MEASUREMENT OF AIR BREAKDOWN VOLTAGE USING STANDAD SPHERE GAP METHOD

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Abstract:
Rapid growth in power sector of nation has given the opportunity to power engineers to protect the power equipment for reliable operation during their operating life. One of the main problem in high voltage (HV) power equipment is the degradation of insulation i.e., quality of insulation of power equipment. In electrical power system, 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 commonly used for measurements of peak values of high voltages and have been adopted by IEC and IEEE as a calibration device. The sphere gaps are filled up with insulating medium such as liquid insulation (transformer oil), solid insulation (polyester, paper) and gas insulation (SF_6, N_2, CO_2, CCl_2F_2 etc). Normally air medium is widely use as an insulating medium in different electrical power equipments as its breakdown strength is 30 kV/cm. Therefore electrical breakdown characteristic of small air gap under the different applied voltage has its great significance for the design consideration of various air insulated HV equipment. In this work to simulate the air breakdown voltage experimentally in high voltage laboratory, standard diameter of 25 cm spheres are used for measurement of air breakdown voltages and electric field of the high voltage equipments. The above experiment is conducted at the normal temperature and pressure.

Keywords: **Air, Breakdown Mechanism, Corona, Sphere gap, Humidity correction, Air density.**

I. Introduction

The generating capacities of power plants and transmission voltage are on the increase because of their inherent advantages. If the transmission voltage is doubled, the power transfer capability of the system becomes four times and the line losses are also relatively reduced. As a result, it becomes a stronger and economical system. In India, we already have 400 kV lines in operation and 800 kV lines are being planned. In big cities, the conventional transmission voltages (110 kV–220 kV etc.) are being used as distribution voltages because of increased demand. A system (transmission, switchgear, etc.) designed for 400 kV and above using conventional insulating materials is both bulky and expensive and, therefore, newer and newer insulating materials are being investigated to bring down both the cost and space requirements. The electrically live conductors are supported on insulating materials and sufficient air clearances are provided to avoid flashover or short circuits between the live parts of the system and the grounded structures.

Atmospheric air is the cheapest and most widely used dielectric. Other gaseous dielectrics, used as compressed gas at higher pressures than atmospheric in power system, are Nitrogen, Sulphur hexafluoride SF_6 (an electro-negative gas) and it's mixtures with CO_2 and N_2. SF_6 is very widely applied for Gas Insulated Systems (GIS), Circuit Breakers and gas filled installations i.e. substations and cables. It is being now applied for power transformers also. The qualitative definition of 'electric strength' or breakdown strength of a dielectric is 'the maximum electric stress a dielectric can withstand'. It is the magnitude of breakdown voltage measured across a gap distance of one cm in uniform field at normal temperature and pressure. To discuss breakdown in gases a brief review of the fundamental principles of kinetic theory of gases, which are pertinent to the study of gaseous ionization and breakdown, will be presented. The review will include the classical gas laws, followed by the ionization and decay processes which lead to conduction of current through a gas and ultimately to a complete breakdown or spark formation. Breakdown occurs in gases due to the process of collisional ionization. According to Townsend Electrons get multiplied in an exponential manner, and if the applied voltage is sufficiently large breakdown occurs.

II BREAKDOWN MECHANISMS

The breakdown in a gas, called spark breakdown is the transition of a non-sustaining discharge into a self-sustaining discharge. The build-up of high currents in a breakdown is due to the process known as 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. At present two types of theories (i) Townsend theory, and (ii) Streamer theory are known which explain the mechanism for breakdown under different conditions. But in practice the breakdown purely depends on gap distance between the electrodes, which was discussed by Paschen's Law. Fig 1 shows the test arrangement for breakdown in gaseous medium. The various physical conditions of gases, namely, pressure, temperature, electrode field configuration, nature of electrode surfaces, and the availability of initial conducting particles are known to govern the ionization process.

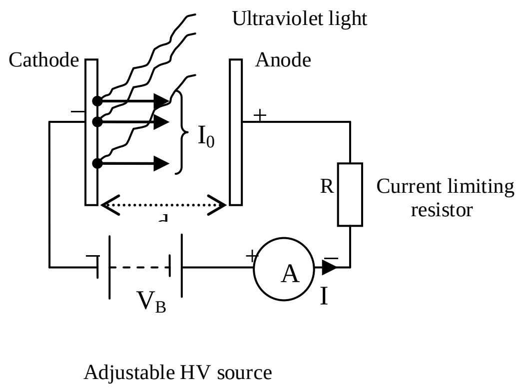

Fig 1 Test arrangement for Townsend's Discharge

If the electric field is uniform, a gradual increase in voltage across a gap produces a breakdown of the gap in the form of a spark without any preliminary discharges. On the other hand, if the field is non-uniform, an increase in voltage will first cause a discharge in the gas to appear at points with highest electric field intensity, namely at sharp points or where the electrodes are curved or on transmission lines. This form of discharge is called a corona discharge and can be observed as a bluish luminescence [11]. This phenomenon is always accompanied by a hissing noise, and the air surrounding the corona region becomes converted into ozone. Corona is responsible for considerable loss of power from high voltage transmission lines, and it leads to the deterioration of insulation due to the combined action of the bombardment of ions and of the chemical compounds formed during discharges. Corona also gives rise to radio interference.

III ELECTRODE CONFIGURATION

A uniform field spark gap will always have a spark over voltage within a known tolerance under constant atmospheric conditions. Sphere gaps can be arranged either (i) vertically with lower sphere grounded, or (ii) horizontally with both spheres connected to the source voltage or one sphere grounded as shown in fig 2. In horizontal configurations, it is generally arranged such that both spheres are symmetrically at high voltage above the ground. The two spheres used are identical in size and shape.

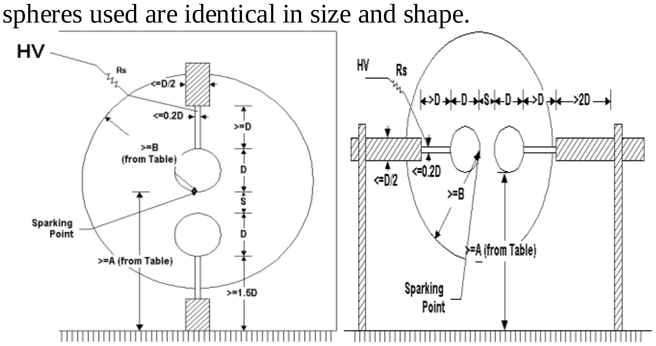

Fig2 Sphere gap arrangement

According to BSS 358: 1939, when one sphere is grounded, the distance from the sparking point of the high voltage sphere to the equivalent earth plane to which the earthed sphere is connected Should lie within the limits. In order to avoid corona discharge, the shanks supporting the spheres should be free from sharp edges and corners [13]. Various factors that affect the spark over voltage of a sphere gap are:

(1) Nearby earthed objects,
(2) Atmospheric conditions and humidity,
(3) Irradiation,
(4) Polarity and rise time of voltage waveforms

IV CORRECTION FOR AIR INSULATION

The dielectric strength of air is influenced by air density (temperature and pressure) and humidity [10]. The breakdown of a non-uniform long air gap takes often the processes as corona inception, streamer propagation, leader formation and propagation, and final jump. The streamer and leader processes are the decisive processes. It has been concluded [15][16] that the influence of air density is most significant on the streamer formation and propagation. The air density has little influence on the leader process. Therefore, as an approximation, one may consider if the streamer dominates the breakdown processes in a gap, the dielectric strength of this air gap is proportional to relative air density. For longer gaps, the breakdown will be resulted by both the streamer and the leader process. Therefore, the dielectric strength of a longer air gap is, in many cases, less than proportional to air density.

The Air density correction factor (K_d) is given by

$$K_d=\left(\frac{p}{p_0}\right)^m X \left(\frac{273+t_0}{273+t}\right)^n$$

Where,
p = atmospheric pressure under test
t = temperature (in degree centigrade) under test conditions.

The breakdown voltage obtained in air will be affected by atmospheric condition such as temperature and absolute humidity. According to IEC 60052 (2002), the absolute humidity and relative air density are effects on air breakdown voltage in the standard sphere gap method. In this work determines the humidity correction factor. The gap configurations used in this present work were sphere-sphere gaps made of aluminum nickel coated with the diameter of 25 cm. The humidity correction factor was helpful to correct the breakdown voltage at each value of humidity. In this work taken humidity range in between 0-32% and find the corresponding humidity factor. This work investigates the influence of humidity on the AC breakdown voltage and determines the humidity correction factor was suitable for application in all atmospheric conditions. In measurement of humidity correction factor the input parameters are temperature is 31.1^0C, pressure is 760 mm of hg and gap between sphere electrodes is 5-80mm taken.

Humidity correction factor of sphere-sphere gap

$$K=[1+(0.002X(\frac{h}{g}-8.5))]$$

Where, h is humidity of air and δ is the relative air density factor[17,18]

The humidity correction factor, K_h is given by $K_h=(K)^w$, The constant ***k*** is given in Fig 3 as a function of absolute humidity. The exponents' ***m, n***, and ***w*** depend on the type and polarity of the voltage and on the flashover distance ***d*** as given in Table 1 and Lacking more precise information, ***m*** and ***n*** are assumed to be equal.

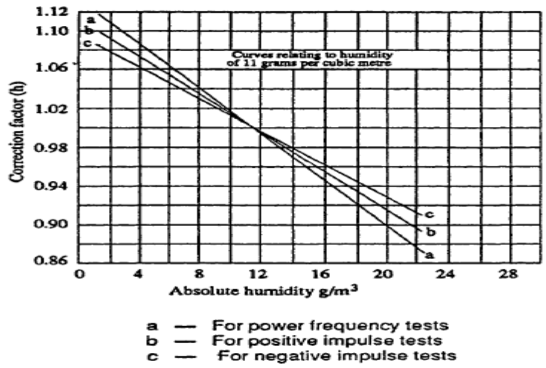

Fig. 3 Humidity correction factor

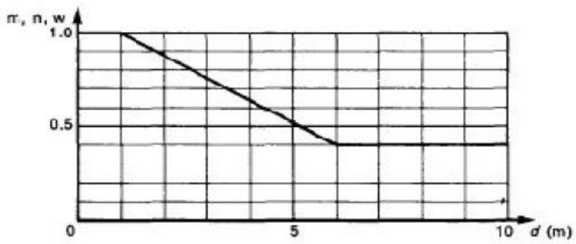

Fig 4. Values of the Exponents m and n for Air Density Correction and w for Humidity Corrections, as a Function of Spark over Distance, in Meters.

δ	0.7	0.75	0.8	0.85	0.9	0.95	1	1.05	1.1
K_d	0.72	0.76	0.81	0.86	0.9	0.95	1	1.05	1.09

Table 1 Relation between Air Density Correction Factor (K_d) & Relative Air Density Factor (δ)

K_d is a slightly non-linear function of δ a result explained by Paschen's law.

In this discussion, there are actually four different atmospheric conditions in the context [14]

1. **Standard reference conditions** with temperature of $\mathbf{t_o}$=20^{0}C, air pressure of P_0=101.3 kPa, and absolute humidity of $\mathbf{h_o}$ =11g/m^3
2. **Normal service conditions** (conditions that specified for various HV equipment in relevant standards) with maximum ambient temperature of, e.g., 40^{0}C, altitude not exceeding 1000 meters, and …
3. **Specific site conditions** (application conditions) with altitude of, e.g., 1600 meters, and…
4. **Laboratory test conditions** (at the day of testing) with ambient temperature of, e.g., 25^{0}C, air pressure of, e.g., 100 kPa and relative humidity of, e.g., 40%.

The breakdown voltage values V (kV) measured under actual conditions with the temperature t(^{o}C), the pressure p (mmHg) and the absolute humidity k (g/m^3) are reported to standard reference atmosphere as defined as $V_0 = \frac{V}{K_d \times K_h}$

V EXPERIMENTAL PROCEDURE

In the Fig 5 adjust the gap distance to an initial value from 5mm to 80mm.

Fig 5 Test Sphere arrangement

230V Power frequency is applied to the Low Voltage side by a Auto Transformer. Slowly raise the voltage till faint hissing audible sound is heard. This is the beginning of corona. Hence the Corona Inception Voltage is appeared. Raise the Voltage further till such time there is a faint visible glow at the high voltage electrode. This is the Visible Corona Inception level. Then slowly reduce voltage further till such time the hissing sound subside i.e., dies down or becomes extinct. This voltage is called Corona Extinction Voltage. Once again raises the voltage till such time there is a Break Down. This voltage is called Breakdown Voltage. Then the measured voltage has been corrected by the Air density correction factor and Humidity Correction factor. Reduce the voltage completely and open the circuit breaker. Then further breakdown has been obtained for different gap distances.

VI EXPERIMENTAL RESULTS

1)Test setup

The test circuit is shown in Fig. 6. It consists of AC voltage source 230 V, Auto Transformer 400V/1000KV transformer, water resistor (R_W)=560 kΩ along with filter.

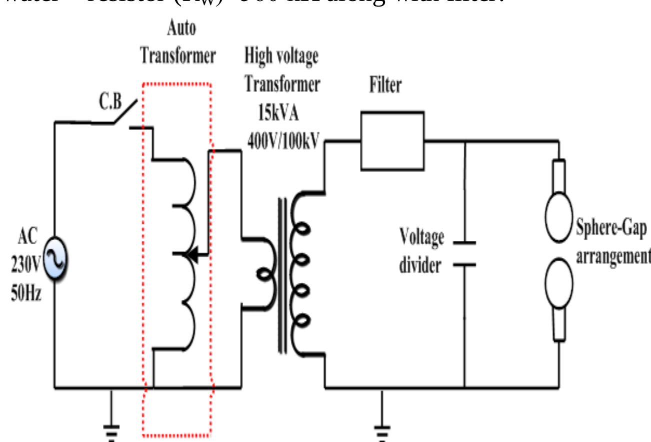

Fig 6 Schematic Circuit showing the source and Breakdown voltage measuring unit using standard sphere gap method.

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 theoretical and experimental results which are depicted in Table 1.

2) Breakdown voltage in respect to gap distances of SPHERE-SPHERE:

The gap configuration of Sphere to Sphere is shown in the fig 7. The electrodes are used of two spheres. One sphere put into HV arm and another is grounded. Now the gap distance vary from 5mm-80 mm and obtained the characteristics of corona inception voltage, visible corona, corona extinction voltage and Breakdown Voltage.

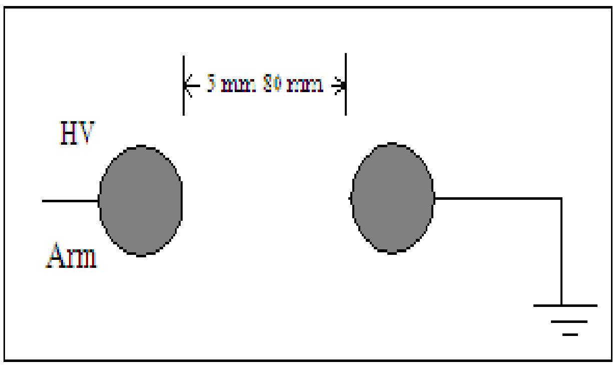

Fig 7 SPHERE-SPHERE arrangement

SI No	gap distance (mm)	corona inception voltage (kv)	variable inception voltage (kv)	corona extinction voltage (kv)	breakdown voltage (kv)	
					measured voltage (kv)	corrected voltage (kv)
1	5	--	--	--	7	8.2382
2	10	--	--	--	15	17.6532
3	15	17	--	12	23	27.0683
4	20	19	--	13	32	37.6603
5	25	21	--	16	40	47.0754
6	30	23	--	17	48	56.4905
7	35	26	--	1	57	67.0824
8	40	29	--	19	64	75.3207
9	45	32	--	19	71	83.5589
10	50	36	--	26	77	90.6202
11	55	31	--	16	83	97.6815
12	60	37	--	27	87	102.389
13	65	38	--	29	93	109.450
14	70	40	--	30	97	114.1579
15	75	42	--	29	101	118.8654
16	80	45	--	28	102	120.0423

Table 2 sphere-sphere Measured and Corrected value with respect to gap distances

Table 2 shows the measured values of Sphere to Sphere are obtained and corrected by Air density correction factor as well as Humidity Correction factor w.r.t standard temperature and Pressure.

3) Breakdown voltage in respect to gap distances of SPHERE-POINT

The gap configuration of Sphere to Point is shown in the fig 8. The electrodes are used of one spheres and one point. The Sphere put into HV arm and the point is grounded. Now the gap distance vary from 5mm-80 mm and obtained the characteristics of corona inception voltage, visible corona, corona extinction voltage and Breakdown Voltage.

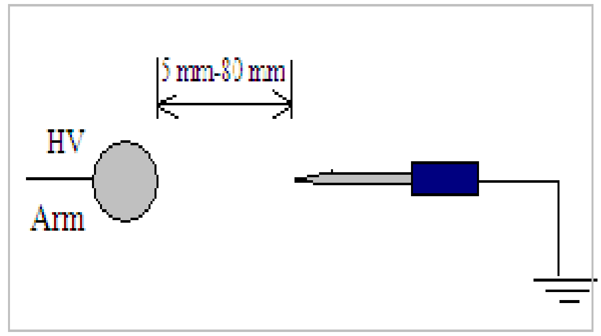

Fig 8 SPHERE-POINT arrangement

SI No	Gap distance (mm)	Corona Inception Voltage (KV)	variable inception voltage (KV)	Corona Extinction Voltage (KV)	Breakdown Voltage (KV)	
					measured voltage (KV)	corrected voltage (KV)
1	5	--	--	--	4	4.7075
2	10	--	--	--	6	7.0613
3	15	9	9	7	10	11.7688
4	20	10	11	9	15	17.6532
5	25	11	13	10	18	21.1839
6	30	13	15	12	22	25.8914
7	35	15	17	13	24	28.2452
8	40	16	19	14	26	30.599
9	45	17	20	14	27	31.759
10	50	19	23	16	29	34.1296
11	55	20	22	17	30	35.3065
12	60	21	25	18	32	37.6603
13	65	21	27	18	35	41.191
14	70	21	29	20	38	44.7216
15	75	23	30	19	40	47.0754
16	80	24	31	20	44	51.7829

Table 3 SPHERE- POINT measured and corrected value with respect to gap distances

In table 3 shows the measured values of Sphere to Point are obtained and corrected by Air density correction factor as well as Humidity Correction factor with respect to the standard temperature and pressure.

4) Breakdown voltage in respect to gap distances of POINT- SPHERE

The gap configuration of Point to Sphere is shown in the fig 9. The electrodes are used of one spheres and one point. The Poin is put into HV arm and the Sphere is grounded. Now the gap distance vary from 5mm-80 mm and obtained the characteristics of corona inception voltage, visible corona, corona extinction voltage and Breakdown Voltage.

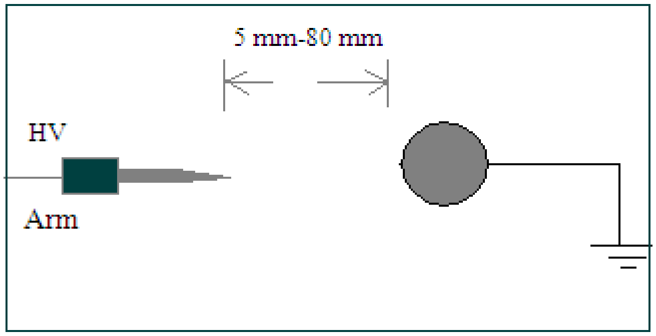

Fig 9 Gap distances are vary from 5mm-80mm of POINT-SPHERE

SI No	Gap distance (mm)	Corona Inception Voltage (KV)	variable inception voltage (KV)	Corona Extinction Voltage (KV)	Breakdown Voltage (KV)	
					measured voltage (KV)	corrected voltage (KV)
1	5	--	--	--	3	3.5306
2	10	--	--	--	6	7.0613
3	15	8	8	7	9	10.5919
4	20	9	10	8	14	16.4764
5	25	10	11	9	18	21.1839
6	30	11	13	9	21	24.7146
7	35	11	13	10	26	27.0683
8	40	12	15	10	26	30.599
9	45	13	14	10	28	32.9528
10	50	13	15	11	37	43.5447
11	55	14	17	12	44	51.7829
12	60	13	16	12	49	57.6674
13	65	14	17	13	52	61.198
14	70	19	22	16	57	67.0824
15	75	19	21	14	61	71.79
16	80	22	24	16	68	80.0282

Table 4 POINT- SPHERE measured and corrected value with respect to gap distances

In table 4 shows the measured values of Point to Sphere are obtained and corrected by Air density correction factor as well as Humidity Correction factor w.r.t standard temperature and pressure.

5) Breakdown voltage in respect to gap distances of ROD (SQUARE)-SPHERE

The gap configuration of Rod(square) to Sphere is shown in the fig 10. The electrodes are used of one Rod of square cross section and another is Sphere. The Rod is put into HV arm and the Sphere is grounded. Now the gap distance vary from 5mm-80 mm and obtained the characteristics of corona inception voltage, visible corona, corona extinction voltage and Breakdown Voltage.

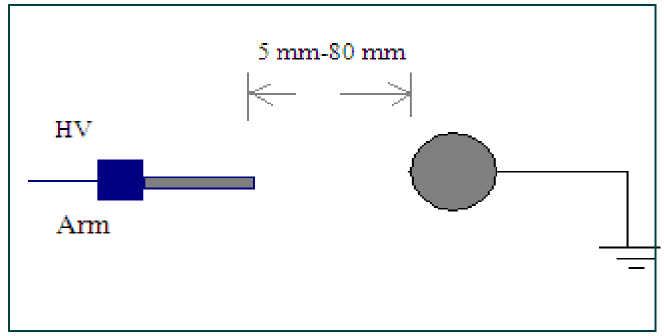

Fig 10 Gap distances are vary from 5mm-80mm of ROD(SQUARE)-SPHERE

SI No	Gap distance (mm)	Corona Inception Voltage (KV)	variable inception voltage (KV)	Corona Extinction Voltage (KV)	Breakdown Voltage (KV)	
					measured voltage (KV)	corrected voltage (KV)
1	5	--	--	--	4	4.7075
2	10	--	--	--	7	8.2382
3	20	12	13	12	13	15.2995
4	40	17	18	15	25	29.4221
5	60	18	20	15	35	41.191
6	80	24	27	19	45	52.9508

Table 5 ROD (SQUARE)-SPHERE Measured and Corrected value with respect to gap distances

VII CONCLUSION

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 with different 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. In addition, as the humidity is one of the important factors for measurement of the air breakdown characteristic and it is not changeable during the experiment. In the experiment the Corona Extinction voltage is less than the Corona Inception voltage. Among two set-up sphere-to-sphere & sphere-to-point, the low breakdown voltage occurred in the set-up of sphere to- point. The breakdown Voltages with respect to following types of electrodes can also measured in Point-Point, Point-Rod(square), Rod(Square)-Rod(Square), Rod(circular)-Rod(circular), Rod(circular)-Point. This study can be extended for analyzing breakdown and pre-breakdown strength including other mediums such as vacuum, SF_6 and N_2 to assess the performance characteristics for measuring AC, DC and impulse voltages.

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BIOGRAPHIES

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