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Exponential Expression of Relating Different Positive Point Electrode for Small Air Gap Distance

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Abstract: The purpose of this research is to draw a-mathematical relationship between different positive point electrodes using air as the dielectric medium for small gap distance. Four electrodes with varying radius of curvature were used at gap distance ranging from 1 to 12.5 cm under the same atmospheric condition. These results were graphically analyzed after finding the fifty percent probability ($V_{50\%}$) of the breakdown voltage. Using the exponential form in expressing them, a general formula was derived for the breakdown voltage for sharply non-uniform field for small air gap distances. The humidity level was noted because of the varying humidity level of environment. The spark over voltage increases with humidity therefore the wet and dry bulb readings were taken before each experiment and the required correction factors were noted.

Key words: Breakdown voltage, field intensity, humidity level, ionization, sharply non-uniform field, streamer discharge

INTRODUCTION

Knowledge of electric fields is necessary in numerous high voltage applications. Electrode geometries that are encountered in practice or under laboratory experimental conditions are very many but the rod-plane arrangement with rod tip of various shapes (cone, needle, sphere etc.,) are more common (Onal, 2004; Qui, 1984).

Several models for explaining the observed characteristics of the fifty percent breakdown of long gaps have been put forward by many researchers (Begamudre, 2008; Gallet *et al.,* 1975). Some theories or models used experimental data to obtain numerical estimates for some factors. Even with the varying assumptions the results were similar because they were based on the same avalanche and streamer theories. Based on the Critical Flash Over (CFO) voltage of long gap put forward by Paris (Begamudre, 2008; Hutzler, 1975), there was need to relate this study to small airgap. This was particularly necessary since calculation of small airgap field distribution is easier because the controlling factors could be checked.

From the experimental results, the functional relationship between Sparkover voltage and gap length for the given electrode geometries were calculated using the experimental form.

Non-uniform fields: The important characteristic of non uniform field is the unequal distribution of field intensity in the space between the electrodes.

If the profile is different the greatest value of field intensity occurs on the surface of the electrode having smaller radius of curvature (Naidu and Kamaraju, 2007) and the region of minimum intensity is shifted to the opposite electrode. The degree of non-uniformity of a field can be characterized by the ratios of maximum intensity of the field E_m to its average value, E_{av} that is $K = \frac{E_m}{E_{av}}$. The coefficient of non-uniformity of sharply non-uniform field and uniform field are shown in Fig. 1a and b. Non-uniformity of a field can exert considerable influence on the nature of the development of discharge (Kassakian and Otten, 1975; Rein *et al.*, 1977).

In a sharply non-uniform field (positive point), an electron formed in the gap while moving towards the point falls into the region of strong field, ionization takes place near the point but at a distance sufficient to permit ionization and form avalanche. As the electrons of the avalanche reach, the anode they move away through the point electrode but the positive charges due to their slow movement will remain in the space, moving slowly towards the cathode. This simulates an extension of the electrode surface (point) and its radius of curvature is increased thereby decreasing the field intensity in the vicinity of the point and slightly increasing the field on the cathode (Naidu and Kamaraju, 2007; Wodton, 1982).

If the voltage between the electrodes is sufficiently high an avalanche begins on the right hand side of the volume charge which by mixing with the positive ions of

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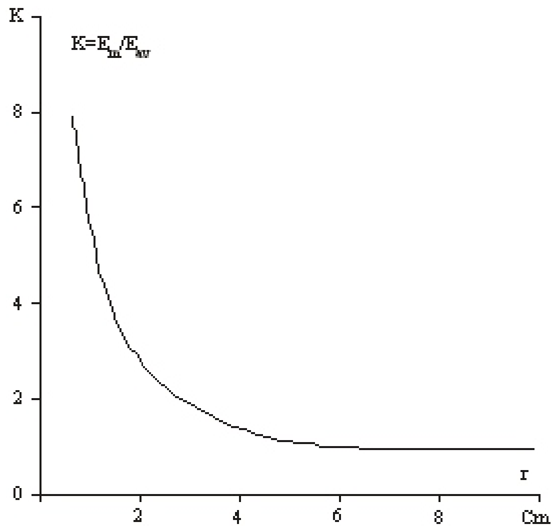
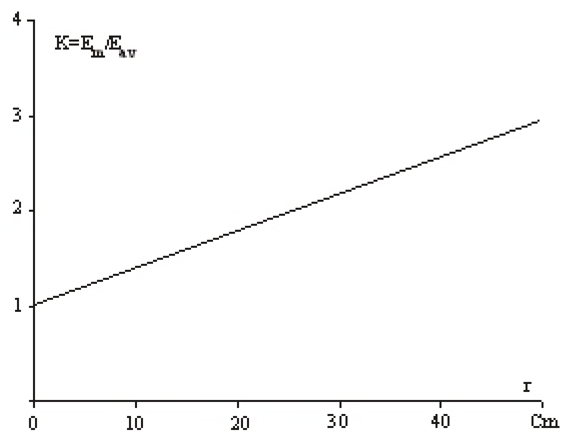


(a)



(b)

Fig. 1: Field distribution for non-uniform and uniform fields

the volume charge creates an embryo of the canal (anode streamers). The charges of the plasma of the streamer are situated in an electric field so that there are surplus positive charges. The charges partly compensate the field in the canal of the streamer itself and create increased intensity at its head. Presence of a region of strong field before the head ensures formation of new avalanches, the electrons of which are attracted in the canal of the streamer and ions establish the positive volume charges which lead to further increase of field before the head of the streamer. The newly formed avalanches convert this volume charges into the continuity of the canal of the streamer and this gradually spread to the cathode. The streamer growth for positive point electrode is shown in Fig. 2.

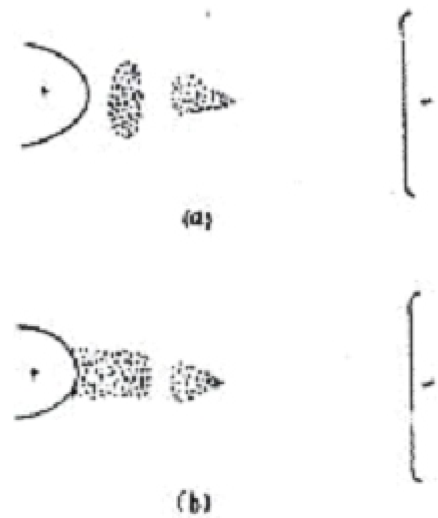


Fig. 2: Streamer Mechanism on breakdown

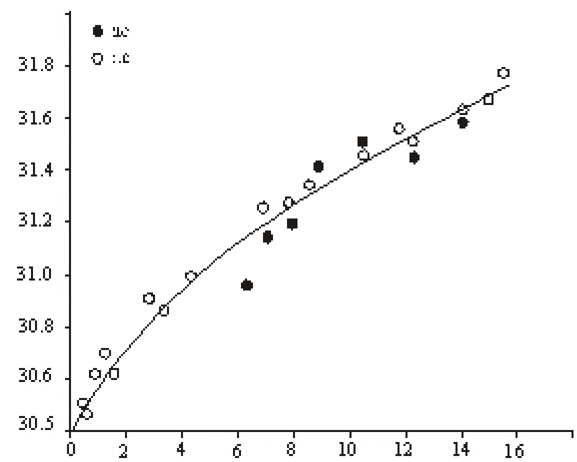


Fig. 3: Breakdown voltage humidity relation for a.c and d.c for 1.0 cm gap between 25 cm diameter spheres

Effect of humidity on breakdown voltage: Humidity in air exerts some significant influence on the breakdown voltage. According to data of Ritz (Razevig, 2003) an increase of absolute humidity of air from 10 to 25 mm of Hg. column at normal atmospheric pressure of gap d = 1 cm between electrodes increases the breakdown voltage by 2% in a uniform field. Kuffels investigation (Razevig, 2003; Alston, 1968) for breakdown of air at normal atmospheric showed that with smaller gap up to 20 mm of Hg the breakdown voltage increases from 4-5% in 85% relative humidity than in dry air. Figure 3 shows the effect of humidity on the breakdown voltage of a 25 cm diameter spheres with spacing of 1 cm when a.c and d.c voltages are applied. The spark over voltage increases with partial pressure of water vapour in air, and for a given humidity condition, the change in spark over voltage increases with the gap length.

Table 1: Relationship between correction factor k and air density factor d

d	0.70	0.75	0.80	0.85	0.90	0.95	1.0	1.05	1.10	1.15
k	0.72	0.77	0.82	0.86	0.91	0.95	1.0	1.05	1.09	1.12

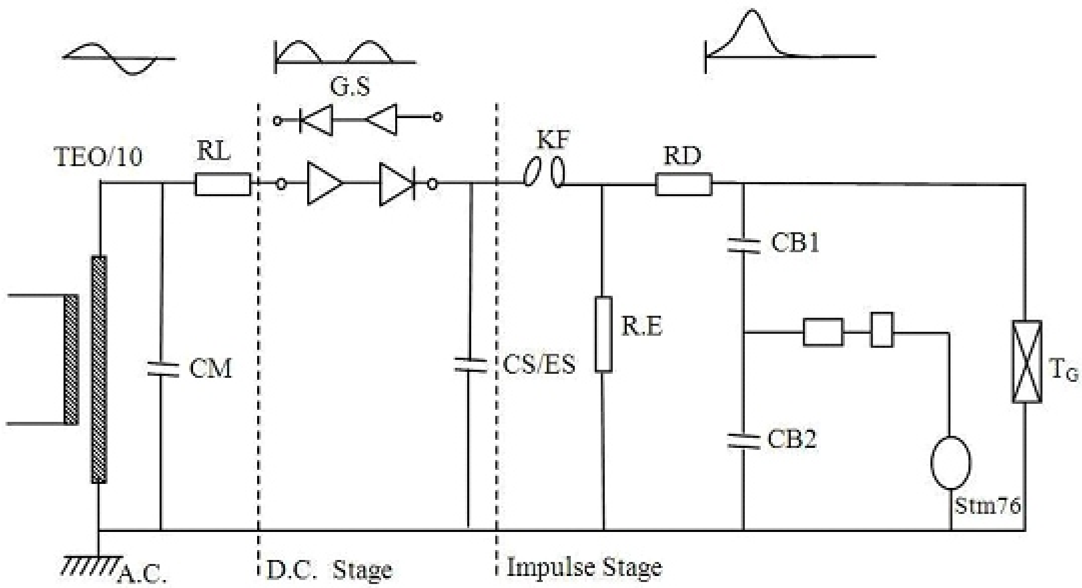


Fig. 4: Stages of the high voltage equipment

The increase in breakdown voltage with increase of humidity is due to the fact that water vapour is electro-negative gas. An increase of content of electronegative gas causes arrest of a large number of electrons with the formation of negative ions, as a result of which the number of ionizing particles in the gap decreases and the breakdown voltage increases. However, in sharply non-uniform field the effect of humidity is considerably more. Usually, the effect of humidity of air is determined according to deviation from the breakdown voltage at standard humidity.

If the spark over voltage is V under test condition of temperature T and pressure P torr and if the spark over voltage is V_0 under standard condition of temperature:

$$V = kV_0$$

Where k is a function of the air density factor d, which is given by:

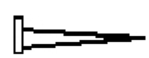
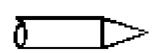
$$d = \frac{P}{760}\left(\frac{293}{273+T}\right)$$

The relationship between d and k is given Table 1.

MATERIALS AND METHODS

The equipment used for the experiment was single stage high voltage equipment. It has the A.C, D.C and the impulse stages. An electrode stand T_G was used to hold the electrode in position, which was also used for adjusting the gap distances. The layout of the different stages of the equipment is shown in Fig. 4.

Table. 2: Electrode configuration and dimension

S.No.	Types of electrode configuration	Electrode and tip dimension
1		Needle r = 0.25 mm
2		Sharp r = 0.75 mm
3		Blunt r = 0.9 mm
4		cone r = 1.3 mm

Four electrodes were used and were designated as needle, sharp, blunt and cone electrodes, as shown in Table. 2. The plate electrode was made of a mild steel square sheet of 280x280 mm with the edge folded and earthed. The experiment was carried out in the High voltage laboratory of the University of Science and

Technology, Port Harcourt Nigeria. It was conducted in November when the dry seasons have set in; therefore the humidity was not high.

The gap distance of 1, 2, 3, 5, 8, 10, 12 and 12.5 cm were maintained for all positive electrodes arrangement. With the electrodes stand $T_{G,}$ the four electrodes were fixed differently with these gap distances and the tests were carried out.

With a test gap, the impulse voltage and the spark gap K_f were adjusted to give a certain percentage of breakdown probability at the test gap.

RESULTS AND DISCUSSION

The results of breakdown voltages for needle are presented in Table 3. The absolute humidity was found from the value of dry and wet bulb reading, using the appropriate graphs. With the spark over voltage V_0 under standard conditions of Temperature and pressure, then the flashover voltage of the test object was found using Eq. (1);

Table 3: Fifty percent breakdown voltage for test electrode

	Breakdown voltage $V_{50\%}$ (corrected voltage)			
Distance (cm)	Needle	Sharp	Blunt	Cone
1	16.3	17.0	17.8	19.0
2	36.0	36.5	37.0	39.0
3	42.6	46.3	48.0	51.0
5	59.4	63.8	66.8	69.0
8	75.8	82.0	88.0	90.0
10	79.0	88.0	106.0	110.0
12	92.8	101.2	112.0	114.5
12.5	96.0	103.0	114.0	123.5

$$V_0 = V \times \frac{h}{d} \qquad (1)$$

Where;
V = Voltage under actual test condition
V_0 = Voltage under reference atmospheric condition
h = Humidity correction factor
d = Air density correction factor

The Gaussian plot (Fig. 5) was used to determine the V50% breakdown voltage.

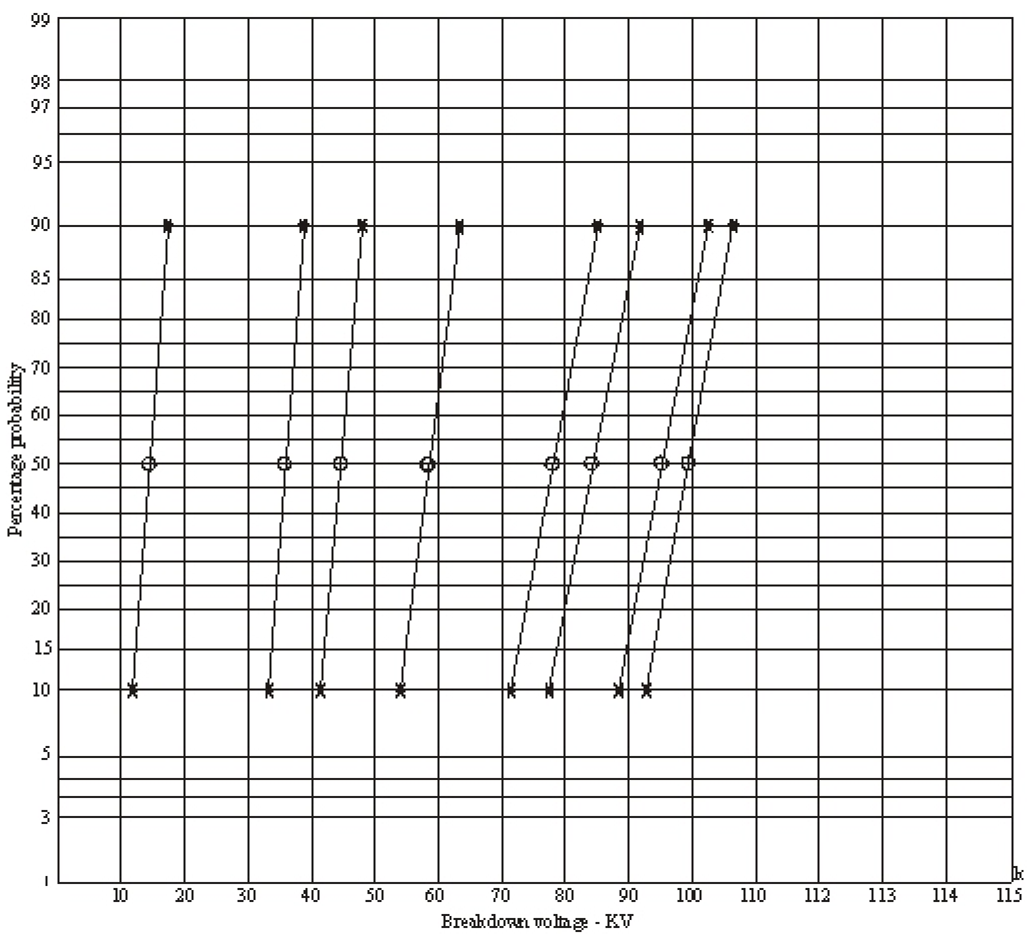


Fig. 5: Gaussian plot for various electrode distance for needle electrode for positive paolarity

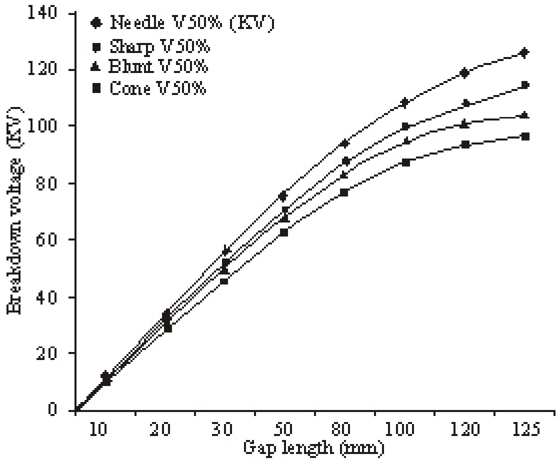


Fig. 6: Graph of impulse breakdown for different positive point electrodes

The 50% breakdown voltage for needle, sharp, blunt and cone electrode are shown in Table 3. From Fig. 6, the breakdown voltage V_B can be expressed as:

$$V_B = Ad^n \tag{3}$$

That is $V_B = \log A + n \log d$

$Y = \log V_B$, $X = \log d$ and $C = \log A$

$$Y = nX + C$$

Using the needle as reference, we have Table 4.

From Table 4, computer programme was used to calculate the constants and are shown in Table 5. The programme flow chart is shown in Fig. 7.

$$\Sigma Y = na + b\Sigma X \tag{4a}$$

$$\Sigma XY = a\Sigma X + b\Sigma X^2 \tag{4b}$$

a = 1.28 and b = 0.66

log A = a = 1.28

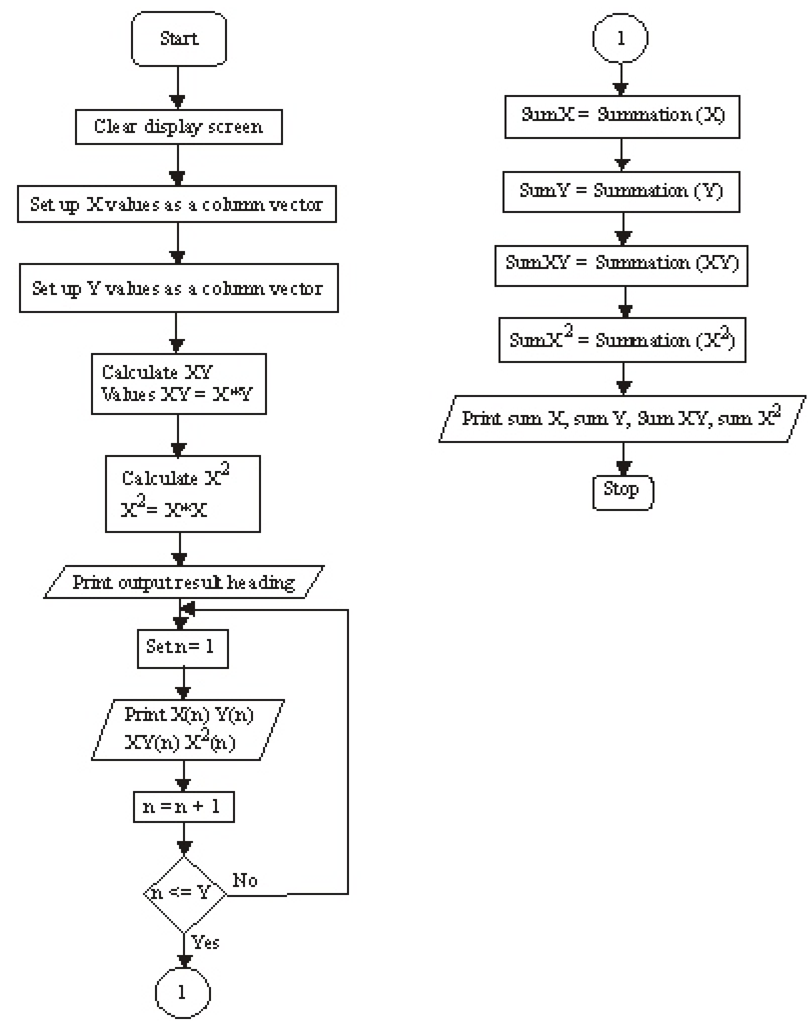


Fig. 7: Flowchart for calculating equation constants

Table 4: Gap distance and $V_{50\%}$ breakdown voltage for needle

log d	0.0	0.30	0.48	0.70	0.90	1.0	1.08	1.10
log V_B	1.7	1.56	1.63	1.77	1.88	1.9	1.97	1.98

Table 5: Constants for calculation of the equation

X	Y	XY	X^2
0.00	1.20	0.00	0.00
0.30	1.56	0.48	0.09
0.48	1.63	0.78	20.23
0.70	1.77	1.24	0.49
0.90	1.88	1.69	0.81
1.00	1.90	1.90	1.00
1.08	1.97	2.13	1.17
1.10	1.98	2.18	1.21
Σ5.56	Σ13.89	Σ10.40	Σ5.00

Table 6: Values of electrode configuration coefficient

S.No.	Distance	Needle	Sharp	Blunt	Cone
1	1.00	1.00	1.06	1.08	1.13
2	2.00	1.00	1.02	1.06	1.14
3	3.00	1.00	1.09	1.17	1.20
4	5.00	1.00	1.06	1.13	1.19
5	8.00	1.00	1.06	1.14	1.19
6	10.00	1.00	1.05	1.22	1.27
7	12.00	1.00	1.07	1.17	1.24
8	12.50	1.00	1.06	1.15	1.22
		1.00	1.06	1.15	1.20

$$n = b = 0.66$$
$$\log V_B = 0.66 \log d + \log 1.28$$
$$Ad^n = 19 * d^{0.66}$$

From Eq. (3) we have:

$$V_B = 19d^{0.66} \text{ for needle Electrode}$$

In order to generalize the equation for the breakdown voltage (Naidu *et al.*, 1979), it is necessary to find a relationship between the needle electrode and other positive point electrode. Since all electrodes were tested under the same atmospheric conditions, it is necessary to define a constant, which is the "Electrode Configuration Coefficient K_e". This is the ratio of the breakdown voltage $V_{50\%}$ of any other positive point electrode to the breakdown voltage $V_{50\%}$ of the needle electrode under test. The value of K_e for sharp, blunt and cone are tabulated as in Table 6:

$$K_e = \frac{\text{Any other electrode configuration}}{\text{Needle electrode configuration}}$$

From Table 3 the electrode configuration coefficient was worked out and are shown in Table 6.

NB: Values were obtained from breakdown voltage $V_{50\%}$ in Table 3. The general modified equation will be:

$$V_B = K_e A d^n = K_e * 19 * d^{0.66} \quad (5)$$

where, K_e is electrode coefficient of the electrode on test.

CONCLUSION

Various ways have been used to describe the breakdown voltage in air gap, liquids and solids. The exponential expression was used in describing the breakdown voltage of the air dielectric for sharply non uniform field for small gaps due to the nature of the graph. The electrode co-efficient K_e gives the relationship between needle and any other electrode configuration (rod-plane) used for small air gap. The humidity in this environment varies from 55% (relative) to 85%, therefore the emphasis was made on humidity correction. This same test done in March may vary in breakdown voltage in July or September due to humidity variation. If all the atmospheric conditions are properly noted and the correction factor applied the expression can be used for any rod-plane electrode configuration for small and medium air gap.

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