

Effect of Metallic Particles on Breakdown Voltage in SF₆/N₂ Gas Mixtures

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Abstract—Performance of the metal particles is determined by the breakdown voltage in SF₆/N₂ gas mixtures. The main factors which influence the breakdown in SF₆/N₂ are the shape, size, and different angles for uniform & non uniform field. Present work is intended to study the effect of metallic particles on breakdown voltage in SF₆/N₂ gas mixtures. Experiments have been carried out for different particles such as copper, aluminum & silver of 10 mm lengths are used under angle of 0° along with different shapes of electrodes for AC voltage. Experimental results show that in copper and aluminium particles affect the insulation performance of SF₆/N₂ more than that with aluminum particle.

Keywords— Breakdown voltage; SF₆/N₂ gas mixtures; electrodes; AC voltage.

I. INTRODUCTION

There is a need for the larger amount of power generation, transmission and distribution networks in the world with the increase in the Industrial growth. Significant advances have been made in the design and development of high voltage Transmission and distribution. There is a need for compressed gas insulated system for transmission of bulk power with rated voltage above 800 kV. In the Gas Insulated Transmission Lines (GITL) and Gas Insulated Systems (GIS), the use of compressed SF₆ gas as an insulating media in all the switchgears and circuit breakers has come into practice. SF₆ is an electro negative gas and it has dielectric strength three times that of SF₆ / N₂, the outstanding properties of SF₆ have resulted in its extensive use as an insulating gas in high voltage. On the other hand, it is a highly potent greenhouse gas due to its high global warming potential. Alternative insulating gases to replace SF₆ has been investigated in recent decade equipment.

Gas insulated substation have been major innovation in Power Transmission and distribution with proven reliability and maintenance free operation the gas insulated substation has its existence more than three decades the insulating material between the electrodes may be in solid, liquid and gaseous forms. These insulating materials will have variation

in insulation strength based on operating condition of system such as applied voltage pressure of SF₆/N₂ bubble in liquid and solid dielectrics.

These factors degraded the insulating materials under partial discharges takes place between the electrodes in the beginning of the gas insulated circuit breakers by insulated gas used was SF₆ alone but after the World Congress the environmentists have taken the objection to the usage of sulphur hexafluoride gas as it is Greenhouse gas Hence engineers start inventing the combination of SF₆, CO₂, N₂ etc. in different proportion in order to decrease the usage of greenhouse gas.

The electrical breakdown is used either by microscopic projection on electrode surface by free conducting particles and occurs as a result of process of ionization of gas molecule by free electrons. With this background keeping the need for gas insulated substation technology and to reduce SF₆ content in gas insulated substation this work has been carried out with the 10% of SF₆ and 90% of N₂.

In this paper, an experimental study has been carried out to study the effect of metallic particles on breakdown voltage by considering three different electrodes (plane-plane, plane-point and plane-sphere) by varying the gap distance of 20 mm, 30 mm and 40 mm under angle of 0° respectively.

II. BREAKDOWN VOLTAGE IN INSULATING MATERIAL

A. Breakdown Voltage in SF₆/N₂

The breakdown in air (spark breakdown) is the transition of a non-sustaining discharge into a self-sustaining discharge. The buildup of high currents in a breakdown is due to the ionization in which electrons and ions are created from neutral atoms or molecules, and their migration to the anode and cathode respectively leads to high currents. Townsend theory and Streamer theory are the present two types of theories which explain the mechanism of breakdown under different conditions as temperature, pressure, nature of electrode surfaces, electrode field. Normally SF₆ / N₂ medium is widely

used as an insulating medium in different electrical power equipment and overhead lines as its breakdown strength is 30kV/cm.

B. Types of Electrode Arrangement for Measurement of BDV

IEC 60052 sets four recommendations concerning the construction and use of standard SF6 /N2 gaps for the measurement of peak values of some like alternating voltages of power frequencies, full lightning impulse voltages, switching impulse voltages and direct voltages are involves unusual problems that may not be familiar to specialists in the common electrical measurement techniques. These problems increase with the magnitude of the voltage, but are still easy to solve for voltages of some 10 kV only, and become difficult if hundreds of kilovolts or even megavolts have to be measured. The high voltage power equipments have large stray capacitances with respect to the grounded structures and hence large voltage gradients are set up. A person handling these equipments and the measuring devices must be protected against these over voltages. For this, large structures are required to control the electrical fields and to avoid flash over between the equipment and the grounded structures. Therefore, the location and layout of the equipments. There are various types of electrode arrangements and circuits for measurement of high voltages and currents. Those are,

- i) Plane - Plane
- ii) Plane - Sphere
- iii) Point – Plane



Figure 1: Plane-Plane electrode arrangement

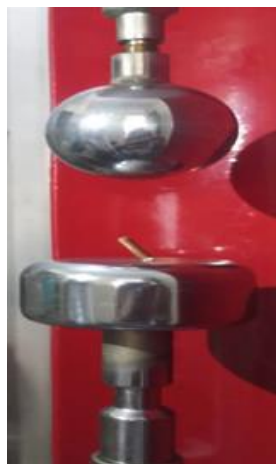


Figure 2: Sphere-Plane electrode arrangement



Figure 3: Point-Plane electrode arrangement

Metallic Particle placed on the surface of the plane electrode with different diameter & angle (0°) is given in Table 1.

Table 1: Conductors dimensions considered for present study

Conductor Type	Diameter of the Conductor (mm)			Length (mm)
Copper Conductor	1 mm	2.5 mm	4 mm	10 mm
Aluminium Conductor	1 mm	2.5 mm	4 mm	10 mm
Silver Conductor	1 mm	2.5 mm	4 mm	10 mm

III. EXPERIMENTAL ARRANGEMENT

An AC output terminal of the high voltage transformer is connected to the gas chamber through water resistor. Different electrodes are placed in gas chamber in their proper positions. Now the main supply is switched on from control panel. Voltage is increased using increase button from the control panel till the spark occurs. Distance between the electrodes is increased from 5 mm - 40 mm. Before placing the next different electrodes in the chamber, proper discharging is done through grounding rod. Test set up used for conducting experiments is as shown in Figure 4.

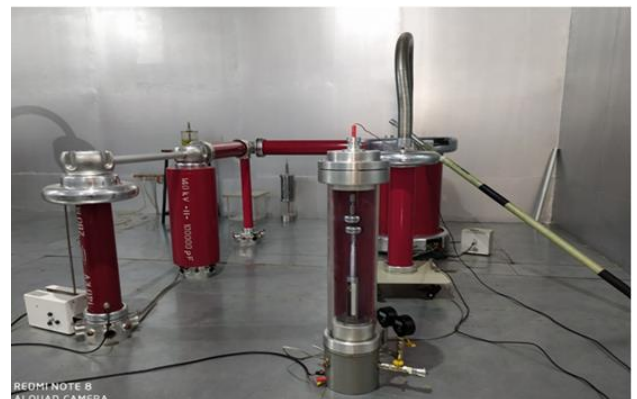


Figure 4: Test setup for HVAC

IV. CIRCUIT DIAGRAM

Experiments for breakdown voltage in SF₆/N₂ gas mixtures for different electrodes for different metals under different angles were conducted. The equivalent circuits are as shown below in Figure 5.

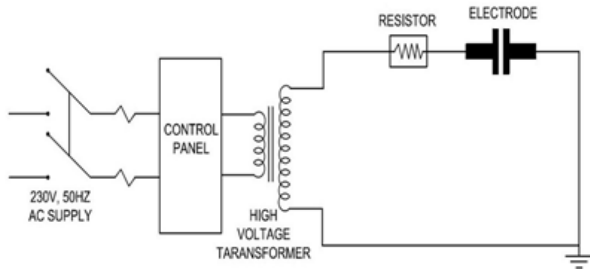


Figure 5: Circuit Diagram for HVAC System

V. RESULTS AND DISCUSSION

To simulate the performance characteristic of the SF₆/N₂ breakdown voltage (BDV) and maximum electric field between the conducting electrodes, two standard electrodes is taken into considered in this work. The main focus of the analysis is variation of breakdown voltage versus electrode gap with different diameters. This characteristic provides significant information on the withstanding capacity of the insulation to sustain the high spark over voltage. The SF₆/N₂ breakdown voltage between the electrodes are measured by conducting the SF₆/N₂ breakdown voltage in high voltage laboratory and corresponding BDV are calculated from the experimental depicted in Table 2 to Table 10 . Variation of SF₆/N₂ gas mixture breakdown voltage of Aluminium metal, Copper metal and Silver metal for the different electrode combinations are shown in Figure 6, Figure 7 and Figure 8.

Table 2: SF₆/N₂ breakdown voltage of Aluminium metal for the Plane-Plane electrode combination

Sl No.	Gap between Electrodes	Type of metal	Type of electrode	Angle	Average BDV in KV (HVAC)
1	20 mm	Aluminium (Ø 1.5 mm)	Plane-Plane	0°	25.95
2	30 mm				37.24
3	40 mm				48.58
4	50 mm				53.62

Table 3: SF₆/N₂ breakdown voltage of Aluminium metal of for the Plane-Point electrode combination

SL NO.	Gap between Electrodes	Type of metal	Type of electrode	Angle	Average BDV in KV (HVAC)
1	20 mm	Aluminium (Ø 1.5 mm)	Plane - Point	0°	15.34
2	30 mm				18.93
3	40 mm				21.10
4	50 mm				25.26

Table 4: SF₆/N₂ breakdown voltage of Aluminium metal of for the Plane-Sphere electrode combination

SL NO.	Gap between Electrodes	Type of metal	Type of electrode	Angle in degrees	Average BDV in KV (HVAC)
1	20 mm	Aluminium (Ø 1.5 mm)	Plane - Sphere	0°	29.63
2	30 mm				40.24
3	40 mm				47.79
4	50 mm				53.45

From the Table 2-4, it was observed that as the gap distance increases the BDV of Aluminium material of diameter 1.5 mm under the angle of 0° in in SF₆/N₂ gas mixtures also increases in Plane -Plane, Plane -Point and Plane -Sphere Electrodes.

Table 5: SF₆/N₂ breakdown voltage of Copper metal of for the Plane-Plane electrode combination

SL NO.	Gap between Electrodes	Type of metal	Type of electrode	Angle	Average BDV in KV (HVAC)
2	20 mm	Copper (Ø 1.5 mm)	Plane - Plane	0°	24.64
3	30 mm				37.06
4	40 mm				47.50
5	50 mm				52.46

Table 6: SF₆/N₂ breakdown voltage of Copper metal of for the Plane-Point electrode combination

SL NO.	Gap between Electrodes	Type of metal	Type of electrode	Angle	Average BDV in KV (HVAC)
1	20 mm	Copper (Ø 1.5 mm)	Plane - Point	0°	13.46
2	30 mm				21.08
3	40 mm				23.82
4	50 mm				28.57

Table 7: SF₆/N₂ breakdown voltage of Copper metal of for the Plane-Sphere electrode combination

SL NO.	Gap between Electrodes	Type of metal	Type of electrode	Angle	Average BDV in KV (HVAC)
1	20 mm	Copper (Ø1.5 mm)	Plane - Sphere	0°	34.81
2	30 mm				45.72
3	40 mm				51.32
4	50 mm				55.04

From the Table 5-7, it was observed that as the gap distance increases the BDV of Copper material of diameter 1.5 mm under the angle of 0° in in SF₆/N₂ gas mixtures also increases in Plane -Plane, Plane -Point and Plane -Sphere Electrodes.

Table 8: SF₆/N₂ breakdown voltage of Silver metal of for the Plane-Plane electrode combination

SL NO.	Gap between Electrodes	Type of metal	Type of electrode	Angle	Average BDV in KV (HVAC)
1	20 mm	Silver (Ø1.5 mm)	Plane - Plane	0°	24.62
2	30 mm				39.03
3	40 mm				47.05
4	50 mm				54.73

Table 9: SF₆/N₂ breakdown voltage of Silver metal of for the Plane-Point electrode combination

SL NO.	Gap between Electrodes	Type of metal	Type of electrode	Angle	Average BDV in KV (HVAC)
1	20 mm	Silver (Ø1.5 mm)	Plane -Point	0°	14.19
2	30 mm				19.17
3	40 mm				24.89
4	50 mm				28.58

Table 10: SF₆/N₂ breakdown voltage of Silver metal of for the Plane-Sphere electrode combination

SL NO.	Gap between Electrodes	Type of metal	Type of electrode	Angle in degrees	Average BDV in KV (HVAC)
1	20 mm	Silver (Ø1.5 mm)	Plane – Sphere	0°	29
2	30 mm				36.22
3	40 mm				46.78
4	50 mm				52.74

From the Table 8-10, it was observed that as the gap distance increases the BDV of Silver material of diameter 1.5 mm under the angle of 0° in in SF₆ /N₂ gas mixtures also increases in Plane –Plane, Plane –Point and Plane –Sphere Electrodes.

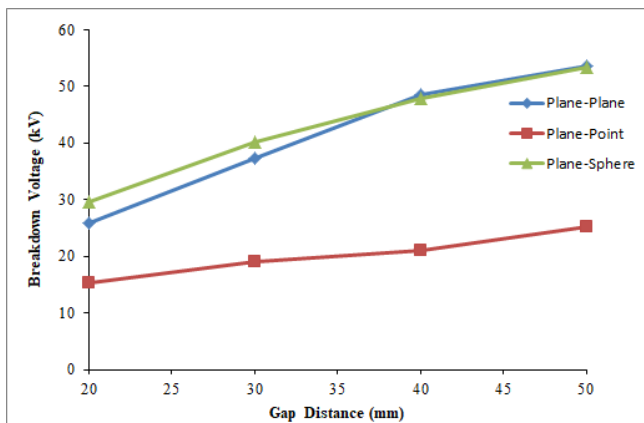


Figure 6: Variation of SF₆/N₂ gas mixture breakdown voltage of Aluminium metal for the different electrode combinations

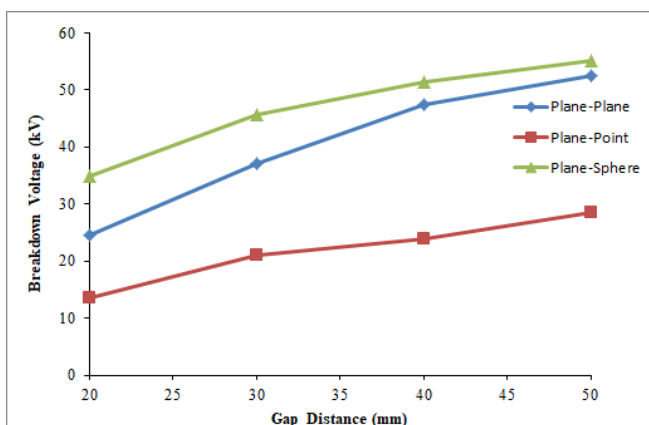


Figure 7: Variation of SF₆/N₂ gas mixture breakdown voltage of Copper metal for the different electrode combinations

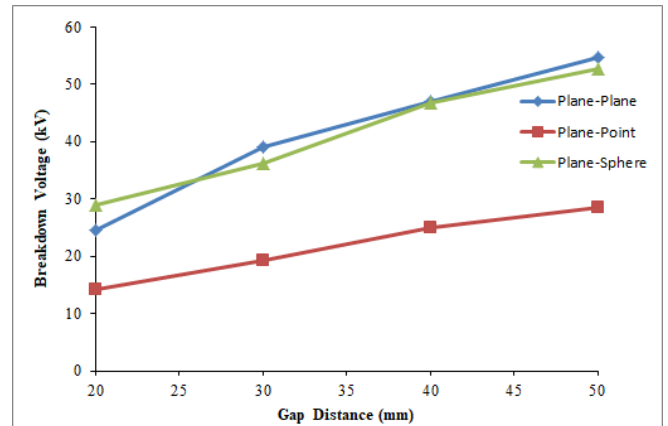


Figure 8: Variation of SF₆/N₂ gas mixture breakdown voltage of Silver metal for the different electrode combinations

VI. CONCLUSIONS

To simulate the performance characteristic of the SF₆ /N₂ breakdown voltage (BDV) and maximum electric field between the conducting electrodes, two standard electrodes is taken into considered in this work. The following conclusions are drawn based on above work

- Breakdown voltages of SF₆/N₂ have been investigated in this work. In addition, the effect of metallic particle contamination has been studied under uniform, non-uniform field configurations.
- The breakdown voltage mainly depends on the configuration of the electrodes
- If the field lines are concentrated towards the electrode then the breakdown voltage is of low value.
- Experimental results were also analyzed in case of breakdown across different conductors with different combination of electrodes.
- It is concluded that with the increase of gap between electrodes, the breakdown voltage and electric field strength are increased and is inversely proportional to electrode radius.
- By looking at this graph we will get to know that which conductor is better. In this copper is linearly increasing hence copper is good & better than other conductors.

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