GAUSSIAN DISTRIBUTION OF BREAKDOWN SHOTS IN NON-UNIFORM FIELDS

John Tarilanyo Afa
Department of Electrical/Electronic Engineering, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria

Abstract

The work is aimed at investigating the pattern of breakdown in an airgap for non-uniform field. In most technical literature it has been stated in gas breakdown that in the surrounding gas, photoelectrons are produced which initiates auxiliary avalanches directed towards the stem of the main avalanche, and that the greatest multiplication in these avalanches occur along the axis of the main where the space charge field supplements the external field.

Before the complete streamer formation (plasma) several breakdowns could occur before the breakdown of the main avalanche. This breakdown occurs in a definite manner due to presence of the applied field.

In order to investigate the pattern of breakdown four point-plane electrodes were used. For every test a kraft paper was placed on the plate electrode and each breakdown shot from the test punches a hole on the paper. After each complete experiment with punches on the paper, circles with intervals of 5mm where drawn until all the punches have been enclosed. From the analyses it was seen that for all point-plane electrodes the shot takes the Gaussian form of distribution within the ionization zone of electrode gap. This form of breakdown is mostly influenced by the resultant field between the external field and the space charge field at the head of the avalanche.

Keywords: Space charge field, Critical length of avalanche, non-uniform field, Ionization zone, Streamer discharge, Filamentary avalanche.

Introduction

In non-uniform fields, the field strength and hence the effective ionization coefficient α vary across the gap. The electron multiplication is governed by the integral of α over a path ($\int \alpha d\lambda$). At low pressure the Townsend criterion for spark takes the form [1-3]

$$\gamma\left[\exp\left(\int_o^d \alpha dx\right)-1\right]=1 \qquad (1)$$

Where d is the gap length

The expression is valid also for higher pressures if the field is only slightly non-uniform. In strongly divergent fields there will be at first a region of high values of E/P over which $\alpha / P > 0$. When the field falls below a given strength E_c, the integral $\int \alpha dx$ ceases to exist. The Townsend mechanism then losses it validity when the criterion relies solely on the γ effect, especially when the field strength at the cathode is low. In reality breakdown (or inception of discharge) is still possible if one takes into account photo ionization processes [1, 3, 6]

To take into account the non-uniform distribution of α

$$\exp\int_o^{xc<d} \alpha dx = N_{cr} \quad (2)$$

Where N_{cr} is the critical electron concentration in an avalanche giving rise to initiation of a streamer, xc is the path of avalanche to reach the size and d the gap length. Hence eqn (2) will be

$$\int_o^{xc<d} \alpha dx = in\, N_{cr} \approx 18-20 \quad (3)$$

From the streamer theory of Meek and Raether [3], the expression for the space-charge field E_r at the head of the avalanche when it has crossed a distance x in non-uniform field is given as

$$E_r = \frac{5.27\times10^{-7}\alpha_x \exp\left(\int_o^x \alpha dx\right)}{(x/p)^{1/2}} V/cm \quad (4)$$

The field distribution in a non-uniform field gap is shown in fig 1.

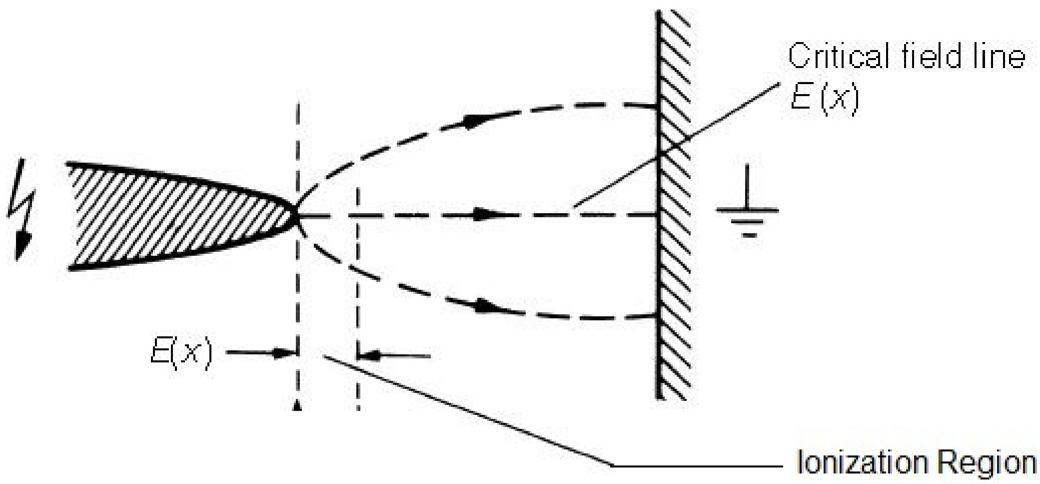


Fig 1: Field distribution in a non-uniform field

When positive voltage pulse is applied to a point electrode, the first detectable ionization is of a filamentary branch nature. This discharge is called a streamer and is analogues to the case of uniform field gaps at higher pd values. As the pulse voltage level is increases [4, 5], the streamers grow both in length and their number of branches as shown in fig 2.

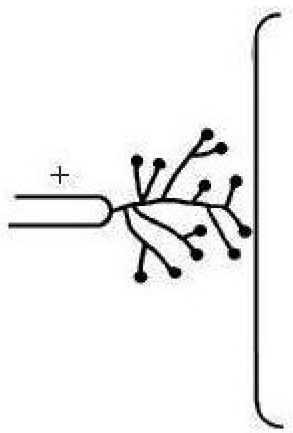


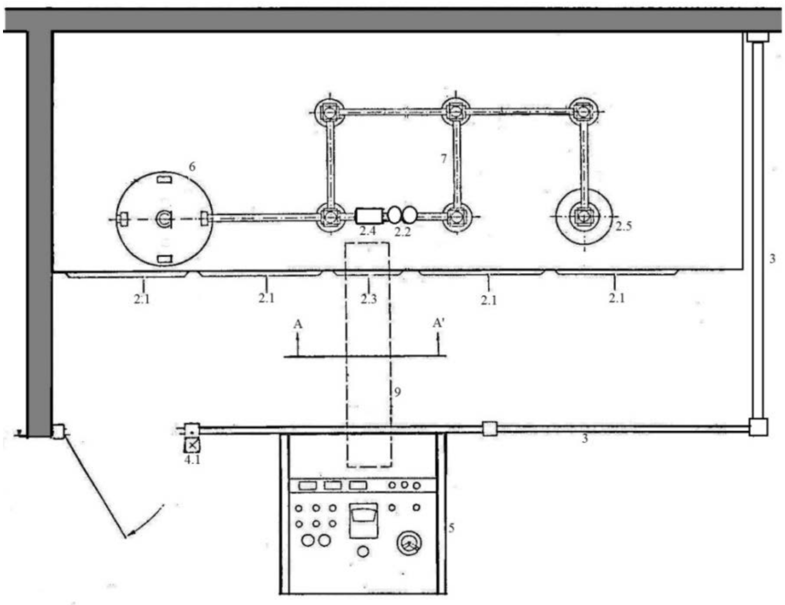
Fig 2: Streamer growth in an airgap

One of the interesting characteristics is their large number which never crosses each other. The velocity if the streamer decreases rapidly as they penetrate the low field region. If the gap length is small (less than 2cm), and the voltage is gradually raised no appreciable ionization is detected up to breakdown. As the gap is increased the field distribution becomes more inhomogeneous, and on increasing the voltage at first a transient slightly branched filamentary discharge appears. These discharges have been shown to be identical with those observed under impulse voltages and are also called streamers. Under steady state the streamer develops with varying frequencies, giving rise to currents that are proportional to their physical length. These streamers are sometimes called onset streamer or burst pulses [1, 6].

On increasing the voltage still further, new and more vigorous streamers appear which ultimately leads to complete breakdown of the gap. In the present investigation due to the formation of filamentary avalanches, breakdown occurred not only within the critical avalanche length (area) but was spread within the area call the ionization zone.

Methodology

The equipment used to investigate was a single stage high voltage (HV) equipment with AC, DC, and Impulse voltage stages. An electrode stand was used to adjust the gap distance as needed. The layout of the HV equipment is shown in figure 3.



1. Wall or protective screen
2. Bench
2.1 Drawer for post insulators, capacitors, resistors and small parts
2.2 Spark gap
2.3 Tap-off panel
2.4 Spark gap adjustment chamber
2.5 Electrode stand
3. Protective screen
4. Protective screen door
4.1 Green and red warning lights
5. Control desk
6. Test transformer – 100 kV AC and 150 impulse.
7. Experimental set-up
8. Floor
9. Cable shaft: W × D = 200 × 150 mm

Fig. 3: Layout of High Voltage Equipment

Four electrodes were used and were designated as needle, harp blunt and cone electrodes, as shown in fig 4.

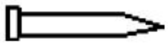
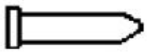
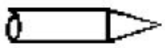
S.No.	Types of electrode configuration	Electrode and tip dimension
1		Needle r = 0.25 mm
2		Sharp r = 0.75 mm
3		Blunt r = 0.9 mm
4		cone r = 1.3 mm

Fig 4: electrode configuration and dimension

With the high voltage equipment and the electrode stand, each of the electrodes was fixed and the gap distance was set using the adjustable rod on the electrode stand. A thin sheet of paper was place on the plate electrode. Having marked the centre of the electrode on the paper the breakdown probability test was carried out. In each experiment, the paper was taken and the centre to the furthest punch (hole) was measured. A circle was drawn, making sure that all punches were enclosed in the circle.

From the four different electrode arrangements, the distances, radius and the mean voltage ($V_{50\%}$) was taken as shown in table 1.

In each of the papers circles with interval of 5mm or 6mm were drawn at each interval the number of shots were counted. The frequency of occurrence of the shots at such interval was tabulated against the distance. This is shown in fig 5.

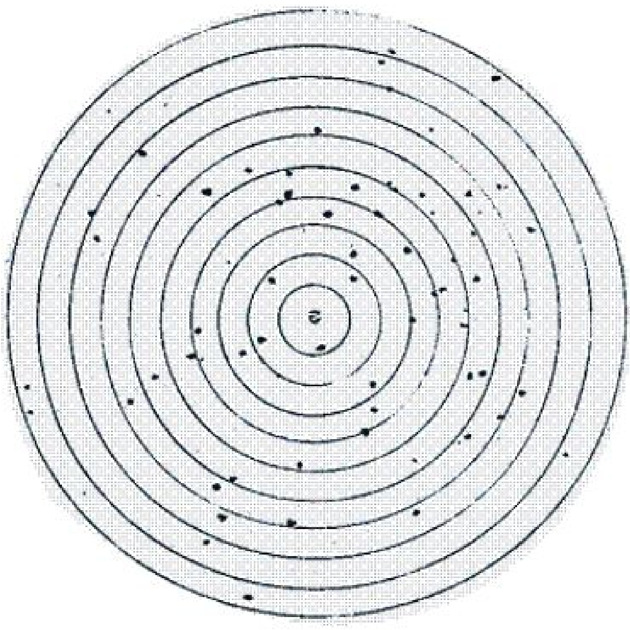


Fig 5: Shot distribution

Results and calculations

The selected gap distances are shown in table 1.

Table 1: Electrode Distance and Frequency of Shots for air gaps

Electrode Distance and Frequency of Shots for 5cm gap								**Electrode Distance and Frequency of Shots for 12cm gap**			
Needle Electrode		**Sharp Electrode**		**Blunt Electrode**		**Cone Electrode**		**Needle Electrode**		**Cone Electrode**	
Spread	**Shots Freq.**	**Spread**	**Shots Freq.**	**Spread**	**Shots Freq.**	**Spread**	**Shots Freq.**	**Spread**	**Shots Freq.**	**Spread**	**Shots Freq.**
6	2	5	11	6.5	3	5	2	5	4	5	1
11	5	10	20	11.5	13	10	3	10	8	10	2
16	12	15	26	16.5	11	15	9	15	13	15	8
21	8	20	17	21.5	20	20	11	20	12	20	9
26	7	25	12	26.5	14	25	14	25	13	25	6
31	2	30	7	31.5	7	30	9	30	5	30	10
—	—	—	—	36.5	2	35	5	35	4	35	15
—	—	—	—	—	—	40	4	40	3	40	8
—	—	—	—	—	—	—	—	—	—	45	7
—	—	—	—	—	—	—	—	—	—	50	3
—	—	—	—	—	—	—	—	—	—	55	2
Total	36	**Total**	93	**Total**	70	**Total**	57	**Total**	62	**Total**	71

From the different frequency tables histogram were drawn as shown in fig 6

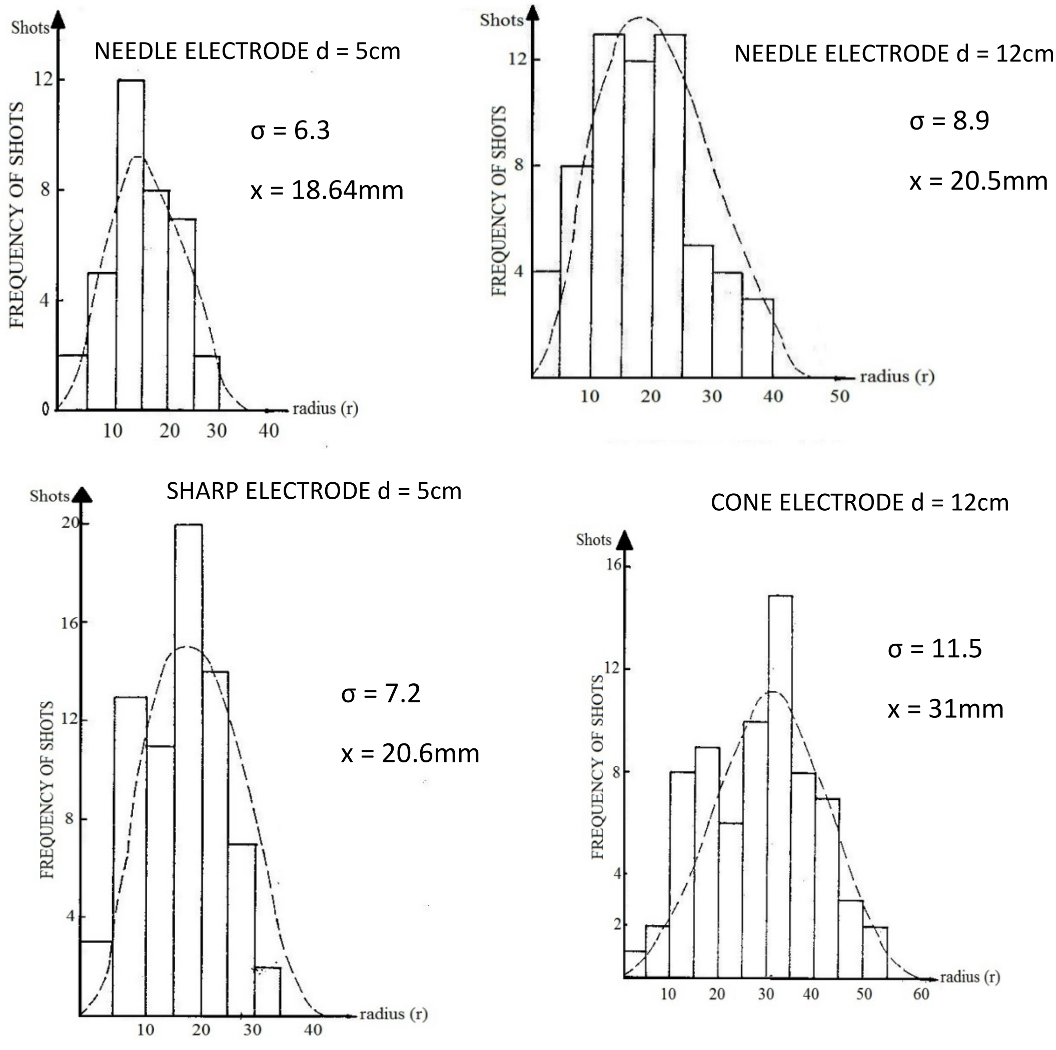


Fig. 6: Histogram and Frequency distribution of breakdown shots

Due to the pattern of breakdown statistical methods was used to find the mean and standard deviation. From the given formular the values were worked out.

$$\bar{x} = x + \frac{\Sigma fd}{\Sigma f} \qquad (5)$$

The standard deviation is

$$\delta = \sqrt{\frac{\Sigma fd^2}{N} - \left(\frac{\Sigma fd}{N}\right)^2} \qquad (6)$$

Where a is assumed mean

From the analysis of the results, the spread, mean and standard deviation and gap distances are shown in fig. 6.

Discusion

The point-plane gap is particularly suitable for obtaining a high localized stress and for localization of dense space charge. When positive voltage pulse is applied to the point electrode, the first detectable ionization is of a filamentary branch nature which is called a streamer and is analogous to the case of uniform field gap at higher (pd) pressure. As the voltage level is increased the streamers growth both in length and their number of branches [7-9].

Due to the exponential character of the ionization in the avalanche the density of ions will be highest near the anode. The positive ion charge will produce field distortion in both radial and axial direction and it will be greatest at the head of the avalanche. In the surrounding gas photoelectrons are produced which initiate auxiliary avalanches directed toward the stem of the main avalanche if the space charge field developed by the original avalanche is comparable to the external field.

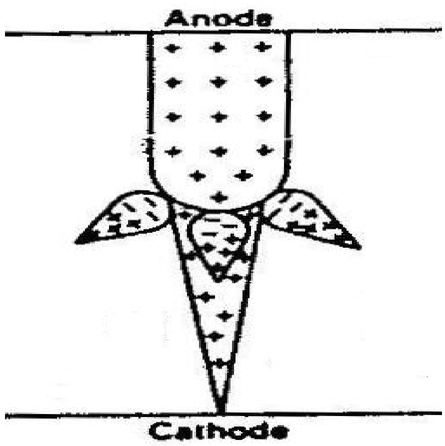


Fig. 7: Cathode directed avalanche

The greatest multiplication in these auxiliary avalanches occurs along the axis of the main avalanche where the space field supplements the external field [10, 11].

Due to the field direction these avalanches are directed towards cathode. From the experiment, these cathode directed multiplication of avalanches sometimes spark over before the breakdown. But due to the attachment within the stem of the main avalanche, they are fewer within the critical length, rather the breakdown charge distribution gives a Gaussian pattern which was evident of all electrodes. With the four electrodes the Gaussian pattern was maintained.

Conclusion

When the avalanche has grown beyond the critical size, its head has opened indicating ionization round the original avalanche head and the cathode directed streamer starts. From the experiment, a hissing corona sound is heard with subsequent breakdown. Since it was impulse voltage used, before the formation of plasma any of filamentary avalanche developed enough is able to cause breakdown. That was why spark or breakdown could follow a subsequent one sometimes with louder sound.

In the various gap length used and with different electrode configuration the shot distributions follows the Gaussian distribution pattern. It is normal to (medium and long) of non-uniform configuration. It does not apply to parallel plate electrodes or weakly non-uniform fields (sphere gaps).

References:

Kuffel, E., Zaengi W.S., Kuffel J., *High Voltage Engineering Fundamentals*, 2nd ed., Butterworth Heinemann Publishers, Oxford, UK, 2000.

Schmid, J., "Influence of absolute humidity on electrical breakdown in air", European Transaction on Electrical Power, 2(5): 327 – 334, 2009.

Meek, J.M., Graggs, J.D., *Electrical Breakdown of Gases*, Oxford University Press, Amen House, London EC1, UK, 1953.

Topalis, F.V., Danikas, M.G., *Breakdown in airgap with solid insulating barrier under impulse voltage stress*, Facta Universitatis Ser., Electrical Engineering, 2005.

Giao-Trinh N., Vincent, C., "Statistical Significance of Test Methods for low Probability Breakdown and Withstand Voltages". IEEE Transactions on Power Apparatus and Systems, 101: 711 – 719, 1980.

Timalkov, V.V., Pietsch, G.J., Saveliev, A.B., Sokolova, M.V., Timalkov, A.G., "Influence of solid dielectric on the impulse discharge behavior in a needle to plane airgap", Journal of Physics D: Applied Physics, 38(6): 877 – 886, 2005.

Onal, E., "Breakdown characteristics of gases in non-uniform field", Journal of Electrical and Electronics Engineering, Istanbul University, Turkey, 4(2): 1177 – 1182, 2004.

Kara A., Kalendeil, O., Mardikyan, K., "Effect of dielectric barriers to the electric field on rod-plane airgap", International Proceeding of the Consol Users Conference, Prague, 2006.

Ming, I., Leijon, M., Bengtsson, T., "Factors influencing barrier effects in an airgap", Proceeding of the 9th International Symposium on High Voltage Engineering, Graz, Austria, 2: 2168 (1-4), 1995.

Kouno, T., "Breakdown of composite dielectrics, the barrier effect", IEEE Transaction EL, 15(3): 259 – 261, 1980.

Abdel-Salam, M., Singe, H., Ahmed, A., "Effect of the dielectric barrier on discharges in non-uniform electric fields", Journal of Physics D: Applied Physics, 34(8): 1219 – 1234, 2001.