PARTIAL DISCHARGE PULSE MAGNITUDE DISTRIBUTION

INDRANEEL SEN, M. N. NARAYANACHAR AND V. PRABHASHANKER

(*Department of High Voltage Engineering, Indian Institute of Science, Bangalore* 560 012)

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ABSTRACT

In many insulation systems the partial discharge (p.d.) pulse magnitude (q_T) *probabilities follow the exponential distribution. A model regarding the discharge sites and their growth during ageing has been proposed to explain the physical conditions leading to this distribution.*

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Breakdown by partial discharges is an important mode of insulation failure in high voltage equipment. Several p.d. quantities such as inception (V_i), extinction (V_e) voltages, charge magnitude (q_T) and their distributions are commonly measured. Several attempts to relate these quantities with the puncture times have led to conflicting results.[1] Experiments were conducted to study amongst other aspects, the p.d. pulse magnitude distributions in a perspex air insulation system.

Experimental Procedure

The schematic diagram of the experimental set up is shown in Fig. 1. The samples having configurations shown in Fig. 2 were aged. The p.d. pulse magnitudes were recorded at 30 preset levels. The measurements were made periodically as the samples were aged at a constant voltage above the inception level.

Experimental Results

Detailed studies of more than 300 pulse magnitude distributions have shown that all the distributions are similar to the typical set shown in Fig. 3. The maximum deviation of the experimental values of N at any level of Q from the fitted curves did not exceed 10%.

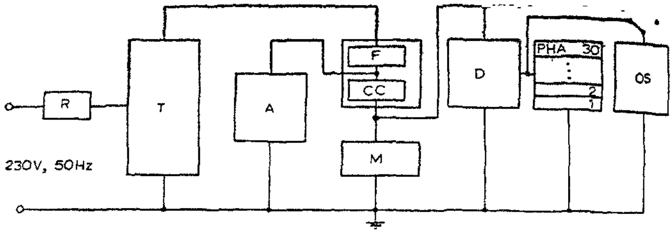


FIG. 1. Schematic diagram of the ageing apparatus.

R—Induction regulator T—Testing transformer F—Filter
A—Ageing cell CC—Coupling capacitor M—Matching unit
D—Discharge detector PHA—Pulse height analyser OS—Oscilloscope

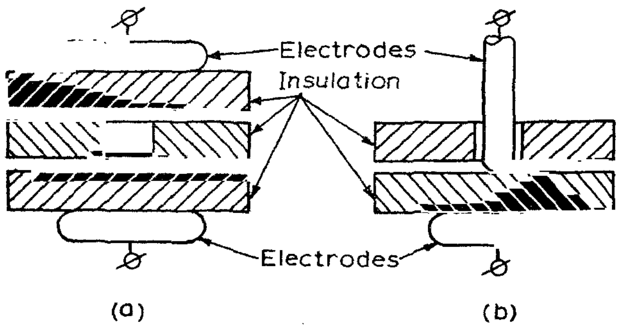


FIG. 2. Two test configurations.
(*a*) Uniform field electrode system with void. (*b*) Rod plane electrode system with void.

Figure 3 shows that the pulse magnitudes follow an exponential distribution as given in Eqn. 1.

$$N_r = A_n \exp\left(-B_{nq} q_r\right) \quad (1)$$

where N_r = number of pulses of all discharges of magnitude greater than q_r.
A_n, B_{nq} = distribution parameters.

When samples of same capacitance are tested, the pulse counts can be expressed in terms of the voltage levels as

$$N_r = A_n \exp\left(-B_n V_r\right) \quad (2)$$

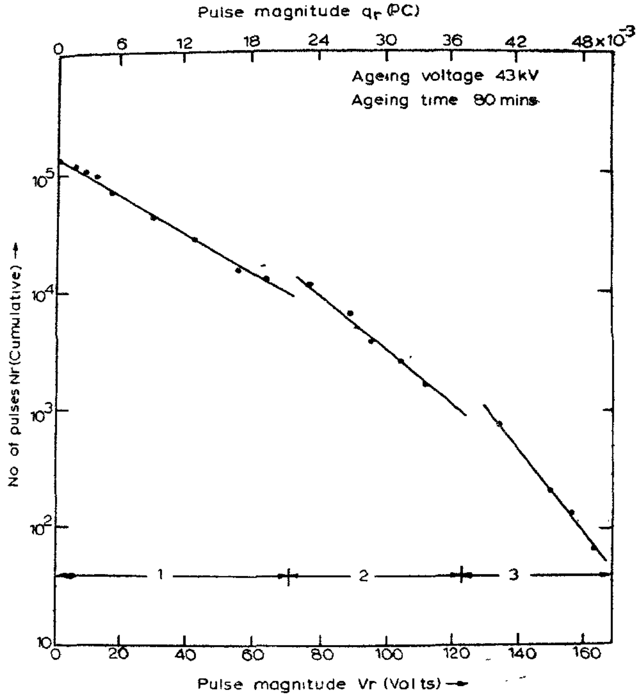


FIG. 3. Typical cumulative probability distribution of partial discharge pulses. (Test configuration figure 2 (*a*)).

where

$$V_r = K \cdot q_r \text{ and } B_n = \frac{B_{nq}}{K}$$

K is a constant depending on the measuring circuit and sample capacitance. In any model which can be suggested to explain Eqn. 1, the following important aspects have to be accounted for :

(1) Even when V_i is constant, there is a distribution of p.d. pulse magnitudes,

(2) These magnitudes of p.d. pulses form into groups (*e.g.*, regions 1, 2 and 3 in Fig. 3)

(3) Almost invariably, the nature of the distribution of any group follows the exponential law as noted as in Eqn. 2.

The Model

To arrive at a suitable model it is necessary to examine Eqn. 2, which leads to the exponential distribution cumulative probability function

$$P(V_r) = 1 - \frac{N_r}{A_n}$$

that is

$$P(V_r) = 1 - \exp(-B_n V_r) \tag{3}$$

where $P(V_r)$ is the probability of finding a pulse of magnitude less than or equal to V_r.

The probability density function $p(V_r)$ is given by

$$p(V_r) = B_n \exp(-B_n V_r) \tag{4}$$

and the hazard function $h(V_r)$ by

$$h(V_r) = \frac{p(V_r)}{1 - P(V_r)}$$

or

$$h(V_r) = B_n \tag{5}$$

Experimental results indicate that for specific regions of V_r, B_n is a constant as may be seen from Fig. 3.

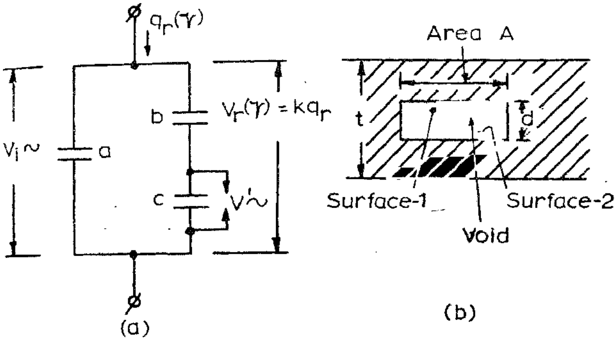
A sample with a void can be represented by the usual *a–b–c* diagram shown in Fig. 4. We have

$$V' = V_i\left(\frac{b}{b+c}\right) \tag{6}$$

where

V_i = inception voltage and

V' = the voltage required for the breakdown of the void *c*, which for air is given by the Paschen's curve.



IG. 4. *a-b-c* Diagram for the test configuration shown in figure 2 (*a*).

te : $q_r(r)$ and $V_r(r)$ indicate pulse magnitudes while V and $V'p$ are AC values.

Vhen the void breaks down, the voltage pulse measured across the discharge etector matching unit is given by

$$V_r = K_1 V' \left(\frac{b}{a+b}\right).$$

here K_1 = constant depending upon sample and circuit capacitance

$$V_r = K_1 \frac{V'}{a} \frac{\epsilon_0 \cdot \epsilon_r A}{(t-d)} \qquad (\text{for } b << a) \tag{7}$$

Then the inception level is constant, implying that d is constant, variation V_r has to be attributed to the variation in area A. According to this model qn. 7 can be written as

$$V_r = K_1 \frac{V'}{a} \frac{\epsilon_0 \epsilon_r A_r}{(t-d)} \tag{8}$$

Ve can rewrite Eqn. 4 using Eqn. 8 as

$$p(A_r) = b_n \exp(-b_n A_r) \tag{9}$$

here

$$b_n = K_1 \frac{V'}{a} \frac{\epsilon}{(t-d)} B_n \tag{10}$$

In the exponential distribution (Eqn. 9) the hazard function is given by b_n which is constant. This implies that the probability of getting partial discharges in a unit surface area is constant and equal to b_n. For the experimental conditions d and t are constants and so also V' and so is B_n. Even apart from this the experimental results show that B_n is constant.

All those sites where this is valid may be considered to constitute one family defined by A_n and B_n.

To obtain the probability $p(A_r)$ we consider the number of pulses (dn_r) within an interval dV_r at a level V_r given by

$$dn_r = p(A_r)\, dA_r \cdot A_n$$

$$= [A_n\, b_n \exp(-b_n A_r)] \cdot dA_r$$

$$\therefore \frac{dn_r}{dA_r} = A_n \cdot b_n \exp(-b_n A_r) \tag{11}$$

Suppose we write Eqn. 11 as

$$\frac{dn_r}{dA_r} = \frac{dn_r}{dt} : \frac{dt}{dA_r} = A_n\, b_n \exp(-b_n A_r) \tag{12, 13}$$

so that

$$\frac{dn_r}{dt} = A_n \tag{14}$$

then

$$\frac{dA_r}{dt} = \frac{1}{b_n} \exp(b_n A_r) \tag{15}$$

These equations 14 and 15 help us to appreciate the phenomena described by Eqn. 1. Equation 14 implies that the number of discharges at any level measured over a fixed interval of time is constant. Thus, if we imagine that the probability of any region of area A_0 discharging is the same then, the condition of Eqn. 14 would be satisfied and one would obtain a discharge magnitude proportional to A_r if the surface area A_r is conducting as given by Eqn. 15.

It may be noted that the data is collected over a period of time when ageing is progressing and hence it is necessary to consider that the relationship of Eqn. 1 holds as the ageing proceeds. This implies that the discharges should alter the surface conditions so that a similar relationship continues to hold. That this should be so can be appreciated if we examine the energy relationships. Whenever a discharge occurs, the energy that is released is given by

$$E_r = \frac{1}{2}\frac{\epsilon_0 A_r}{d} \cdot V'^2 \tag{16}$$

Let e_f = energy of formation of the dissociated products per gram. The mass M_r of the products is given by

$$M_r = E_r/e_f = m_r A_r \tag{17, 18}$$

where

$$m_r = \frac{1}{2}\frac{\epsilon_0}{d} \cdot \frac{V'^2}{e_f} \tag{19}$$

This mass of material would get deposited on the opposite surfaces of the void increasing the area A_r to A'_r.

Suppose the average mass of material per square centimetre on the two surfaces are z_1 and z_2, then the discharge products deposited on any one surface will be given by

$$z_1 A'_r = \frac{M_r\, z_1}{Z_1 + Z_2} = \left(\frac{Z_1}{Z_1 + Z_2}\right) m_r\, A_r \tag{20, 21}$$

Only under these circumstances, can the experimental facts enumerated earlier be explained.

Conclusions

The study of pulse magnitude distributions show that when the exponential distribution is obtained the probability of partial discharge per unit surface area is constant.

Under this condition one can define a family of discharge sites for which A_n and b_n are constants. In this group of sites the average growth of thickness of the conducting deposits on the surfaces due to the discharges is proportional to the discharge magnitudes.

REFERENCES

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