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Flashover on H.V. Insulators Coated with a Non-Linear Conductive Film.

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FLASHOVER ON H.V. INSULATORS COATED WITH A NON-LINEAR CONDUCTIVE FILM

BY

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ABSTRACT

Aiming to improving the insulator resistance in the polluted media, a new proposed model consisting of an insulating surface coated by a non-linear conductive film has been studied.

There are two important roles of the non-linear film. At low voltage gradient, a very small current passes. This low leakage current tends to raise the surface temperatures slightly above the ambient and retards dew deposition, which contributes to many flashovers. At high voltage gradient, i.e. the condition of dry zones formation; the leakage current increases sharply under the discharge across the dry zones, so this discharge diminishes.

To investigate the effect of this non-linear film on the surface discharge and flashover, the electrical characteristics of non-linear film has been studied, and both theoretical model and experimental work; which has been carried out with simple model are discussed.

It has been found that the chance of the formation of local surface discharges decreases, and the critical flashover voltage has increased due to the existence of this non linear film. The mathematical experessions of the electric field in the discharge column and pollution layer were deduced for computing the critical flashover voltage.

I. INTRODUCTION

The main way to improve the behavior of H.V.polluted insulators is to increase their leakage length. The other way is to coat the insulator surface by linear conductive film such as the type of semi-conductive glass insulator.

The insulators which are coated by linear conductive films had been studied in both aspects: in real insulator /1/ for measuring the flashover voltage; and by physical-experimental laboratory models /2/ to understand the flashover mechanism and investigate the different criteria for calculating the critical flashover voltage.

Owing to the linear conducting film; a continuous leakage current flows. It has been found that /1,2/ this leakage current raises the surface temperature slightly above the ambient and retards dew deposition. Besides; the linear film uniformely distributes the electric field on the insulator surface, which increases the value of flashover voltage. So these two important effects contribute to many flashovers.

The linear film is normally designed with high resistance to avoid the bad effect of high leakage current, which should be within a maximum of 1 mA. in such type of insulators /1/. This value is high enough to contribute to flashover, specially if the surface discharge has already been formed. In addition, this value of leakage current causes an increase in losses without benifits in normal condition.

The aim of this present work is to investigate and study the behaviour of H.V. insulator coated with non-linear conductive film. The non-linear film gives very small leakage current in low electric field, so it decreases the losses in normal operation conditions. In the cases of high electric field zones formation; the non-linear film gives very high surface current, which aviods the surface discharge and flashover.

II. ELECTRICAL CHARACTERISTICS OF NON-LINEAR MATERIALS

In general; the current-voltage characteristics of semi - conductive materials such as silicon or zinc oxyde can be represented by /3,4/ the following equation:

$$I_s = a\ V_s^b \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where,

a & b are parameters of current-voltage equation.

Figure (1) shows the current-voltage characteristics which may be divided into three zones depending on the value of b. In the first zone; the value of b is equal to one and then the characteristic is linear. The value of b in the second zone equals two; and in the third zone this value is greater than two, and may reach 30 or greater than 30 depending on the type of semi - conductive material used.

A simple experimental test has been set up for measuring the I-V characteristics for different lengths of a substrate of zinc oxide 97 % with five oxide additions. These are: Bi_2O_3 0.5 % MnO_2 0.5%, Co_3O_4 0.5 %, Cr_2O_3 0.5 %, and Sb_2O_3 1%. This mixture is used /3/ normaly in the fabrication of the lighting arrest disks. The specimen has been tested using the total length h cm; 3/4 h; ½h; and 1/4 h.

In the test, the voltage has been increased gradually and the current was measured. At the end of the test, the Specimen was tested another time for the total length h beginning with high value of voltage and decreasing it gradually.

The h.V. source is a rectified voltage from 0-40 kV; with maximum current of 10 mA. model ABK-45 ZANID. The specimen was

33 mm long; 4.5 mm wide; and 2 mm thick.

Figure (2) shows the experimental results for different values of length h. It has been found that, after the specimen passes the value of a threshold voltage V_{SS}; the I(v) characteristics with the length h (line A) can be represented by:

$$I_s = \frac{a}{h} V_s^b \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

The characteristics before V_{SS} were not regular i.e the value of I_S for length equal to 3/4 h is greater than } h (line B). This non regularity may be caused /3/ by thermal effects in the specimen which strongly affect conductivity. Also when the experiment was performed starting with the highest voltage value and decreasing it gradually, the characteristics obtained did not coincide with the characteristics of the first experiment for the same specimen. This may be also due to the thermal effect in another form. As we started with the high value, the heat content was formed early in the specimen.

The following form may be used for computing the potential gradient in the specimen:

$$E_s = \frac{\partial}{\partial h} \left(\frac{I_s}{a} \right)^b \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

This equation must be calculated numerically at each point on the surface of the specimen.

III. POLLUTION LAYER ON THE NON LINEAR FILM

In the flashover test /5,6/, the pollution layer has been presented by a solution of Nacl which has a linear characteristic of its resistance. So if a pollution layer has deposited on an insulator surface which is coated with a non-linear film, the characteristics of the two layers together will normally depend on the value of the applied voltage. Two cases of the applied voltage are illustrated in Figure (3). The applied voltage is greater or lower than the threshold voltage V_{SS} of the non-linear film.

When the applied voltage value is lower than the threshold voltage V_{SS} of non linear film; the characteristic of non-linear film is linear. Therefore, the total resistance of the two layers together is the parallel resultant of the two layer resistances. Because the resistance of non-linear film is too highly greater than the resistance of pollution layer; the resistance of the two layers together is equal to the resistance of pollution layer alone.

The second case when the applied voltage is greater than the threshold voltage was not considered in this study. This is because the applied voltage must be lower than the threshold voltage in normal condition to avoid the high leakage current. However on a certain zone of insulator surface, which have a very high pollution resistance or dry zone; the characteristic of non linear film has the only role without considering the pollution layer.

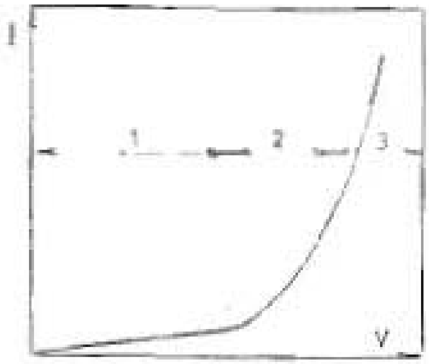

Fig.(1):Characteristic of current-voltage.

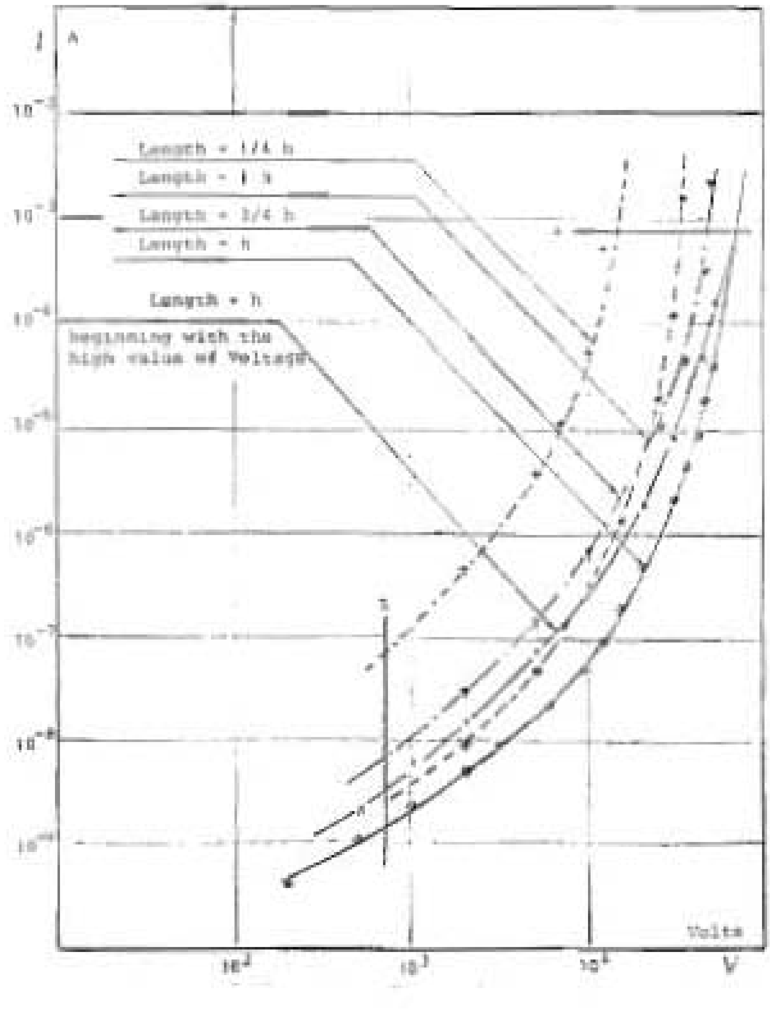

Fig.(2): Experimental results of I-V.

IV. ROLE OF NON-LINEAR FILM ON THE INSULATOR IN OPERATION:

There are two important roles of the non linear film, which coats the insulator surface. The first role affects at normal operation of insulator where the leakage current tends to raise the surface temperature slightly above the ambient and ratards dew deposition, which contributes to many flashovers.

The other role dominates when a dry zone is formed and the discharge grows across it. The high gradient which formed this discharge increases also sharply the leakage current in this portion of the non linear film because the applied voltage at this zone will be greater than the threshold voltage at the moment of growth, so this discharge will diminish. This is so, because the high leakage current in the non linear film under the discharge affects the electric field in the discharge column; and the current necessary for the discharge.

V. FLASHOVER VOLTAGE CALCULATION

Flashover voltage calculation /2,7,8,9/depends on the calculation of electric field on the discharge column and the pollution layer which is in series with the discharge; and also the current path under the discharge in the nonlinear film which affects the electric field in the discharge.

Because of non-linearities in the electrical equation; the electric field calculation is very difficult; so the numerical computation such as finite element or finite difference can be used for solving the electric field problem in such cases.

The following equations have been deduced for the different necessary relation for solving this problem:

$$E_d = A\, Id^{-n} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

$$E_p \doteq (L-X)\, r_{eq} \frac{\partial I_s}{\partial X} - r_{eq}\,(I_d+I_s) \quad \ldots \quad \ldots \quad (5)$$

where,

- E_d & E_p are electric field in the discharge column and pollution layer, respectively.
- L & X are total leakage and discharge length, respectively
- A & n are constants of static-discharge.
- I_d is discharge current
- I_s is non linear film current.
- r_{eq} is the equivalent resistance of non linear film and pollution layer.

The discharge current I_d can be calculated by using the transition characteristic of discharge in gases between glow and arc.

The current in non linear film Is can be calculated where the voltage across the discharge is equal to the voltage across the dry portion of the non linear film as shown in Fig. (4). So the current I_s can be calculated as follows:

$$I_s = a\left(\frac{A \times I_d^{-n} + V_B}{h}\right) \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

where,

V_B = total electrodes voltage drop.

h = the length of non linear film which represents the dry zone.

VI. RESULTS AND DISCUSSIONS

The formation of flashover begins by a local discharge across a dry zone on the insulator surface, and after that the discharge propagates to include all the leakage path on the insulator surface between the high voltage and earthed electrodes. This propagation of discharge is restricted by the critical values of current and voltage /5,6/.

To illustrate the effect of the non linear film coating the insulator surface on the flashover; the following results deal with the effect of non linear film on the first stage of the flashover where a local discharge is formed across the dry zone.

In figure (5), the electrical characteristicsI-V have been presented for three specimens of zinc oxide coating the surface of ceramic plates as shown in Figure (6). This characteristic of each specimen is used to calculate Table (1); which includes the threshold voltage V_{ss}, and the values of a and b for the specimen. The curve of I-V has been divided into three zones and hence, the values of a & b have been calculated for each zone. So, the values of a and b are given by a_1, a_2, a_3 & b_1, b_2, b_3.

Table (1): Values of a, b; and V_{ss} of non linear films.

Specimen No.	Length cm	Width cm	a			b			V_{ss}
			a_1	a_2	a_3	b_1	b_2	b_3	kv
1	6.5	2	2.67×10^{-10}	2.04×10^{-14}	5.13×10^{-56}	1.2	2.3	11.8	33
2	8	2	4.0×10^{-12}	2.6×10^{-17}	2.43×10^{-32}	1.07	2.6	13.6	30
3	8	2	2.79×10^{-13}	8.24×10^{-19}	2.1×10^{-56}	1.63	1.25	15.0	26

It was observed that the specimen 2 has the same length and width as specimen 3; but the results of a, b, and V_{ss} are not identical for each specimen. This contradiction may be due to the available technique for preparing the specimens. This technique used the power of zinc oxide and mixed it with water or alcohal. The mixture is deposited on the surface of ceramic plates. The specimens are dried in an oven. This technique is good technique but gives the film without control of thickness, and hence the difference between the two specimens.

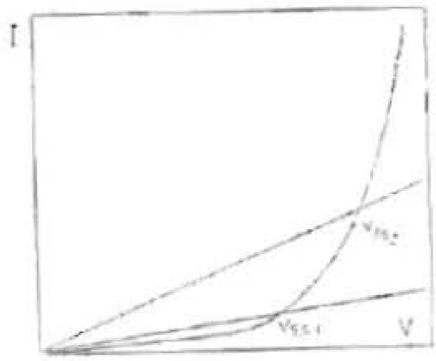

Fig. (3): I-V characteristics of pollution layer and non linear film.

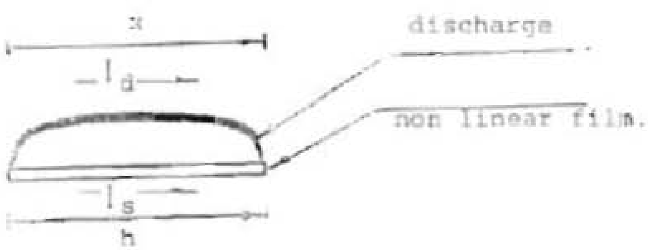

Fig. (4): Electrical model.

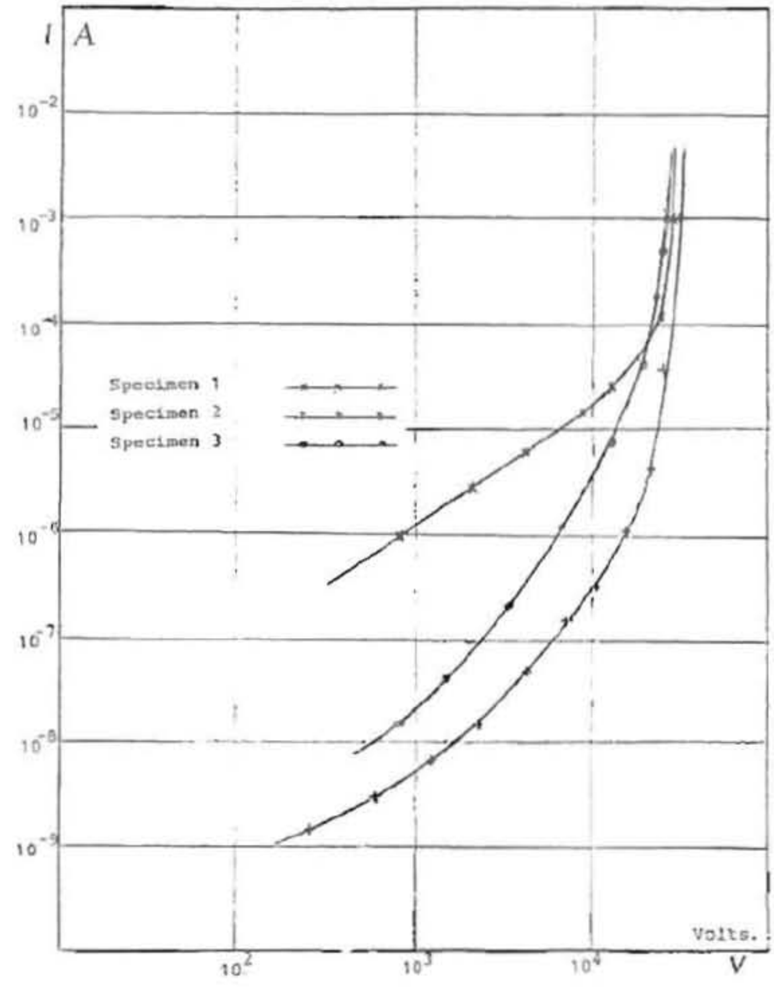

Fig.(5): Experimental results of I-V characteritic of non linear films.

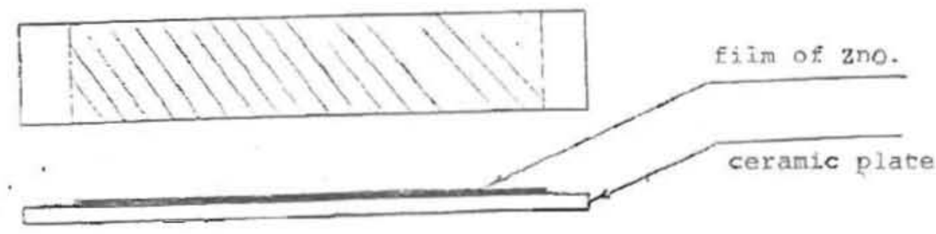

Fig.(6): Specimen of non linear film on the surface of ceramic.

Table (2) gives the variations of I_d and I_s which are calculated by the equations given in section V for the two specimens.

Table (2): Variation of I_d & I_s

Specimen (1) Lenth 0.5 cm large 2 cm $a_2 = 7.1\times10^{-43}$ $b_1 = 11.8$ V_{ss}=2076 Volts.	V volts	947	1021	1146	1883	2075
	I_d A	2×10^{-1}	1×10^{-1}	5×10^{-5}	1×10^{-2}	8×10^{-3}
	I_s A	9.4×10^{-8}	2.3×10^{-7}	9.1×10^{-7}	3.1×10^{-4}	[illegible]$\times10^{-3}$
Specimen (2) Length 0.5 cm Large 2cm $a_3=3.1\times10^{-48}$ $b_3 = 13.6$ V_{ss}=1875 Volts.	V volts	947	1021	1146	1883	2075
	I_d A	2×10^{-1}	1×10^{-1}	5×10^{-2}	1×10^{-2}	8×10^{-3}
	I_s A	9.3×10^{-8}	2.6×10^{-7}	1.25×10^{-6}	1.07×10^{-2}	4×10^{-3}

It has been found that, if the voltage across the dry zone increases due to the pollution on the insulator surface which choked the electric field across the dry zone; the current I_s increases accordingly depending on the voltage of non linear film coating the insulator surface. This increase of current will diminish the discharge across this dry zone.

Refering to the previous results, the choice of the characteristics of non linear film is very important because the sharp increase of current I_s depends on the value of threshold voltage V_{ss} which depends on the length of dry zone.

VII. CONCLUSIONS

The electrical characteristics of non-linear conductive film have been studied to investigate the role of non-linear film which coats the surface of H.V insulators.

The influence of the length of non linear film has been studied and the equations for computing the flashover voltage have been deduced.

It has been found that, the characteristics of non linear film, not only increases the flashover voltage, but also diminishes the surface discharge itself.

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