were all taken into account. The quantum mechanical spherical complex optical potential formalism was used to model the elastic cross section of electron scattering from C_4F_7N. The dielectric strength of pure C_4F_7N was investigated using cross-sectional measurements. The breakdown threshold agreed well with the experiment. Furthermore, the dielectric strength of C_4F_7N/CO_2 mixtures was determined. When the gas pressure exceeded 1300 torr, the breakdown threshold in 80% C_4F_7N and 20% CO_2 was greater than that in pure C_4F_7N [14].

In non-uniform electric fields, the AC insulation properties of C_4F_7N/CO_2 combinations were examined. For a range of electric field non-uniformity f, the optimal interval duration between AC breakdowns for C_4F_7N/CO_2 combinations was determined. The test results revealed some interesting dielectric behavior at high f values. Until the crucial non-uniformity f_o, the breakdown electric field intensity of C_4F_7N/CO_2 was inversely related to f. The breakdown electric field strength became constant once f exceeded f_o. Furthermore, the gas pressure was favorably connected with one another. The breakdown voltage of 59% C_4F_7N/CO_2 mixes is more susceptible to non-uniformity variation than SF6. The AC insulation strength of the 9% C_4F_7N /91% CO_2 mixture is 80% that of SF_6 [15].

In this research, the effect of various contaminating particles such as sphere and wire particles without spacer and others with the presence of various shapes of spacers such as disc and conical spacer on the breakdown voltage values under high voltage D.C is studied.

2 Ionization Coefficients for SF_6-Gas Mixtures

In order to compute the breakdown voltages of SF_6–gas mixtures, a knowledge of the effective ionization coefficient $\overline{\propto}$ as a function of the electric field intensity (E) in the neighborhood of $\overline{\propto}=0$ is a prerequisite. The net ionization coefficients for SF_6 –gas mixtures $(\overline{\propto})$mix can be calculated from the values of $\overline{\propto}$ in pure gases. For pure Nitrogen the net ionization coefficients $\overline{\propto}$ can be approximated by [16, 17];

$$\frac{\overline{\propto}}{P} = 66\exp\left[\frac{-2.15}{E/P}\right] \quad (1)$$

The measurements of the effective ionization coefficient $\overline{\propto}$ for CO_2 have been summarized by Rein and can be approximated by the following equations [18, 19]:

$$\frac{\overline{\propto}}{P} = 176.5\exp\left[\frac{-2.565}{E/P}\right] \quad \text{for } 0.2<=E/P<=0.28 \quad (2)$$

$$\frac{\overline{\propto}}{P} = 50.3\exp\left[\frac{-1.515}{E/P}\right] \quad \text{for } 0.28<E/P<=100 \quad (3)$$

For air, the ionization coefficients can be approximated by [20, 21],

$$\frac{\overline{\propto}}{P} = 22\left(E/P-0.244\right)^2 \quad \text{for } 0.244<E/P<=0.5 \quad (4)$$

$$\frac{\overline{\propto}}{P} = 15.8114\left(E/P-0.244\right)^{1.75} \quad \text{for } 0.5<E/P<=1.2 \quad (5)$$

For pure SF_6, $\overline{\propto}/P$ can be expressed as [15],

$$\frac{\overline{\propto}}{P} = 27\left(E/P-0.8775\right) \quad (6)$$

In Eqs. (1) through (6) , P is the gas pressure in kPa , $\overline{\propto}/P$ is given in $(cm.kPa)^{-1}$ and E/P has the units of $kV(cm.kPa)^{-1}$.

For a given SF_6-gas mixture, the effective ionization coefficient is assumed to be given by [19]:

$$(\overline{\propto}/P)mix=F(\overline{\propto}/P)SF_6+(1-F)(\overline{\propto}/P)gas \quad (7)$$

where, F = $P(SF_6)$ / P(mix) is the partial pressure ratio of the SF_6 component in a given gas mixture.

3 Methodology for Breakdown Voltage Calculations

With an applied electric field, discharges in the gas occur as a result of ionization, which leads to streamer formation and ultimately to the breakdown of the gas mixture. One way to predict the breakdown voltage of the gas mixture is, therefore, by knowing its effective ionization coefficient.

In a non-uniform field gap, corona discharges will occur when the conditions for a streamer formation in the gas are fulfilled. Streamer formation is both pressure and field-dependent, and therefore depends on the electrode profile, geometry of the contaminating particle, its position in the gap between electrodes if it is free, and on the instantaneous value of the ambient field. The condition for streamer formation is given by [21];

$$\int_0^{xc} \overline{\propto}(x)dx \ge K \quad (8)$$

Where, $\overline{\propto}(x)=\alpha(x)-\eta(x)$, $\alpha(x)$ and $\eta(x)$are the first ionization coefficient and the coefficient of attachment, respectively; both being functions of field and thus of geometry.

The distance (xc) from the particle's tip or triple junction point is where the net ionization is zero, normally known as the ionization boundary. There is some controversy over the value of K, the discharge constant. The value of K for pure gases in the pressure range of 100 to 400 kPa is obtained as follows using the breakdown data given in the CIGRE paper [22];

In this study for breakdown voltages, we take the value of K = 18.42 for SF_6 gas and SF_6 - gas mixture.

4 Experimental Setup and Procedures

The experiment was conducted in a test chamber having 12 cm diameter and 50 cm length and is capable of withstanding pressure up to 5 bars. The electrode system was installed in the chamber which filled with SF_6 gas or air at room temperature as shown in Fig. 1. Electrode system which it used in this experiment is two parallel plane electrodes bridged by Epoxy Resin spacer inside test vessel. The gap space (G) between two parallel electrodes is taken as 20mm.
Fig. 2 shows experimental setup for breakdown voltage test. Firstly, connect the ground and the return of high voltage D.C (H.V.D.C) supply to the test link which it connected to the earth to make protection for the persons who deals with the supply. Then connect the lower plane electrode of the system to the earth. Secondly, connect output of H.V.D.C supply to one terminal of water resistance (1MΩ) and then connect the other terminal to the test vessel as shown in the Figure. There are two meters which connected with the test vessel; one of them is for vacuum gauge and other for gas pressure gauge. Then connect high voltage evacuation pump to the test vessel through conduit and valve. After that, connect SF_6 gas tube to the test vessel through conduit and valve. Finally, connect 1-ph A.C supply to H.V.D.C power supply to start the high voltage test. Then start the experiment by press on push button to operate high voltage D.C supply, adjust voltage range and then increase the voltage which applied to upper electrode gradually until breakdown occurred. Three breakdown voltages were measured at a given test condition and the mean values of measured breakdown voltages are taken.

Fig. 1. Test vessel with electrode system.

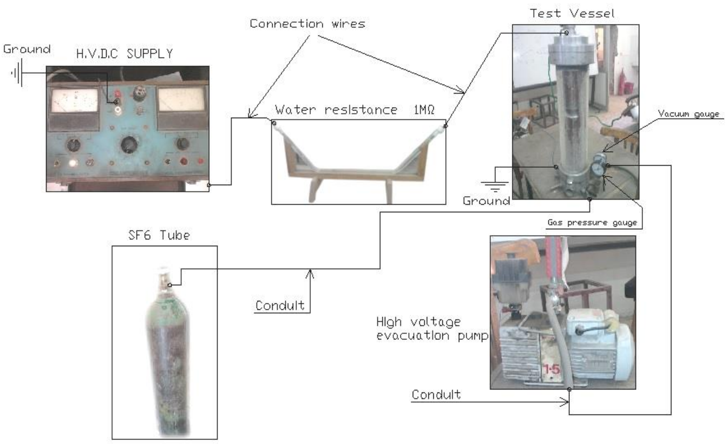


Fig. 2. Experimental setup for breakdown voltage test.

5 Design of Spacer Material

Epoxy resin material is used to make manufacturing for spacer. Epoxy resin consists of two materials (Bisphenol-A and hardener (Anhydride type). In this stage, we make a various concentrations of Bisphenol and hardener and then it mixed to form epoxy resin material. Then the optimum concentration of these materials is selected to form various shapes of spacers such as disc and conical spacers.

Fig. 3 shows Bisphenol and hardener materials.

Fig. 4 shows different samples of epoxy resin with various concentrations of Bisphenol-A and hardener. The height of sample is taken as 20mm. Firstly, it was so difficult to determine special thing to be used to mix the materials which consists epoxy resin. Many things are used to make mixing for these materials but it attached with this thing. Finally, after many times, it can be reached to optimum solution in which the strong aluminum paper can be used to mix these materials and obtain the final material of Epoxy resin.

(a) Bisphenol-A material. (b) Hardener material.

Fig. 3. Bisphenol-A and hardener materials.

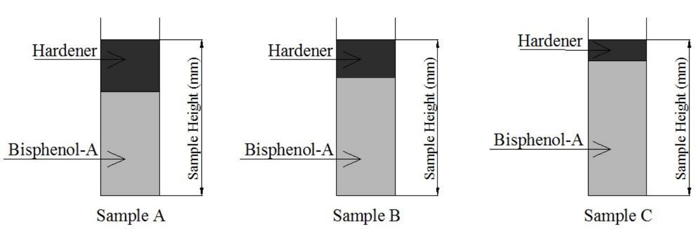


Fig. 4. Samples of Epoxy resin.

Table 1 shows different samples of epoxy resin. From this table, it can be used many concentrations of Bisphenol-A and hardener to form epoxy resin. From different concentrations, it can be noted that (85% of Bisphenol-A & 15% of hardener) is considered the optimum mixture to form uniform and strong epoxy resin. After that, it used the optimum mixture to form different shapes of spacers such as disc and conical spacer.

Table 1

Different samples of epoxy resin.

Sample	Bisphenol-A	Hardener	Mixture
Sample A	60%	40%	Mixture percentage
Sample B	65%	35%	Mixture percentage
Sample C	85%	15%	Mixture percentage

6 Experimental Results for Breakdown Voltage Values

In this section, the experimental results for breakdown voltage values in case of presence two parallel electrodes with Air or SF_6 gas are studied. The effect of single and multi-contaminating particles such as spherical and wire particle on the breakdown voltage values is carried out. The effect of various shapes of spacers such as disc and conical spacer with presence of various contaminating particles on the measured breakdown voltage values is also studied.

6.1 Breakdown voltage for SF6 gas or Air with single or multi-contaminating particles

In this section, the experimental results for breakdown voltage values for SF_6 gas or Air in case of clean gap and other with single or multi-contaminating particles are studied. The comparison between measured and calculated values of breakdown voltage is carried out.

6.1.1 Breakdown voltage for SF6 gas in case of two parallel electrodes without any particle contamination

Fig. 5 shows two parallel electrode systems without any particle contamination. The gap space between two parallel electrodes is taken as 20mm. The test vessel is filled with SF_6 gas.

Fig. 5. Two parallel electrodes system without any particle contamination.

Fig. 6 shows the measured and calculated breakdown voltages for various SF_6 gas pressures. From this figure, it can be observed that the breakdown voltage increased as gas pressure increased. Also, there is a good agreement between the calculated and the measured values of breakdown voltage for various SF_6 gas pressures from 0.1 bar up to 0.4 bar.

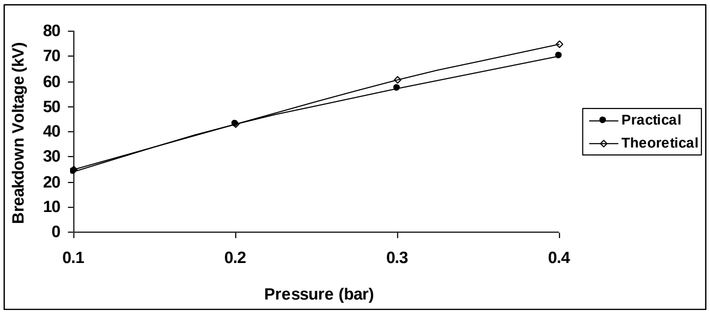


Fig.6. Calculated and measured breakdown voltages as a function of SF_6 gas pressure.

6.1.2 Breakdown voltage for SF6 gas in case of two parallel electrode with spherical particle contamination rested at ground electrode

Fig. 7 shows two parallel electrodes system with fixed spherical particle contamination rested at ground electrode. The gap space between two parallel electrodes is taken as 20mm. The test vessel is filled with SF_6 gas.

Fig. 8 shows measured breakdown voltage as a function of SF6 gas pressure at different radius of spherical particle. From this figure, it can be observed that the breakdown voltage decreases as radius of spherical particle increases. At constant pressure 0.4 bar, the breakdown voltage in case of presence spherical particle of 4mm radius decreases to half value in case of clean gap.

Fig. 9 shows calculated and measured breakdown voltages as a function of fixed spherical particle radius at constant pressure 0.8 bar. From this figure, it can be observed that there is a good agreement between measured and calculated values of breakdown voltage at different radius of sphere particle.

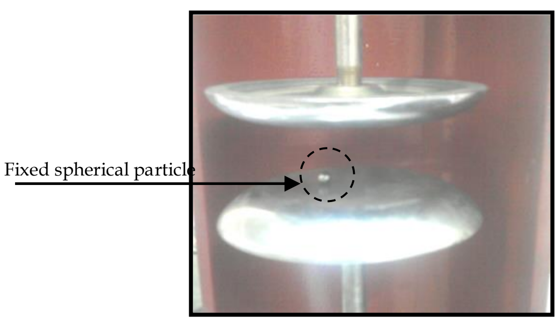


Fig. 7. Two parallel electrodes system with fixed spherical particle contamination rested at ground electrode.

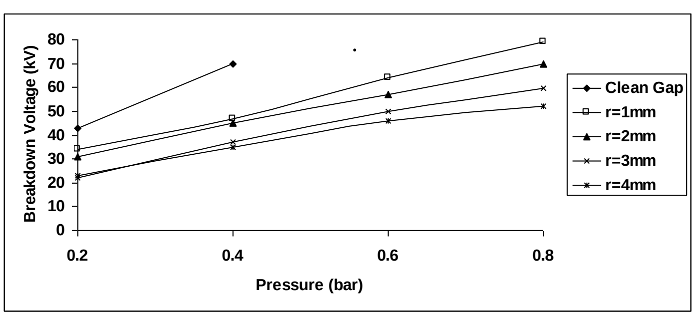


Fig. 8. Measured breakdown voltage as a function of SF_6 gas pressure at different radius of spherical particle.

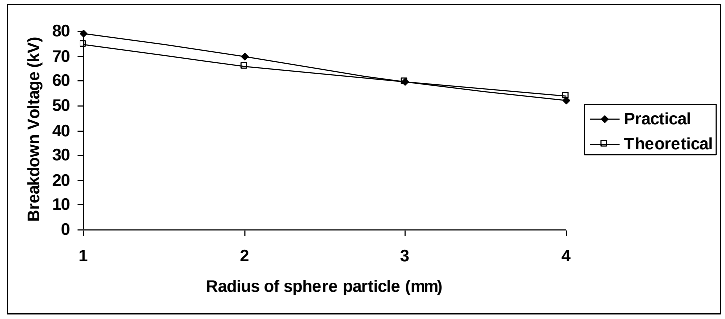


Fig. 9. Calculated and measured breakdown voltages as a function of spherical particle radius at constant pressure 0.8 bar.

6.1.3 Breakdown voltage for SF6 gas in case of two parallel electrodes with multi-fixed spherical particles rested at ground electrode

Fig. 10. shows two parallel electrodes system with multi-fixed spherical particles contamination rested at ground electrode. The separated distance between two ground spherical particles is taken as 14mm. The radius of two spherical particle is taken as 2mm. The test vessel is filled with SF_6 gas.

Fig. 11 shows calculated and measured breakdown voltages as a function of SF_6 gas pressure in case of presence two fixed spherical particles at ground electrode. Fig. 12 shows Comparison between Calculated and measured breakdown voltages for single and multi-spherical particles with respect to clean gap. From Fig. 11 and Fig. 12, it can be observed that there is a good agreement between measured and calculated values of breakdown voltage at different values of SF_6 gas pressure. From Fig. 12, it can be seen that the breakdown voltage in case of presence multi-fixed contaminating spherical particles is less than it in case of presence single spherical particle which is less than case of clean gap. So, the most dangerous case is observed with multi-contaminating spherical particles.

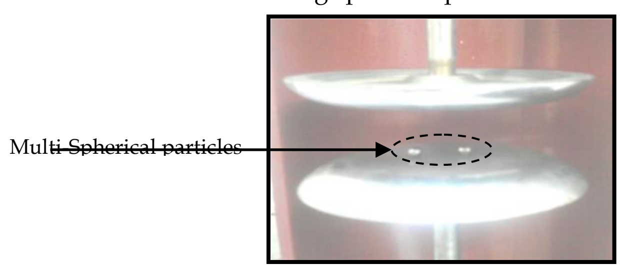


Fig. 10. Two parallel electrodes system with multi-fixed spherical particles contamination rested at ground electrode.

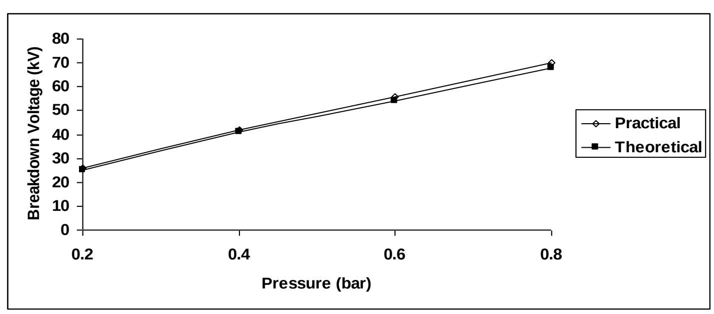


Fig. 11. Calculated and measured breakdown voltages as a function of SF_6 gas pressure in case of presence of two fixed spherical particles at the ground electrode.

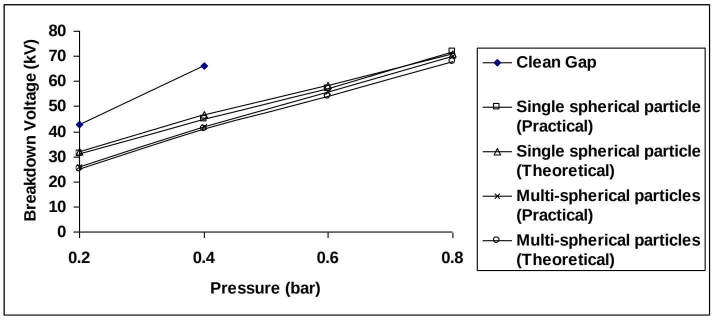


Fig. 12. Comparison between Calculated and measured breakdown voltages for single and multi-spherical particles with respect to clean gap.

6.1.4 Breakdown voltage for SF_6 gas or Air in case of two parallel electrodes with single wire particle rested at the ground electrode

Fig. 13 shows two parallel electrodes system with a single wire contaminating particle resting at the ground electrode. The test vessel is filled with Air or SF_6 gas.

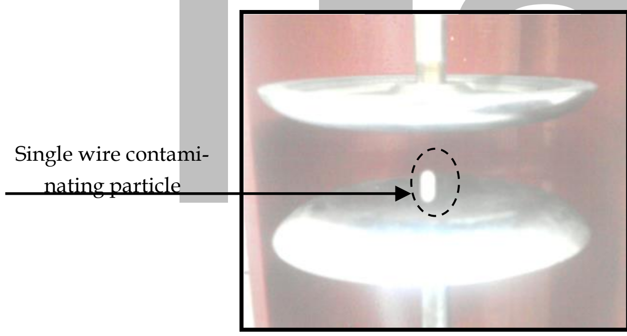


Fig. 13. Two parallel electrodes system with single wire contaminating particle rested at ground electrode.

Fig. 14 shows calculated and measured breakdown voltages as a function of SF_6 gas pressure in case of presence single wire contaminating particle at constant particle radius (r=0.75mm). Fig.15 shows the effect of particle length on measured breakdown voltages at constant particle radius (r=0.75mm) and constant pressure (P=1bar). From these figures, it can be observed that breakdown voltage decreases as particle length increases. From Fig. 14, it can be seen that there is very small error between calculated and measured values of breakdown voltage. From Fig. 15, it can be observed that the breakdown voltage in case of the presence of SF_6 gas is equal to 2.5 times of breakdown voltage in case of the presence Air.

Fig. 16 shows calculated and measured breakdown voltages as a function of Air or SF_6 gas pressure in case of the presence single wire contaminating particle at constant particle length (L=6mm). From this figure, it can be observed that breakdown voltage increases as the hemispherical radius of the particle increases. Also, there is a good agreement between calculated and measured values of breakdown voltage.

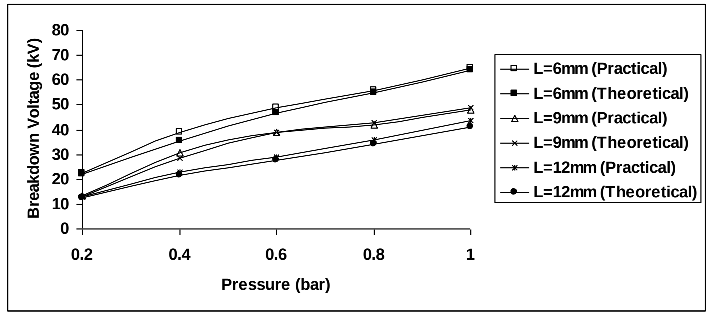


Fig. 14 Calculated and measured breakdown voltages as a function of SF_6 gas pressure in case of the presence single wire contaminating particle at constant particle radius (r=0.75mm).

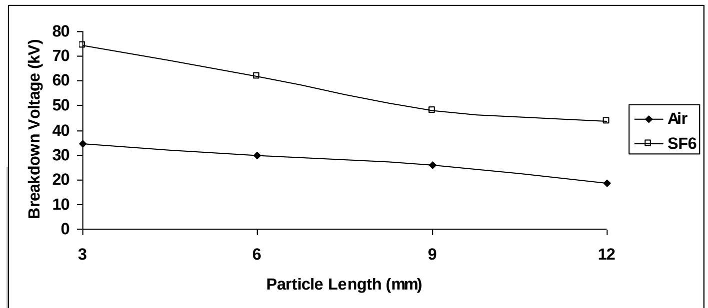


Fig. 15. Effect of particle length on measured breakdown voltages at constant particle radius (r=0.75mm) and constant pressure (P=1 bar).

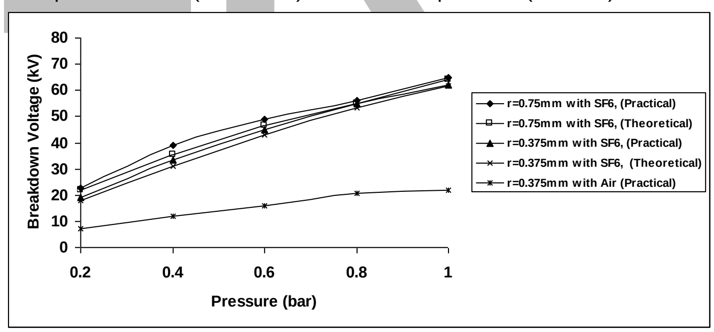


Fig. 16. Calculated and measured breakdown voltages as a function of Air or SF6 gas pressure in case of presence single wire contaminating particle at constant particle length (L=6mm).

6.1.5 Breakdown voltage for SF_6 gas or Air in case of two parallel electrodes with multi-wire particles rested at ground electrode

Fig. 17 shows two parallel electrodes system with multi-wire contaminating particles resting at ground electrode. The test vessel is filled with Air or SF_6 gas. The length and hemispherical radius of wire particles are taken as 6mm and 0.75mm respectively.

Fig. 18 shows a Comparison between measured breakdown voltages for single and multi-wire particles with respect to clean gap. From this figure, it can be observed that the breakdown voltage in case of presence of multi-wire contaminating particles is less than it in case of presence single wire particle which is less than case of clean gap. So, the most dangerous case is observed with multi-wire contaminating particles. Also, the breakdown voltage for case with multi-contaminating particles with Air is less than it with SF_6-gas.

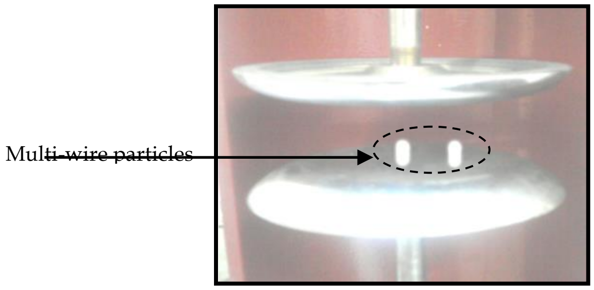


Fig. 17. Two parallel electrodes system with multi-wire contaminating particles rested at ground electrode.

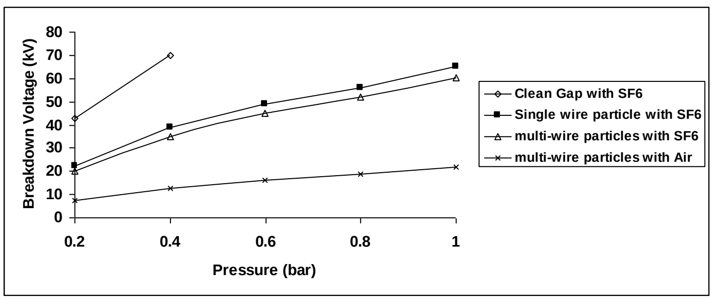


Fig. 18. Comparison between measured breakdown voltages for single and multi-wire particles with respect to clean gap.

6.2 Breakdown voltage for SF_6 gas or Air with presence of spacer and single or multi-contaminating particles

In this section, the effect of various shapes of spacers such as disc and conical spacer with presence of various contaminating particles on the measured breakdown voltage values is studied.

6.2.1 Breakdown voltage for SF_6 gas or Air in case of two parallel electrodes bridged with disc spacer

Fig. 19 shows two parallel electrodes system bridged with disc spacer. The gap space between two parallel electrodes is taken as 20mm. The width and length of spacer are taken as 20mm and 20mm respectively. The test vessel is filled with SF_6 gas or Air.

Fig. 19. Two parallel electrodes system bridged with disc spacer.

Fig. 20 shows measured breakdown voltage as a function of gas pressure in case of the presence disc spacer. From this figure, it can be observed that the breakdown voltage when the gap is filled with SF_6 gas is equal 2.5 to 3 times from its value when the gap is filled with Air.

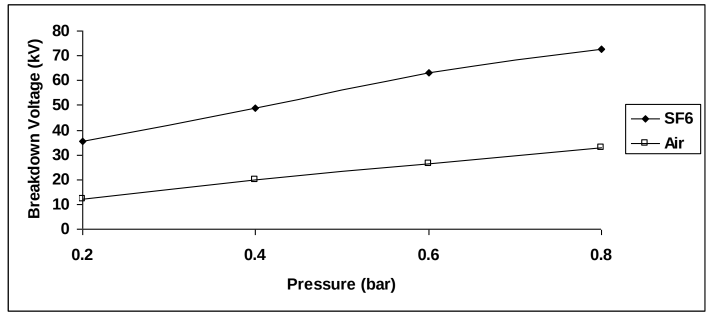
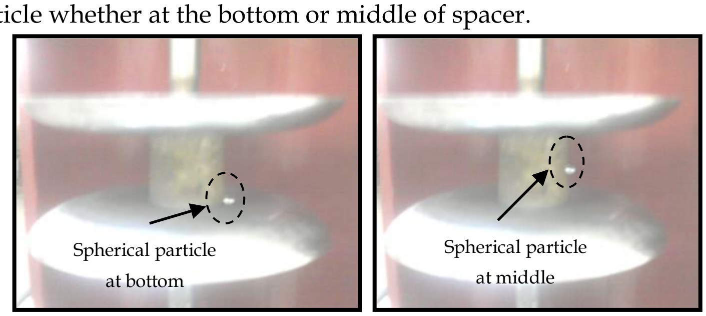


Fig. 20 Measured breakdown voltage as a function of gas pressure in case of the presence disc spacer.

6.2.2 Breakdown voltage for SF_6 gas in case of two parallel electrodes bridged with disc spacer and sphere particle

Fig. 21 shows two parallel electrodes system bridged with disc spacer and spherical particle. Fig. 21(a) shows spherical particle rested at bottom of spacer. Fig. 21(b) shows spherical particle at middle of spacer. The radius of spherical particle is taken as 2mm.

Fig. 22 shows the relationship between breakdown voltage and pressure when a spherical particle is attached on a disc spacer surface at the different locations on the spacer in SF_6-gas. From this figure, it can be observed that the breakdown voltage when the particle in contact with the earthed electrode and attached at the bottom of spacer is lower than that for the particle located in the middle of spacer. The breakdown voltage in case of clean disc spacer is greater than that for the particle whether at the bottom or middle of spacer.



(a) (b)

Fig. 21. Two parallel electrodes system bridged with disc spacer and (a) spherical particle at bottom of spacer or (b) Spherical particle at the middle of the spacer.

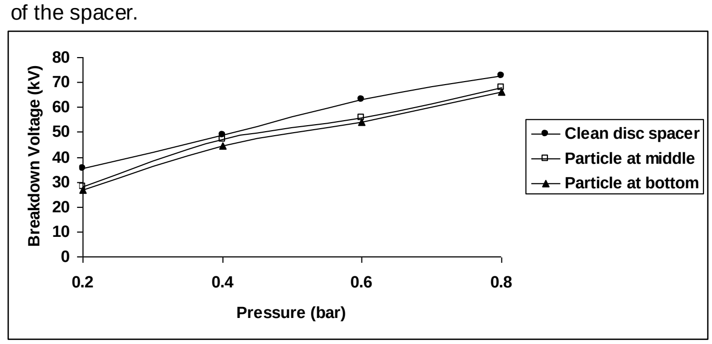


Fig. 22. Breakdown voltage as a function of gas pressure with different spherical particle locations of radius 2mm along disc-spacer.

6.2.3 Breakdown voltage for SF_6 gas in case of two parallel electrodes bridged with disc spacer and stick wire particle

Fig. 23 shows two parallel electrodes system bridged with disc spacer and stick wire particle. The particle length and radius are taken as 6mm and 0.5mm respectively. The height of stick particle from ground electrode is taken as 10mm.

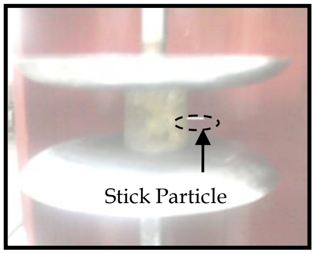


Fig. 23. Two parallel electrodes system bridged with disc spacer and stick wire particle.

Fig. 24 shows measured breakdown voltage as a function of SF_6 gas pressure in case of presence stick particle at middle of disc spacer. From this figure, it can be observed that the measured values of breakdown voltage are reduced due to presence of stick particle at middle of disc spacer that it in case of clean disc spacer.

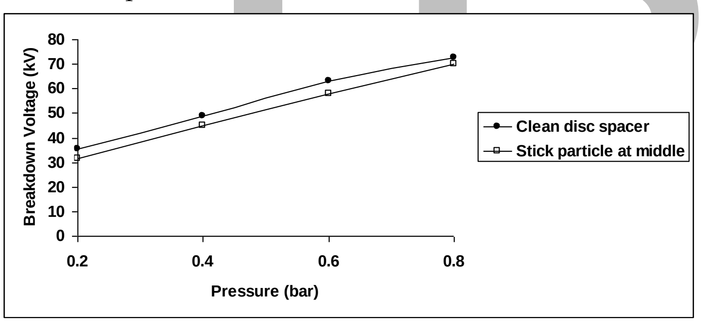


Fig. 24. Breakdown voltage as a function of SF_6 gas pressure in case of the presence of stick particle at the middle of disc spacer.

6.2.4 Breakdown voltage for SF_6 gas or Air in case of two parallel electrodes bridged with disc spacer and multi-wire particles

Fig. 25 shows two parallel electrodes system bridged with disc spacer and multi-wire particles. The particles lengths and radiuses are taken as 6mm and 0.5mm respectively. The particles are rested at ground electrode. One of these particles is attached with disc spacer as shown in the figure. The separated distance between two particles is taken as 4mm.

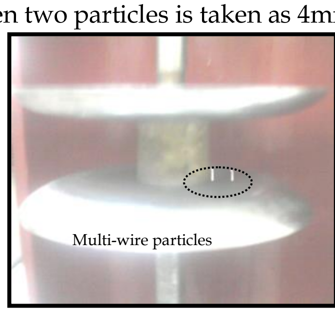


Fig. 25. Two parallel electrodes system bridged with disc spacer and multi-wire particles.

Fig. 26 shows Comparison between measured breakdown voltages for single and multi-wire particles with respect to clean gap in case of filling gap with Air or SF6 gas. From this figure, it can be observed that the breakdown voltage in case of presence multi-wire contaminating particles is less than it in case of presence single wire particle which is less than case of clean gap. So, the most dangerous case is observed with multi-wire contaminating particles. Also, the breakdown voltage for case with multi-contaminating particles with Air is less than it with SF_6-gas.

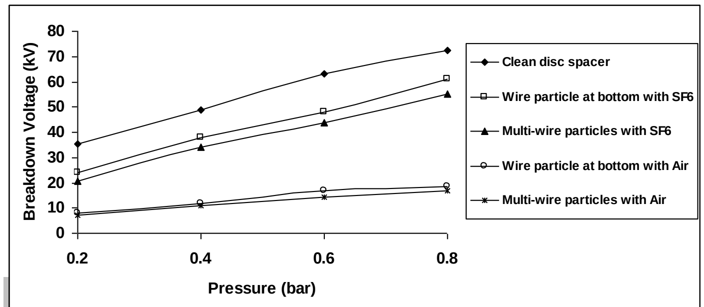


Fig. 26. Comparison between measured breakdown voltages for single and multi-wire particles with respect to clean gap in case of filling gap with Air or SF_6 gas.

6.2.5 Breakdown voltage for SF_6 gas in case of two parallel electrodes bridged with conical spacer and single sphere particle

Fig. 27 shows two parallel electrodes system bridged with conical spacer and single spherical particle at different positions. The height of conical spacer is taken as 23mm. The upper width and lower width of conical spacer are taken as 20mm and 30mm respectively. The radius of spherical particle is taken as 2mm. The test vessel is filled with SF_6 gas at different pressures.

(a) (b) (c)

Fig. 27. Two parallel electrodes system bridged with (a) clean conical spacer or (b) Conical spacer with ground spherical particle or (c) Conical spacer with a spherical particle at the middle.

Fig. 28 shows the relationship between breakdown voltage and pressure when a spherical particle is attached on a conical spacer surface at the different locations on the spacer in SF_6-gas. From this figure, it can be observed that the breakdown voltage in case of spherical particle rested at ground electrode and in contact with spacer is less than it in case of spherical particle at middle of spacer which is less than it in case of clean conical spacer.

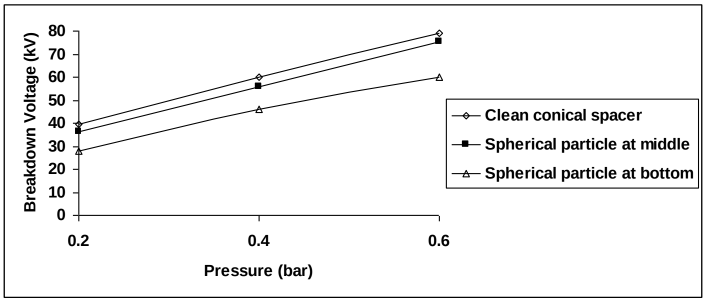


Fig. 28. Breakdown voltage as a function of SF_6 gas pressure with different spherical particle locations of radius 2mm along conical spacer.

6.2.6 Breakdown voltage for SF_6 gas or Air in case of two parallel electrodes bridged with conical spacer and multi-spherical particles

Fig. 29 shows two parallel electrodes system bridged with conical spacer and multi-spherical particles rested at ground electrode. One of these particles is in contact with spacer surface. The radius of two spherical particles are taken as 2mm. The separated distance between two spherical particles is taken as 7mm. The test vessel is filled with SF6 gas or Air at different pressures.

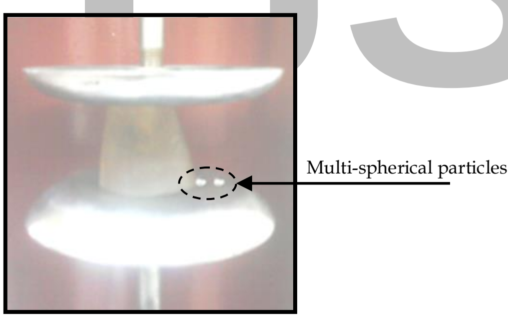


Fig. 29. Two parallel electrodes system bridged with conical spacer and multi-spherical particles rested at ground electrode.

Fig. 30 shows comparison between breakdown voltages for single and multi-spherical particles with respect to case of clean conical spacer. From this figure, it can be observed that the breakdown voltage is reduced due to the presence of single or multi-contaminating spherical particles with respect to the case of clean conical spacer but the percentage of reduction in breakdown voltage for case with multi-spherical particles is larger than it in case of single spherical particle. Also, the breakdown voltage for the case with multi-spherical particles with Air is less than it is for the case with SF_6 gas.

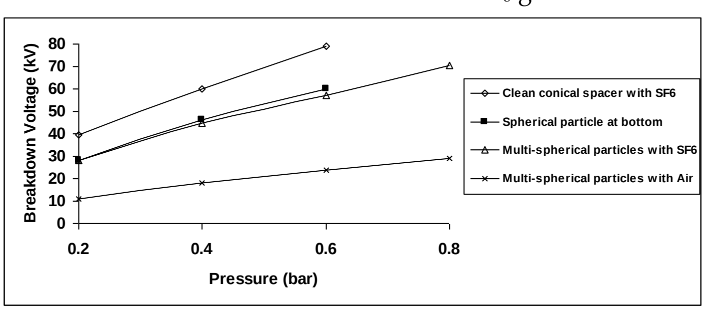


Fig. 30. Comparison between breakdown voltages for single and multi-spherical particles with respect to the case of clean conical spacer.

6.2.7 Breakdown voltage for SF_6 gas or Air in case of two parallel electrodes bridged with conical spacer and wire particle

Fig. 31 shows two parallel electrode systems bridged with conical spacer and wire contaminating particles. The wire-contaminating particle surface is in contact with the conical spacer surface and is located in the middle of it. The length and hemispherical radius of wire particles are taken as 6mm and 0.75mm respectively. The test vessel is filled with SF6 gas or Air at different pressures.

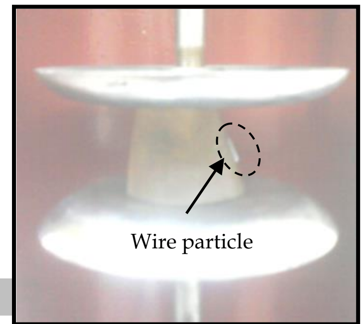


Fig. 31. Two parallel electrodes system bridged with conical spacer and wire contaminating particle.

Fig. 32 shows measured breakdown voltages as a function of gas pressure for single wire particle located at middle of conical spacer. From this figure, it can be observed that the breakdown voltage in case of presence wire contaminating located at middle of spacer with SF6 gas is greater than it with Air.

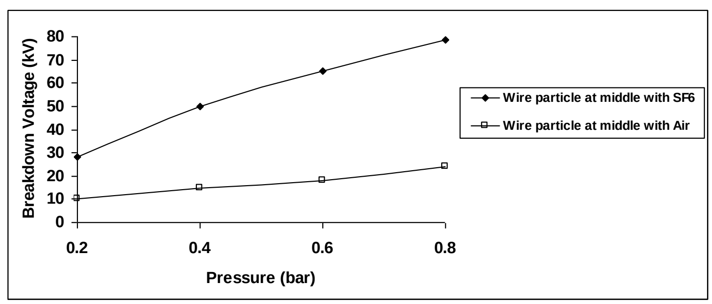


Fig. 32. Measured breakdown voltages as a function of gas pressure for single wire particle located at the middle of a conical spacer.

7 Conclusion

From the results and discussions throughout this work, the following conclusions are drawn:

- The optimum solution is obtained by using the strong aluminum paper to make mixing for Bisphenol and hardener and obtain the final material of Epoxy resin.
- 85% of Bisphenol-A and 15% of hardener is considered the optimum mixture to form a uniform and strong epoxy resin.
- The breakdown voltage when the spherical particle is in contact with the earthed electrode and attached at the bottom of the spacer is lower than that for the particle located in the middle of the spacer.

- At constant pressure, breakdown voltage in case of the presence of multi-contaminating particles reduces to 40% from its value in case of the presence of single wire protrusion.
- There is a good agreement between the calculated and the measured values of breakdown voltage for various Air or SF_6 gas pressures.

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