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Study of Creepage Distance of the Contaminated Insulator in Correlation with Salt Deposit Density

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Abstract: For design purposes, the specific knowledge about the creepage distance of the insulator for the contaminated environment is important. This can be done easily if the mathematical relationship between the creepage distance and Salt Deposit Density (SDD) is known. In this paper, a relationship between the creepage distance of the insulator and SDD has been proposed using Dimensional Analysis technique. The results calculated from the proposed expression are compared with other researcher's results and found to be in close agreement.

INTRODUCTION

In the transmission lines operating 132 kV to 500 kV, the cap-and-pin glass insulators are used as either V-string or I-string configuration. They are usually served in-line with the cross arm to prevent the transverse movement of the conductor under all but extreme loads. At the same time horizontal VEE, horizontal line post and also strut/suspension string have been used in the transmission network systems. The insulator leakage or creepage distance is dependent on its total height. The creepage distance of the insulator increased with increasing string length. The string length of the insulator is required to increase with increasing SDD value.

The line insulators are exposed to the outdoor environment. These insulators are contaminated by the seawater spraying near sea and also by industrial fumes near the industrial areas. The insulation strength of those contaminated insulators is dependent on so many variables namely (1) the type and amount of contaminant and inert binder, (2) the configuration of the insulator, (3) the length of the insulator string, (4) weather conditions and testing method. The deposited contaminants on the insulator surface can be expressed and represented by the Salt Deposit Density. The creepage distance of the insulator is closely related with the SDD. Some researchers [1-3] have established the relationship between creepage distance and the SDD empirically. The data of the CIGRE working group [1] is given in terms of the withstand specific leakage or creepage distance in mm/kV rms line to line voltage as a function of contamination level in terms of SDD. The IEEE working group [4] has proposed similar empirical relationship between creepage distance and SDD. For developing empirical relationship more working time and large amount of data is required. For minimizing these kinds of problems, a mathematical relationship between the creepage distance and the SDD of the contaminated insulator has been proposed using Dimensional Analysis technique. The proposed analytical expression has been verified by the other researcher's results.

THEORETICAL DEVELOPMENT

In the practical field, the creepage distance of the insulator directly depends on average diameter (D), Salt Deposit Density (SDD), exposure time (et) and static arc constant (N). According to Dimensional Analysis technique [5], the relationship between them can be written as,

$$p = F\,(D, N, SDD, et) \tag{1}$$

where:

F - Function;
p - Creepage distance of the insulator;
et - Exposure time of the insulator;
N - Static arc constant;
SDD - Salt Deposit Density.

The dimensional matrix of the above variables can be written as,

	p	D	N	SDD	et
L	-1	1	1	-2	0
M	-1	0	1	1	0
T	3	0	-3	0	1
A	1	0	$n-1$	0	0

where:

L - Length in SI units;
M - Mass in SI units;
T - Time in SI units;
A - Current in SI units;
n , N - Arc constant.

The rank of the above dimensional matrix is 4 and dimensionless product of the whole set is 1. The homogeneous linear algebraic equations from the above matrix can be written as follows,

$$-k_1 + k_2 + k_3 - 2k_4 = 0 \quad (2)$$

$$-k_1 + k_3 + k_4 = 0 \quad (3)$$

$$3k_1 - 3k_3 + k_5 = 0 \quad (4)$$

$$k_1 + (n-1)\,k_3 = 0 \quad (5)$$

Where k_1, k_2, k_3, k_4 and k_5 are the exponents of the respective variables. The expression of k_2, k_3, k_4 and k_5 in terms of k_1 can be derived from equation (2) to (5). These expressions are,

$$k_2 = \frac{3n}{n-1}k_1, k_3 = -\frac{1}{n-1}k_1, k_4 = \frac{n}{n-1}k_1,$$
$$k_5 = \frac{-3n}{n-1}k_1 \quad (6)$$

By assigning the value of k_1 as 1 the expression of equation (6) can be written in matrix form as follows,

	k_1	k_2	k_3	k_4	k_5
	p	D	N	SDD	et
π	1	$\frac{3n}{n-1}$	$\frac{-1}{n-1}$	$\frac{n}{n-1}$	$\frac{-3n}{n-1}$

The general expression from the above matrix can be written as,

$$\pi = p\, D^{\frac{3n}{n-1}}\, N^{\frac{-1}{n-1}}\, (SDD)^{\frac{n}{n-1}} (et)^{\frac{-3n}{n-1}} \quad (7)$$

By applying the Buckingham's π theorem [5], equation (7) can be re-written as,

$$p = d_c\, D^{\frac{-3n}{n-1}}\, N^{\frac{1}{n-1}}\, (SDD)^{-\frac{n}{n-1}} (et)^{\frac{3n}{n-1}} \quad (8)$$

Where d_c is the dimensional constant. It should be noted that in an work [6] on application of Dimensional Analysis technique for relating insulators flashover voltage with pollution resistance, other variables were considered as constant. Therefore, in the present work equation (8) has been modified by denoting the exponent $\left(\frac{-n}{n-1}\right)$ by b and treating N and et as constants so as to highlight the relationship between creepage distance and Salt Deposit Density.

$$p = d_c\, (SDD)^{b}\, D^{3b} \quad (9)$$

COMPARISON OF RESULTS

Actually the creepage distance of the insulator is the most important determinant for studying the contamination performance and also design purposes. The values of creepage distance are calculated from equation (9) with different values of d_c, b for V-string and I-string insulator arrangement. For comparison, the calculated results are plotted with the other researcher's result [4] and are shown in Fig. 1. In Fig.1, it is observed that the creepage distance of the I-string insulator is much lower than the V-string insulator for the range of SDD value 0.04 to 0.1 mg/cm^2. Because in case of V-string, large number of insulators are required than I-string. The results obtained from the proposed analytical expressions are more consistent with other researcher's results for both V and I string.

Again the creepage distances for I-string are calculated from equation (9) for the range of SDD from 0.02 to 0.44 mg/cm^2. These calculated values are plotted with the other researcher's results i. e. CIGRE [1], NGK [2], and CESI [3] results. These are shown in Fig. 2. From the Fig. 2, it has been seen that the proposed analytical results are in close agreement with the NGK [2] researcher results. The deviation between the proposed analytical results and CIGRE [1] results is slightly higher. Because in CIGRE [1] models the values of

d_c and b constants are considered 66 and 0.223 respectively.

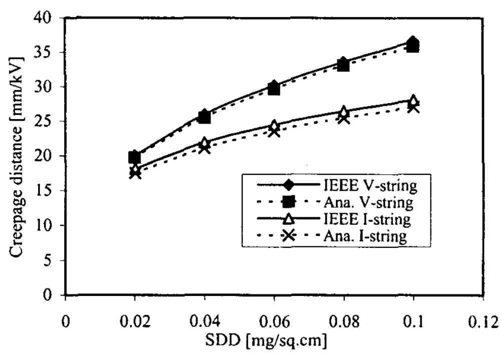

Fig. 1. Variation of creepage distance with SDD

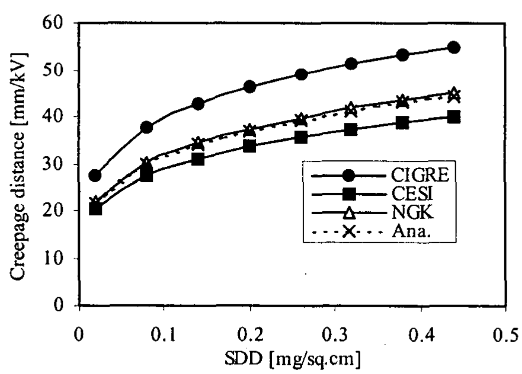

Fig. 2. Specific creepage distances with SDD

CONCLUSIONS

The analytical expression between the creepage distance and Salt Deposit Density for the polluted insulator has been derived using Dimensional Analysis technique. The creepage distances calculated from the proposed analytical expression are compared with the other researcher's results and found to be in close agreement.

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