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Breakdown mechanism in air insulating medium by an experimental study

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ABSTRACT

Various phenomena occur in Air dielectric when a voltage is applied. When low voltage is applied, small current flows between the electrodes and the insulation retains its electrical properties. If the applied voltage is large, the current flowing through the insulation increases very sharply and an electrical breakdown occur. A strongly conducting spark formed during breakdown, practically produces a short circuit between the electrodes. The maximum voltage applied to the insulation at the moment of breakdown is called the breakdown voltage. For a uniform gap, the effect of humidity on the breakdown voltage is negligible. For non-uniform gaps such as rod-sphere, point-sphere like gaps the influence of humidity is found to be of significant. A correction procedure recommended by IEC is commonly used for converting the measured voltage or the test voltage from non-standard to standard reference atmosphere. So the result in analysis is then corrected into the standard reference conditions [in STP].

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. Electrons get multiplied in an exponential manner, and if the applied voltage is sufficiently large breakdown occurs.

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. 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. 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.

Electrode Configuration

A uniform field spark gap will always have a spark over voltage within a known tolerance under constant atmospheric

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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 1. 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.

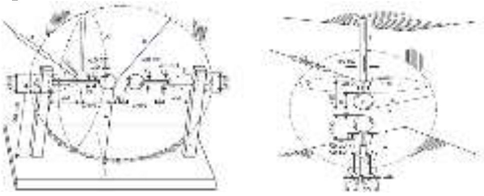

Fig 1 Sphere gap arrangement

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

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. This is in principle the case for shorter gaps, shorter than 2 meters. 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 (Kd) 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 humidity correction factor, Kh is given by Kh=(K)w, The constant ***k*** is given in Fig 2 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.

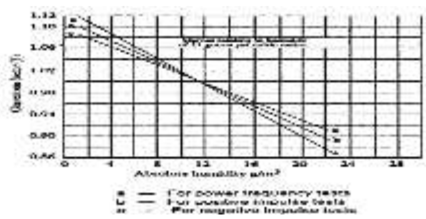

Fig. 2 Humidity correction factor

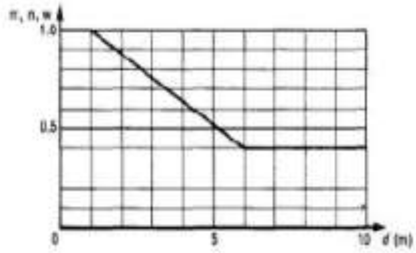

Fig 3. Values of the Exponents *m* and *n* for Air Density Correction and w for Humidity Corrections, as a Function of Spark over Distance, in Meters

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 (Kd) & Relative Air Density Factor (δ)

Kd 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 to=200C, air pressure of P0=101.3 kPa, and absolute humidity of ho =11g/m3
2. Normal service conditions (conditions that specified for various HV equipment in relevant standards) with maximum ambient temperature of, e.g., 400C, 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., 250C, 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(oC), the pressure p (mmHg) and the absolute humidity k (g/m3) are reported to standard reference atmosphere as defined as $V_0 = \frac{V}{K_d \times K_h}$

Experimental Procedure

In the Fig 4 adjust the gap distance to an initial value from 5mm to 80mm. 220V 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.

Experimental Results

1)Test setup The test circuit is shown in Fig. 5. It consists of AC voltage source 220 V, Auto Transformer (0-220 V), 220V/300 kV transformer, water resistor (RW)=560 kΩ .

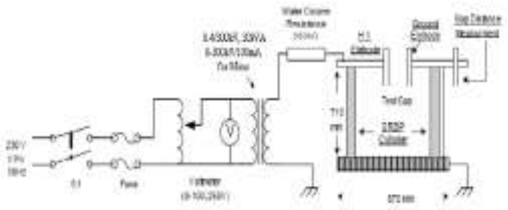

Fig 4 Test circuit

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

The gap configuration of Sphere to Sphere is shown in the fig 5. 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

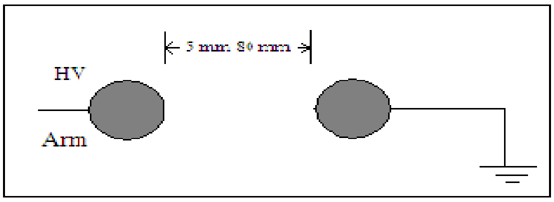

Fig 5 SPHERE-SPHERE arrangement

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.

Sl 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	1	–	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

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

The gap configuration of Sphere to Point is shown in the fig 6. 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.

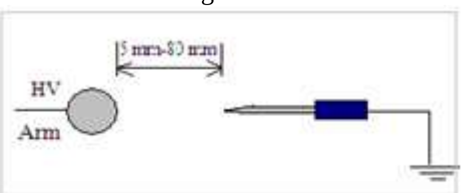

Fig 6 SPHERE-POINT arrangement

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 w.r.t standard temperature and pressure.

Sl 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

Conclusion

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. If the air gap is present between the high voltage electrodes is very small, the Corona Inception, Visible Corona and Corona Extinction voltage measuring is not possible in physically. The breakdown Voltages with respect to following types of electrodes as Point-Point, Point-Rod(square), Rod(Square)- Rod(Square), Rod(circular)- Rod(circular), Rod(circular)-Point. Can also find the common Model Equation of Breakdown Voltages with respect to various gap distances.

References

[1] IEEE Paper "High Frequency Breakdown Voltage"; by Thanh Duy Chu; March 1992.

[2]IEEE paper "Influence of corona discharges on the breakdown voltage of airgaps"; K.Feser, Dr.-lng; Reprinted from PROC. IEE, Vol. 118, No. 9, SEPT. 1971.

[3] IEEE Paper "Evaluation of Humidity Correction Factor of Disruptive Discharge Voltage of Standard Sphere Air Gaps";by Osamu Fujii, TakahiroHayakawa, YukioMizuno, KatsuhikoNaito; EEJTrans 2008; 3:100–105.

[4] IEEE Paper "Tests on the breakdown of air at elevated temperatures in non-uniform electric fields" by N.L.Allen, D.S.K.Lam and D.A.Greaves,in 2nd February 2000.

[5] IEEE Paper "Effect Of Humidity On DC Breakdown Voltages In ambient Air At High Altitude"by P A Calva Chavarria and A Robledo-Martinez;in San Franicisco, October 20-23, 1996.

[6]IEEE Paper "Corona Inception and Breakdown in No uniform Field with Insulating Support in Air";by V. Navinchandra Maller and Krishan D. Srivastava; in January 16,1987.

[7]IEEE Paper "Dielectric Breakdown in Nonuniform Field Air Gaps";by N. L. Allen and M. Boutlendj, H. A. Lightfoot.

[8] IEEE Transactions on "Power Apparatus and Systems", Vol. PAS-97, No. 6, Nov/Dec 1978.

[9]"IEEE Standard Techniques for High-Voltage Testing";6th edition; by Approved April 26,1982.

[10] IEEE paper "Uncertainties In The Application Of atmospheric And Altitude Corrections As Recommended In IEC Standards" Dong Wu, Ming Li and Mats Kvarngren, 16th

International Symposium on High Voltage engineering, Cape Town, South Africa, 2009

[11]A Text Book on “High Voltage engineering”; M.S Naidu & V.Kamaraju,4th edition, Tata McGraw Hill Education Private Limited, ISBN: 978-0-07-066928-4

[12] A Text Book on “High Voltage Engineering Fundamentals ” Second edition, E. Kuffel, W.S. Zaengl & J. Kuffel; ISBN 0 7506 3634 3

[13] A text book” High Voltage Engineering” second Edition, CL Wadwa. Newage Publication, India

[14] IEC 62271-1, High-voltage switchgear and controlgear – Part 1: Common specifications. Edition 1.0, 2007-10

[15] K. Feser, A. Pigini, ”Influence of atmospheric conditions on the dielectric strength of external insulation” Paper prepared at the request of the Chairman of SC 33, Electra No. 112.

[16] WG 33-07, “Guidelines for the evaluation of the dielectric strength of external insulation” Cigré Brochre 72.