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Measurement of Air Breakdown Voltage and Electric Field Using Standard Sphere Gap Method

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Absrtact: In this paper the theoretical Break Down Voltage (BDV) is compared with the results obtained from the practical set up results and the results obtained from MATLAB simulation under different size and spacing of the electrodes. Maximum electric field and relative air density factor characteristics are obtained with different temperature and pressure and the effect under all the methods i.e. theoretical, practical and simulation results are compared and plotted for the easy grasp and some salient conclusions for the reliability of the alternate methods and quantum of errors involved are derived to support the version.

***Index Terms*—Break Down Voltage (BDV), air density factor**

INTRODUCTION

It has been seen from the studies conducted that, one of the main problem in high voltage power (HV) equipment is the degradation of insulation i.e., quality of insulation of power equipment. As the high voltage power equipments are mainly subjected with spark over voltage caused by the lighting strokes, switching action, a protective device is used for determine the safe clearance required for proper insulation level. The sphere gaps of different configuration are commonly used for this purpose

I SPHERE-GAP ELECTRODES FOR MEASUREMENT OF BDV

The standard sphere gap is the one of the standard methods for the measurement of peak value of DC, AC and impulse voltages and is used for checking the high voltage power equipments and other voltage measuring devices used in high voltage test circuits. Two identical metallic spheres are separated by certain distance form a sphere gap provided that, the gap length between the spheres do not exceed a sphere radius. If these conditions are satisfied and the specifications regarding the shape, mounting, clearances of the spheres are met, the results obtained by the use of sphere gaps are reliable to within ±3%. It has been suggested in standard specification that in places where the availability of ultraviolet radiation is low, irradiation of the gap by radioactive or other ionizing media should be used when voltages of magnitude less than 50 kV are being measured or where higher voltages with accurate results are to be obtained.

In this arrangement one sphere is normally connected directly to earth. Low ohmic shunts may be connected between the sphere and earth of special purpose. The surfaces of spheres is cleaned and dried but need not be polished. In normal use the surfaces of spheres become roughened and pitted. The surface should be rubbed with fine abrasive paper and the resulting dust removed with lint-free cloth, the trace of oil or grease if any, should be removed with a solvent. Moisture may condense on the surface of the sparking points in conditions of high relative humidity causing measurements to become erroneous. So the spheres are made with their surfaces are smooth and their curvatures as uniform as possible. The curvature should be measured by a spherometer at various positions over an area enclosed by a circle of radius 0.3 D about the sparking point where "D' is the diameter of the sphere and sparking points on the two spheres are those which are at minimum distances Sphere gaps can be arranged in vertically, typically with the lower sphere grounded (earthed), and horizontally from each other. The surroundings do have an effect on the breakdown voltage, as they alter the field configuration. Standard clearances are specified for spheres of various sizes in both configurations. These clearances reduce the effect of the surroundings to less than the specified accuracy (e.g. 3%). In the following: "D" is the diameter of the spheres, „S" is the spacing of the gap, S/D ≤ 0.5. "A" is the height of the lowest point of the HV sphere above the ground. "B" is the radius of clearance from surrounding constructions. Figure 1 shows the vertical arrangement of sphere gap method

FIG. 1. VERTICAL SPHERE GAP SCHEMATIC DIAGRAM

II APPARATUS FOR MEASUREMENT OF AIR BDV

To conduct the air breakdown test using standard sphere-sphere electrode in the high voltage laboratory the following apparatus is required

(a) Control Panel

(b) Circuit Breaker

(c) High Voltage Transformer

(d) High Voltage Filter

(e) Voltage Divider

(f) Sphere-sphere gap arrangement

III THEORETICAL STUDY OF AIR BREAKDOWN VOLTAGE

Measurement of high voltages and currents are having more complex and these equipments have large stray capacitance and large voltage gradient. High voltage equipments are protected against over voltages. Sphere gap method is the one of the standard method for measurement of peak values of AC, DC voltages in high voltage circuits. The gap distance between the spheres should not exceed the radius of the sphere. In short duration of time we can measure the breakdown voltage using this method. Sphere electrodes are made with many materials like aluminum, steel, brass, light alloys, bronze and copper .

The electric breakdown strength of a gas-insulated gap between two metal electrodes can be improved considerably when one or both of the electrodes are covered with a dielectric coating, so-called hybrid insulation. The effect of the coating depends on the electrode shape, voltage polarity, pre-charging and the duration and form of the applied voltage. Dielectric barriers in air and oil gaps are well known for bringing improvement to the electric breakdown strength and widely used in high voltage engineering. For example in oil insulated power transformers. Barriers help preventing short circuiting caused by the bridging of particles in the transformer oil, increasing the withstand voltage compared to an oil gap without barriers.

In this method air is acting as an insulating medium between the spheres. The atmospheric air is the combination of various types of gas molecules which influence the breakdown voltage of the system. By increasing the applied voltage between the sphere gaps the breakdown of air takes place at a certain applied voltage which is call as breakdown voltage. The influence of the grounded objects and the shanks, connecting the spheres to the HV supply and to the ground, on the breakdown voltage and the field between equal spheres was reported to be small (a few percent) and depended on the dimensions of the spheres, the gap separation, and the shanks.

To conduct the practical experiment of air breakdown voltage in high voltage laboratory, the theoretical study is the most important or understanding the performance characteristics of the air breakdown voltage. The voltage between the spheres rose till a spark passes between the two spheres. The value of the voltage required to spark over (breakdown) depends upon the dielectric strength of air, the size of the spheres, the distance between the spheres, humidity of the air and many other factors. The breakdown voltage of a sphere

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gap increases by increasing the pressure quantity and decreases by increasing the temperature quantity. The air density factor

$$\delta = \frac{293b}{760(273+t)}$$

where, atmospheric pressure is "b" in mm of Hg and Temperature is "t" in ºC and the breakdown voltage of air between the sphere gap

$$V = \frac{27.2\delta r\left(1+\frac{0.54}{\sqrt{\delta r}}\right)\frac{s}{r}}{0.25\left(\frac{s}{r}+1+\sqrt{\left(\frac{s}{r}+1\right)^2+8}\right)}$$

where, gap between sphere electrodes is "S" in cm and radius of the sphere electrode is "r" in cm, electric field in the gap is where, distance between the sphere electrode is "d" in cm.

Sphere Gap	BDV	BDV	BDV Simulation	Electric field Experiment	Electric field Theory	Electric field Simulation	%Error
1.0	19.5	21.92	33.65	19.35	21.80	33.52	11.0
1.5	30.0	32.17	40.32	20.15	21.35	26.79	6.7
2.0	37	41.71	53.12	18.55	20.70	26.48	11.22
2.5	49	51.40	59.27	19.45	20.42	23.68	4.62
3.0	58	60.81	65.25	19.30	20.15	21.67	4.62
3.5	65	70.0	71.25	18.60	19.98	20.22	7.12
4.0	74	79.19	76.60	18.51	19.70	19.08	6.52
4.5	82	88.38	82.40	18.20	19.50	18.18	7.22
5.0	85	97.58	87.80	16.97	19.35	17.34	12.82
5.5	97	99.77	92.7	17.50	19.25	16.75	9.11

Simulation Study of Air Breakdown Voltage

The present research work focused on the experimental validation of the air breakdown characteristics in high voltage test laboratory and a thorough comparison is made with the theoretical calculations with computer simulation results. The present research work includes comparison of experimental results with the results derived from the empirical formulations with the MATLAB environment. To simulate the practical breakdown test of air the input parameters such as sphere diameter, gap between sphere electrodes, atmospheric pressure, humidity presence in air and temperature are taken 25 cm, range from 1 cm to 5.5 cm, 760mm of Hg, 2-32% and 3 respectively.

In this study the unknown parameters such as air breakdown voltage and electric field for each 0.5 cm of gap between the sphere electrodes are calculated and further compared with the experimental study. As the air breakdown voltage and electric field is the function of electrode geometry, the different radius of sphere electrodes (i.e., 2.5cm, 5cm, 7.5cm and 12.5cm) are also considered in computer simulation. In this simulation study the maximum electric field and relative air density factor are determined at each temperature (100 to 800C; - 100 to -800C) and pressure (710 to 780 torr.) of atmosphere. Humidity correction factor, air breakdown voltage and maximum electric field are found at different humidity of air in atmosphere.

To simulate the performance characteristic of the air breakdown voltage (BDV) and maximum electric field between the conducting spheres, two standard sphere electrodes is taken into considered in this work using MATLAB simulation. 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 air breakdown voltage between the sphere electrodes are measured by conducting the air breakdown voltage in high voltage laboratory and corresponding electrical field strength and % of error BDV are calculated from the experimental, theoretical and simulation results which is depicted in Table 1.

TABLE:1 MEASUREMENT OF BREAKDOWN VOLTAGE AND ELECTRIC FIELD STRENGTH BETWEEN SPHERES

The performance characteristic of air breakdown voltage versus electrode gap for sphere electrodes of 25 cm diameter is shown in Fig. In this Fig the theoretical BDV and simulation

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BDV for different electrode gap spacing are plotted with experimental results

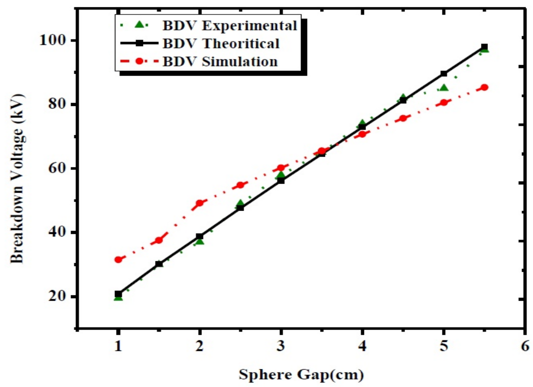

FIG.2. COMPARISON PLOT BETWEEN SPHERE-GAP AND BREAKDOWN VOLTAGE IN EXPERIMENTAL, SIMULATION AND THEORETICAL.

It is clear from the Fig.2 that the gap between the sphere electrode is varies in the wide range from 1 cm to 5.5 cm and the corresponding breakdown voltage is varies in the range from 19.5 kV to 99.77 kV. It is also observed that the increase of sphere gap the air breakdown voltage is also increases. Figure 3 shows that electric field distribution along the gap distance in between the sphere electrode. In this Fig. 3 the theoretical electric field and simulation electric field for different electrode gap spacing are plotted with experimental results.

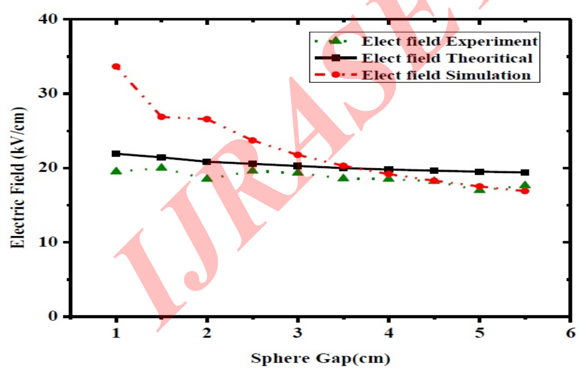

FIG.3 COMPARISON OF EXPERIMENTAL, THEORETICAL AND SIMULATION RESULTS OF ELECTRIC FIELD DISTRIBUTION FOR SPHERE-SPHERE (Φ = 25 CM) ELECTRODE AT DIFFERENT ELECTRODE GAP.

While comparing with the experimental, theoretical and simulation results it is observed that the electric field decreases as the distance between electrodes increases. In addition, to find out the relation between the diameter of sphere electrode with the air breakdown voltage and the corresponding electric field, a theoretical as well as simulation study has been made in this work which is depicted in the Table 2.

Table 2 MEASUREMENTS OF BREAKDOWN VOLTAGE AND ELECTRIC FIELD STRENGTH FOR DIFFERENT SPHERES

Sphere Radius (cm)	2.5	5	7.5	12.5
Breakdown Voltage Theory (kV)	32.2	31.6	31.9	22.34
Breakdown Voltage Simulation (kV)	32	31.9	31.5	30.9
Electric field Theory (kV/cm)	22.76	22.34	22.13	21.92
Electric field Simulation (kV/cm)	22.62	22.55	22.27	21.84
%Error (Breakdown Voltage)	0.6	0.9	0.6	0.3

As the air breakdown voltage and corresponding electrical field strength is depends on the geometric configuration of the sphere electrode, the theoretical and simulation work has been done in this work which shown in Fig.4 and Fig.5 respectively.

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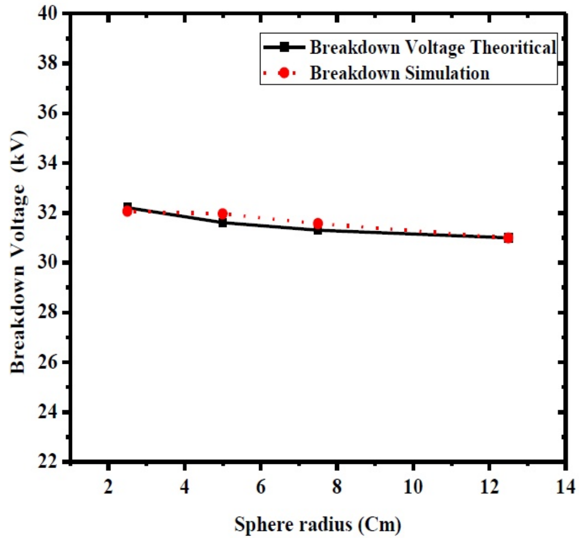

FIG.4. COMPARISON STUDY WITH VARIATION OF SPHERE RADIUS AND AIR BREAKDOWN VOLTAGE.

From Fig.4 it is observed that air breakdown voltage decreases with the increase of the sphere radius in both the theoretical and the simulated results.

Figure 5. shows results between the electric field distributions with wide variation of the sphere diameter.

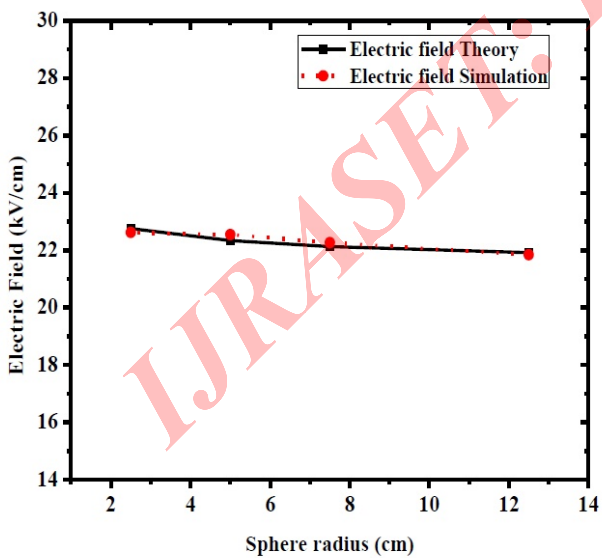

FIG.5. COMPARISON STUDY WITH THE VARIATION OF SPHERE RADIUS AND ELECTRIC FIELD DISTRIBUTION

It is clear from the Fig.5. that with the increase of sphere radius electric field distribution between the sphere electrode decreases.

Atmosphere temperature effects on maximum electric field and relative air density factor. The maximum electric field and relative air density factor at each temperature‟s‟ are determined in simulation. These are given in Table 3. At these parameters, radius of the sphere electrodes is 12.5cm, sphere electrode material is aluminium and atmospheric pressure is 760 mm of Hg.

TABLE 3 MEASUREMENTS OF RELATIVE AIR DENSITY FACTOR AND MAXIMUM ELECTRIC FIELD STRENGTH FOR DIFFERENT TEMPARATURES

Temperature (^{0}C)	Relative air density factor δ	Maximum Electric field (kV/cm)
10	1.03	82.43
20	1	78.71
30	0.96	75.29
40	0.93	72.12
50	0.9	69.18
60	0.87	66.45
70	0.85	63.91
80	0.83	61.54
10	1.03	82.43

IV CONCLUSIONS

In electrical power system, high voltage (HV) power equipments are mainly subjected with spark over voltage. These over voltage which may causes by the lighting strokes, switching action, determine the safe clearance required for proper insulation level. Normally, the standard sphere gaps are widely used for protective device in such electrical power equipments. The sphere gaps are filled up with insulating medium such as liquid insulation (transformer oil), solid insulation and gas insulation (SF6, N2, etc). Generally, air medium is widely use as an insulating medium in different electrical power equipments as its breakdown strength is 30 kV/cm. In this study the performance characteristics of air breakdown voltages and electric field behaviors are studied theoretically as well as experimentally by using the standard sphere gap method. The air breakdown characteristics between the sphere-sphere electrodes are observed with variations in electrode arrangements, both in size and spacing. It is concluded that with the increase of gap between spheres the breakdown voltage and electric field strength are increased and is inversely proportional to sphere radius. Maximum electric field and relative air density factor characteristics are derived with different temperature and pressure. It is concluded that with increase of temperature the maximum electric field and relative air density factor are decreased and with increase of pressure the maximum electric field and relative air density factor are increased.

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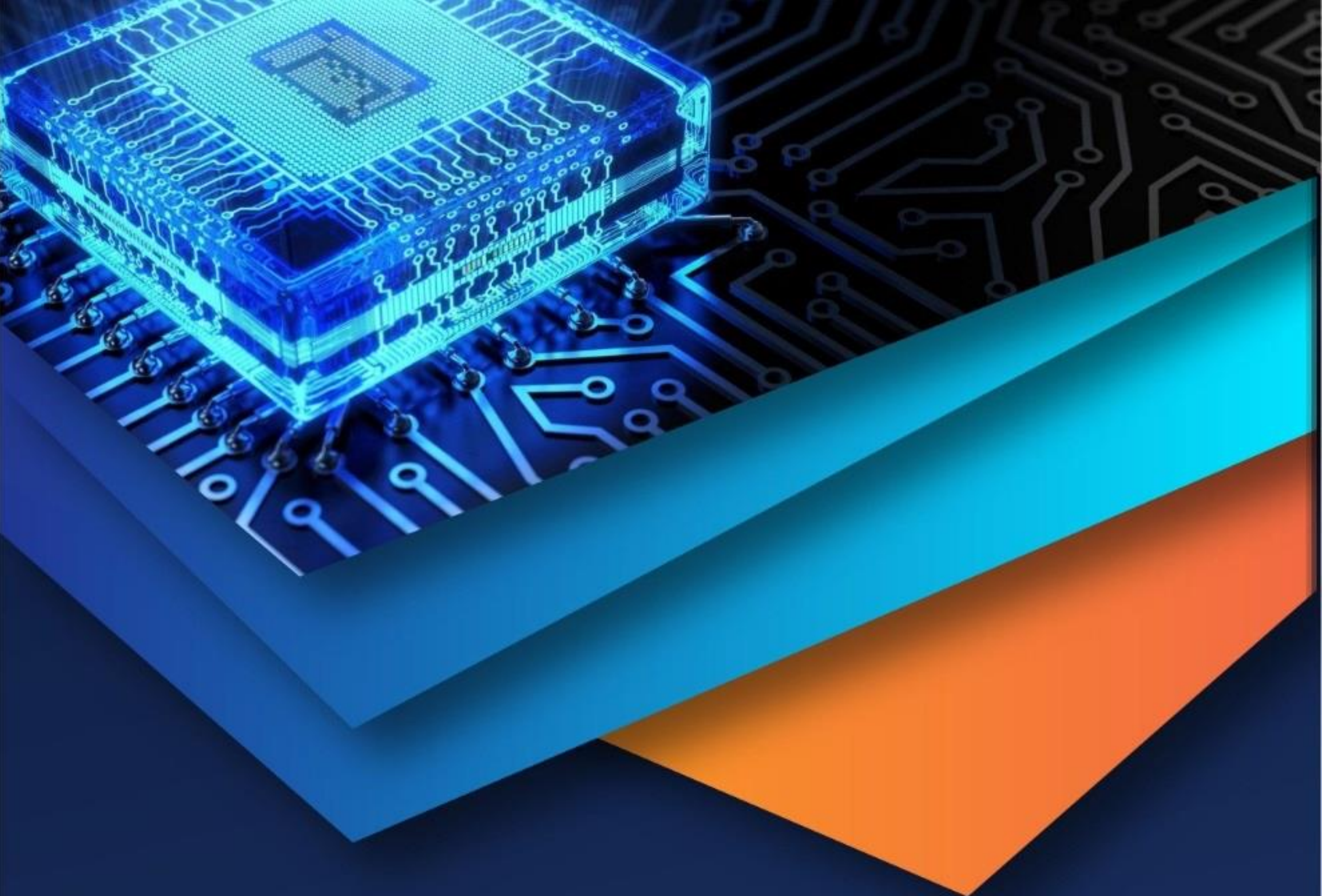

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