Estimation of Volt-time Characteristics and the Onset voltage in Disruptive Effect Method

S. Venkatesan, K.Udayakumar, S.Martin Paul, V. Jeyabalan

Abstract—**Disruptive Effect (DE) method has been well-recognized world wide as a suitable method in estimating the insulating strength of non-standard impulse waveshapes. This paper addresses the procedure in extracting the parameters of DE method namely onset voltage (U_0) and critical Disruptive Effect area (DE^*). Experimental volt-time characteristics are plotted by statistical procedure. The impulse breakdown in an insulating medium is a statistical phenomenon, in which Normal probability distribution gives the best result when plotting the volt-time characteristics. The DE parameters are extracted from these characteristics. Uniform and non-uniform field gaps are chosen, while oil insulating medium is considered for analysis. The AC, DC and impulse breakdown voltages of these insulating medium are estimated. From this a relation is arrived to estimate the onset voltage.**

Index Terms- **Non-standard impulse, Volt-time characteristics, Statistical breakdown phenomena, Normal distribution, small oilgaps.**

I. INTRODUCTION

Most of the Power apparatus in the power system experiences non-standard impulse waveshapes during operating conditions, which are not according to the shape defined in standards. While testing Large power transformers, it is very difficult to adjust the impulse generator to generate standard waveshape. Also, parts of the windings are stressed with nonstandard impulse voltages of both unidirectional and bi-directional oscillating voltage waves. Hence apart from the standard 1.2/50 μs waveshape, it is essential to estimate the insulation strength of the insulation such as air, oil and Oil Impregnated Paper (OIP) for nonstandard waveshapes. But it is impracticable to estimate the insulation strength for all possible waveshapes. For example, the use of the standard v-t characteristics is not adequate to determine the impulse strength with nonstandard waves. The most convenient approach to the problem is to develop an analytical prediction procedure based on the sparkover data obtained with standard waves. Kind (1958), made the first significant advance in the development of a suitable analytical method by proposing the equal area criterion using the generalized integration method. The Disruptive Effect (DE) method is a generalized integration method developed based on equal area criterion, used to estimate the instant of breakdown of insulation under non-standard lightning impulse. There exists a theoretical basis for the Disruptive Effect method for predicting the impulse strength of insulation subjected to non-standard impulse wave shape [1]. It has a reasonable success as far as waveforms close to lightning impulses (unidirectional) are concerned but does not fare well for bi-directionally oscillating impulse. Hence, a new method called "Unconditionally Sequential Approach" developed by Usa et. al., [2] serves as a measure of insulation strength under bi-directionally oscillating impulse voltages. The co-authors have already reported this method in the reference cited. Thus the Disruptive Effect method shall be utilized to predict the insulation strength of any insulation.

In this paper the procedure in extracting the parameters of the DE method (U_0 and DE^*) is addressed. Uniform and non-uniform field gaps are chosen, while oil insulating medium is considered for analysis. The AC, DC and impulse breakdown voltages of these insulating medium are estimated. From this a relation is arrived to estimate the onset voltage.

II. DISRUPTIVE EFFECT METHOD

This method is based on Equal area criteria, suggested by Darveneiza et.al.,[1] called Disruptive Effect method proved by Usa et., al.,[2] Assumptions forming the basis of this General Integration method are, (a) There is a minimum voltage called onset voltage U_0 beyond which any breakdown process starts. (b) Process, which leads to breakdown, is a function of shape of the applied voltage and duration of the applied voltage above U_0 [3]. According to this method the Critical Disruptive Effect DE* is a function of applied voltage (U), Onset voltage (U_0) and the time to breakdown (t_b).

$$DE^* = \int (U, Uo, t) \qquad (1)$$

$$DE = \int_{t_0}^{t_b} (U(t) - U_o)\, dt \qquad (2)$$

where t ranges from t_o to t_b, U(t) is the time function of applied voltage. Here t_o is the first instance at which the applied voltage exceeds the inception voltage (U_0). The unit of DE is kV-μsec. The flow chart depicting the procedure followed to extract the parameters of this model is shown in appendix.

III. EXPERIMENTAL SETUP

Marx generator is used to produce the standard impulse voltages 1.2/50 μs for plotting the v-t characteristics. MWB

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make impulse generator, which is capable of generating a maximum of 100 kV is preferred. The impulse is captured with a DSO (Digital Storage Oscilloscope) connected to a capacitive voltage divider. TDS – 420, DSO with a sampling rate of 100 MSamples per second is used to measure the impulse peak value, time to breakdown and to store the data points corresponding to digitized impulse waveform. This data points are taken into the computer by interfacing the system with DSO by using specially written software. The data points taken from DSO are used to extract the energy balance model parameters.

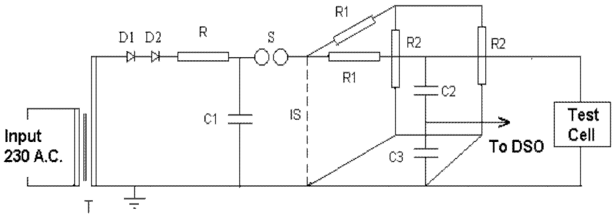


Fig. 1: Test setup used to plot the v-t characteristics

T - Transformer, 230/140 kV
D1, D2 - Diodes
R, - Charging Resistor
R1, R2 - Wave shaping resistors
C1 - Charging Capacitor
C2, C3 - Dividing capacitors
IS - Insulating Rods
S - Sphere Gap
R = 2.5 Mohms; R1 = 245 ohms; R2 = 1200 ohms;
C1 = 100 nf; C2 = 1200 pf; C3 = 900 nf ;

The electrode is designed as per standard specifications, without sharp edges, so as to avoid the corona losses. Care has been taken for the surface to be so smooth, with no sharp perturbation. These electrodes form the part of a test cell, filled with oil insulating medium.

IV. VOLT-TIME CHARACTERSTICS

In practical conditions there will always be some deviations in the time to breakdown and the formative time lag will play a significant role while plotting the experimental volt-time curve. Due to variations in the time to breakdown, it is essential for the breakdown to be considered as statistical phenomenon. This process will lead to statistical impulse volt-time curve band. While performing constant voltage test, the time to breakdown of the impulse, where breakdown occurs in the tail follows Normal probability distribution. Hence, for each gap setting, constant voltage tests are performed at different voltage levels, so that the breakdown occurs in tail of the impulse. A number of n_i impulses resulting in breakdown is applied at every voltage level and the time to breakdown t_b is measured every time. The mean value of time to breakdown (t_b) shall be expressed as

$$t_{b,\,mean} = \frac{\sum_{n_i} t_{bi}}{n_i} \tag{3}$$

and the standard deviation ($s(t_b)$) is given by

$$s(t_b) = \sqrt{\frac{1}{n_i - 1}\sum_{n_i}(t_{bi} - t_{b,\,mean})} \tag{4}$$

With the applied voltage and the mean time to breakdown ($t_{b,mean}$) a characteristic is plotted and is known as mean volt-time characteristics. In a normal probability distribution, the probability of a voltage to breakdown at any time t_b can be expressed as

$$f(t_b) = \frac{1}{\sigma\sqrt{2\pi}}\left[-\frac{(t_b - \mu)^2}{2\sigma^2}\right] \tag{5}$$

Based on this expression the 5% and 95% probability breakdown curves are also constructed. These forms the volt-time characteristic band. For small oil gaps from 0.5mm to 2.5mm, from standard impulse waveshapes, the impulse volt-time band is obtained experimentally. The volt-time characteristics for the plane-plane configurations (uniform configuration) are shown in Fig. 2 and 3.

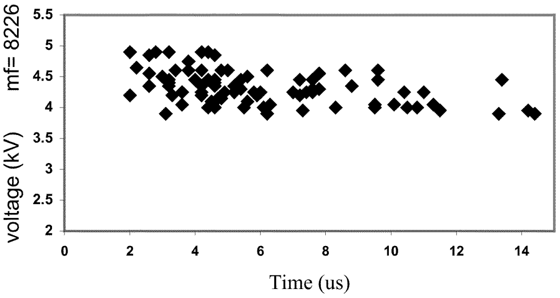


Fig. 2: v-t for 0.5 mm plane-plane configuration

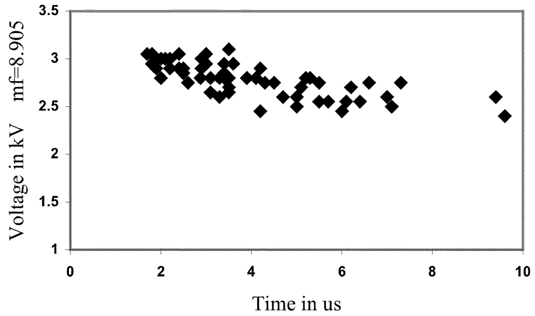


Fig. 3: v-t for 2.5 mm plane-plane configuration

Similarly for Plane-Cone configuration, it is as shown in Fig. 4 and 5. Fig. 6 and 7 shows the mean volt-time curves of all the gaps between 0.5 to 2.5 mm.

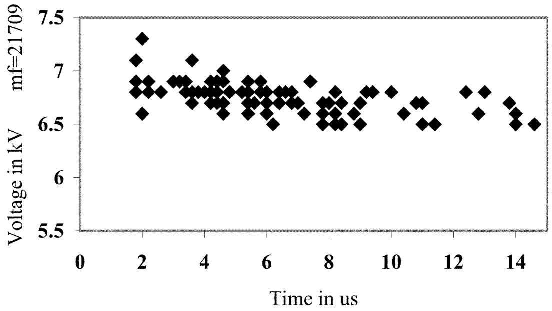


Figure 4: v-t for 0.5 mm plane-cone configuration

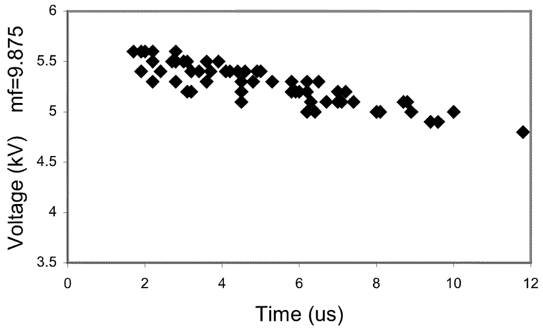


Fig. 5: v-t for 2.5 mm plane-cone configuration

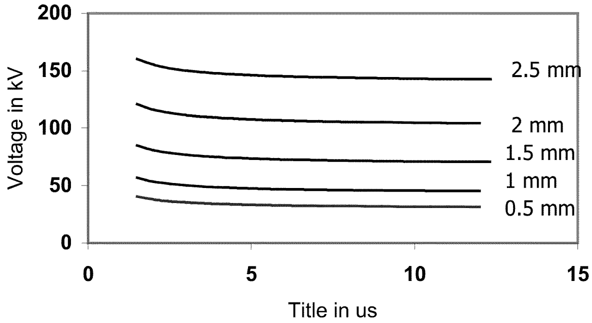


Fig. 6: Mean v-t characteristics of plane-plane configuration

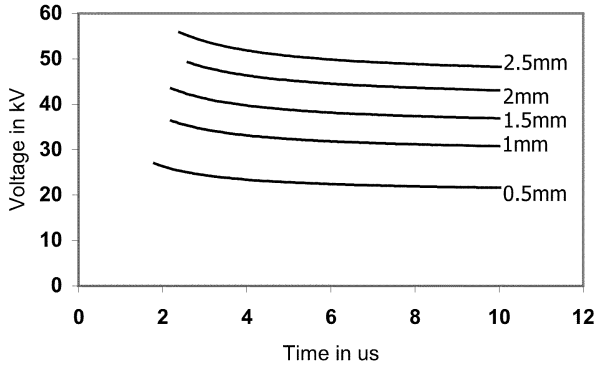


Fig. 7: Mean v-t characteristics of plane-cone configuration

From these volt-time characteristics, data points corresponding to the mean v-t curve are considered for the extraction of DE parameters. The DE parameters are as shown in the Fig. 8 and 9.

From the graph it can be concluded that both U_0 and DE^* increase linearly with respect to distance. The onset voltage for plane-plane configuration is higher than the onset voltage of plane-cone configuration. Similarly for the Critical Disruptive Effect area, the value is higher for plane-plane configuration than for the plane-cone configuration of any particular distance.

The estimated value of the onset voltage is analytically calculated value, which signifies that it corresponds to a voltage, below which there is no breakdown process initiation. To make a comparative study, the breakdown voltages under AC, DC and impulse voltages are experimentally found out and are explained below.

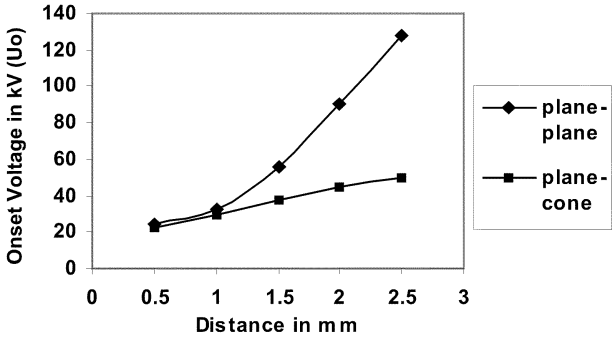


Fig. 8: Onset voltage for various gap distances

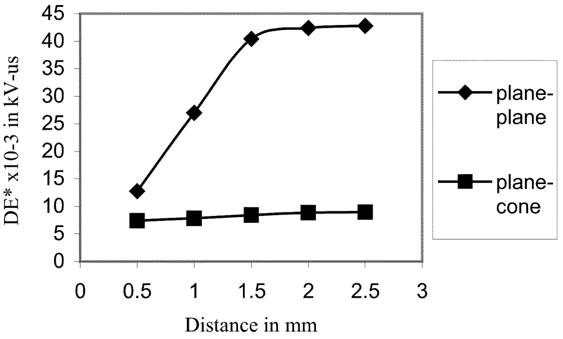


Fig. 9: Critical Disruptive Effect for various gap distances

V. ESTIMATION OF BREAKDOWN VOLTAGES

This chapter gives the experimentally obtained breakdown voltages under AC, DC and Impulse condition [4]. In order to estimate the breakdown values under different electrode configurations; Plane-Plane, Plane-Rod, Plane-Cone and Plane-Needle (from best to worst field configuration) are chosen and their breakdown values are as shown in the following Figures. Fig. 10 gives the average breakdown voltage values under AC excitation. It can be found that it has a direct relation to the efficiency factor of the electrode configuration.

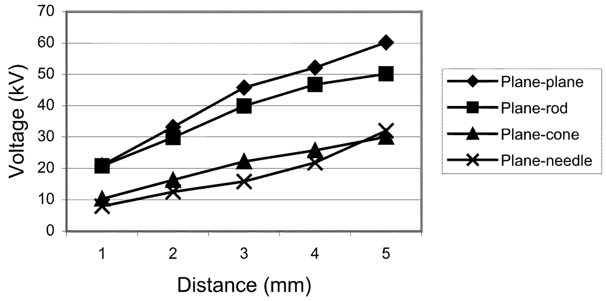


Fig. 10: Average AC breakdown voltages

Fig. 11 shows the breakdown voltage values under DC, +ve voltage excitation. It also follows the similar fashion as that of AC excitation. But the breakdown voltage value is higher than the AC breakdown voltage value.

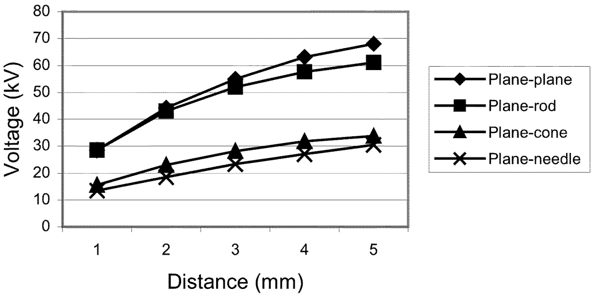


Fig. 11: Average DC (positive) breakdown voltages

Fig. 12 shows the breakdown voltage values under DC, -ve voltage excitation. It also follows the similar fashion as that of AC and DC +ve excitation. But the breakdown voltage value is higher than the Ac and DC +ve breakdown voltage values.

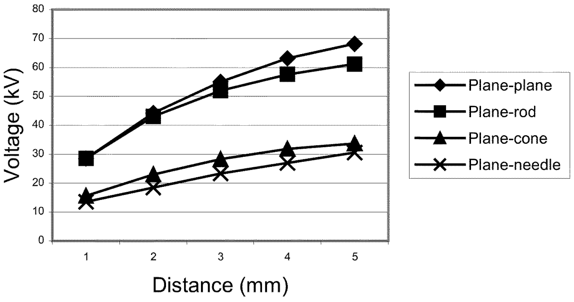


Fig. 12: Average DC (Negative) breakdown voltages

Fig. 13 shows the breakdown voltage values under +ve impulse voltage excitation. It also follows the similar fashion as that of AC and DC (+ve and –ve) excitation. But the breakdown voltage value is higher than the AC and DC (+ve and –ve) breakdown voltage values.

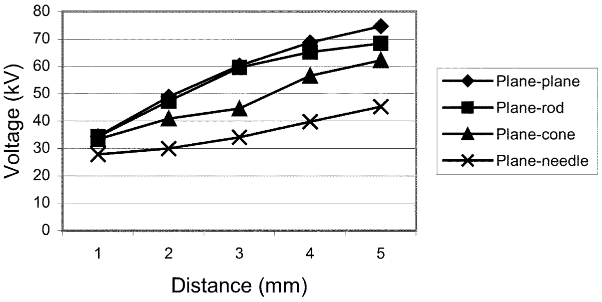


Figure 13: 50% Impulse (Positive) breakdown voltages

Fig. 14 shows the breakdown voltage values under -ve impulse voltage excitation. It also follows the similar fashion as that of AC, DC (+ve and –ve) and Impulse (Positive) excitation. But the breakdown voltage value is higher than the AC, DC (+ve and –ve) and Impulse (Positive) breakdown voltage values.

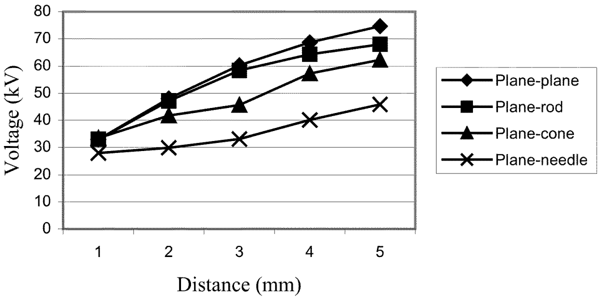


Fig. 14: 50% Impulse (Negative) breakdown voltages

A further regression analysis is carried out, to relate the utilization factor (η) of each configuration to the breakdown voltages (AC, Impulse positive and negative). The model used is given by

$$V_{b/d} = a\,(\eta)^{b} \tag{6}$$

where a and b are model constants. The values of the model constants are tabulated in Table I.

TABLE I'a' AND 'b' CONSTANT VALUES

Dist. (mm)	AC (average)		+ve Imp (50%)		-ve Imp (50%)	
	a	b	a	b	a	B
1	69.92	1.85	35.9	0.14	39.48	0.24
2	176.68	1.7	106.9	0.75	106.48	0.75
3	306.4	1.54	190.2	0.87	182.68	0.85
4	374.74	1.35	197	0.7	182.92	0.65
5	196	0.83	166.4	0.52	158.62	0.49

From the Table I it can be concluded that there is a direct relation between the breakdown voltages and utilization factor. Further regression analysis is carried out between onset voltage (U_0) and 50% positive impulse breakdown voltage, which concluded that there is linear relation between onset voltage and the 50% positive impulse breakdown voltage. This shows that the analytically estimated onset voltage coincides with the experimental values.

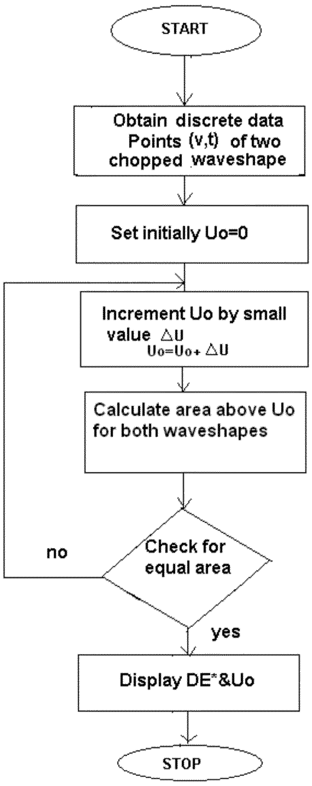
VI. CONCLUSIONS

In this paper the statistical estimation procedure to the volt-time characteristics were clearly explained. Also it can be noted that in a constant impulse voltage test on a particular gap setting (from 0.5 to 2.5 mm), the time to breakdown in the tail follows Normal probability distribution. The parameters of the DE method can be extracted from this volt-time curve. While estimating the parameters, it can be shown that the DE parameters will also have upper and lower limits, according to the volt-time curve band.

The AC, DC and Impulse breakdown voltages under different field configurations were estimated and it is found that they are related to the utilization factor. Also from the regression analysis, it is found that the 50% impulse breakdown voltages have direct relation with analytically estimated onset voltages (U_0). Which means, by knowing one value, the other can easily be obtained.

APPENDIX

The algorithm used to calculate the Disruptive Effect parameters (DE^* and U_0) is as shown below.



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BIOGRAPHIES

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