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A MODEL FOR THE FLASHOVER PROCESS ON NON-UNIFORMLY POLLUTED INSULATORS

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Abstract

The flashover process over polluted insulators is described by well-known analytical equations, published by various investigators, mainly Obenhaus and Alston. These procedures were used for the formulation of a mathematical model that permits determination of the parameters of the flashover under uniform or non-uniform pollution of the insulator. The calculated values were found to be in agreement with laboratory tests on artificially polluted insulators. All the experimental techniques use uniform distribution of the pollution layer on the surface of the insulator. Tests on artificially polluted insulators under non-uniform pollution are rare. On the other hand, Rizk measured the deposit of natural pollution on the surface of various insulators for a long period of time. The mathematical model of this work was applied for the calculation of the dielectric strength of the insulator under the determined non-uniform distribution. The type of insulator investigated here is similar to the ones of Rizk. The surface of the insulator is divided into finite elements, uniformly contaminated, across the creepage length. The required parameters for the calculation of the critical voltage for the flashover are the dimensions of the insulator, the arc constants, and the specified distribution of the pollution. The dependence of the critical voltage upon the distribution of the pollution layer and the total pollutant deposit on the insulator are also presented.

Key Words

Insulators, pollution, equivalent salt deposit density

1. Introduction

The safe operation of a power system is threatened by the flashover of polluted insulators. The accumulation of air-borne pollutants due to natural, industrial, or even mixed pollution during a dry weather period and their subsequent wetting, mainly by high humidity, is a major problem of the insulation systems. The flashover of polluted insulators can cause transmission line outage of long durations and over large areas. This problem motivated the installation of a test station in order to perform laboratory tests on artificially polluted insulators. Although these tests are indispensable for the study of insulator behaviour under pollution, they are of long duration. The equipment, necessary for these experiments is very costly. For these reasons, it seems useful to predict the performance of insulators under pollution conditions using analytical expressions and computer models. The surface conductance of a polluted insulator is a parameter that gives the overall picture of those surface conditions of the insulator (quantity of pollution and degree of humidity of the layer) that directly affect the electrical performance of the insulator, itself, when energized. The experiments were carried out [1] using either the salt fog method or the solid layer cool fog method. Numerous experimental data were obtained (maximum withstanding voltage versus pollution, ratio between creepage distance and minimum flashover voltage versus pollution, maximum withstanding salinity at a given applied voltage, leakage current, etc.) for several insulator types. These data were used for the determination of the arc constants [2] and the development of a generalized model for the dielectric behaviour of polluted insulators. The application of this model for non-uniformly polluted insulators is presented in this article.

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2. Mathematical Model

The most known model for the explanation and evaluation of the flashover process [3–4] of a polluted insulator consists of a partial arc spanning over a dry zone and the resistance of the pollution layer in series. The applied voltage U follows [3] the following equation:

$$U = A \cdot I^{-n} + I \cdot r_p \cdot (L - x) \tag{1}$$

where x is the length of the arc, L is the leakage distance of the insulator, I is the leakage current, r_p is the resistance per unit length of the pollution layer, and A, n are the arc constants.

At the critical condition, when the partial arc is developed into a complete flashover, the current I obtains its critical value I_c which is given [5] by:

$$I_c = (\pi \cdot A \cdot D_m \cdot \sigma_s)^{\frac{1}{n+1}} \tag{2}$$

where D_m is the maximum diameter of the insulator disk and σ_s is the surface conductivity given versus the equivalent salt deposit density C (ESDD). σ_s is obtained in Ohm^{-1} and r_p in Ohm/cm, for C expressed in $\mathrm{mg/cm}^2$.

The critical voltage U_c is given [5-8] by the following formula:

$$U_c = \frac{A}{n+1} \cdot (L + \pi \cdot n \cdot D_m \cdot F \cdot K) \cdot I_c^{-n} \tag{3}$$

where K is the coefficient of the pollution layer resistance with consideration of the current concentration at the arc foot point. In the case of cap-and-pin type insulators, a simplified form of K is given [2, 5, 6] as follows:

$$K = 1 + \frac{n+1}{2 \cdot \pi \cdot F \cdot n} \cdot ln\Big(\frac{L}{2.94 \cdot \sqrt{I_c} \cdot F}\Big) \tag{4}$$

F is the form factor of the insulator that is defined as ollows:

$$F = \int_0^L \frac{d\ell}{\pi \cdot D(\ell)} \tag{5}$$

vhere $D(\ell)$ is the diameter of the insulator, varying across ts leakage length L.

Equation (3) provides the value of U_c versus only the nown geometrical characteristics L, D_m of the insulator, he constantsA, n and the pollution C, as I_c is a function f the above parameter, as σ_s is a function of C, and F nd K are functions of L and D_m.

In the case of non-uniform distribution of the pollution ıyer, the insulator is divided into m parts across its creepge distance L [7, 8]. The equivalent salt deposit density $'_i$ of each part is considered to be constant; therefore the ırface conductivity of the i-th part will be:

$$\sigma_{si} = (369.05 \cdot C_i + 0.42) \cdot 10^{-6} \tag{6}$$

The coefficient of the insulator shape, according to (5) ill be:

$$F = \sum_{i=1}^{m} F_i = \sum_{i=1}^{m} \frac{l_i}{\pi \cdot D(l_i)} \tag{7}$$

here $D(\ell_i)$ is the mean diameter of part i and l_i is the ıkage length of part i. Each term of the above sum ırresponds to the shape coefficient F_i of part i :

$$F_i = \frac{\ell_i}{\pi \cdot D(\ell_i)} \tag{8}$$

Finally, the surface conductivity σ_s of the total pollu- ın layer will be given from the following relation:

$$\sigma_i = \frac{F_i}{\sum_{i=1}^{m} \frac{F_i}{\sigma_{si}}} \tag{9}$$

The total salt deposit P_i of each part is given by:

$$P_i = \pi \cdot \ell_i \cdot D_i \cdot C_i \tag{10}$$

and therefore, the total salt deposit P of the insulator surface can be calculated as follows:

$$P = \sum_{i=1}^{m} P_i = \sum_{i=1}^{m} \pi \cdot \ell_i \cdot D_i \cdot C_i \tag{11}$$

The average ESDD $C_{a\nu}$ of the insulator is:

$$C_{a\nu} = \frac{P}{S} \tag{12}$$

where S is the surface of the insulator disk.

The meaning of (3) is that, if the values of the arc constants are known, the model of the polluted insulator can be used to draw conclusions about the flashover mechanism not only qualitatively but also quantitatively: the critical voltage of any insulator under any pollution severity can be evaluated in a very simple way, using the above equations. Obviously, the dielectric behaviour of insulators under pollution conditions can be precisely predicted, and, eventually, the relevant expensive and time consuming experimental tests can be omitted, or at least limited to the absolutely indispensable number.

3. Simulation Method

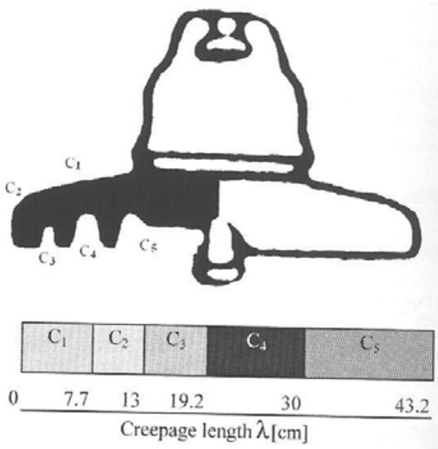

Figure 1. Distribution of the pollution layer.

The insulator investigated for the application of this model is of the cap-and-pin type (Fig. 1). Its maximum diameter D_m is 25.4 cm, and the creepage distance L is 30.5 cm. The total surface S of the insulator is 1539 cm^2, the top area of insulator 660 cm^2, and the bottom one 879 cm^2. The form factor F of insulator is 0.696.

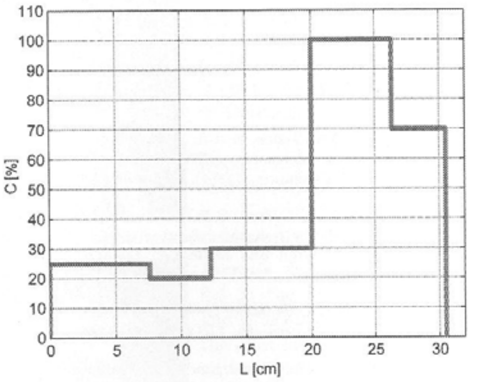

Figure 2. Distribution of the pollution layer $C_{\min} : C_{\max} =$ 1.5.

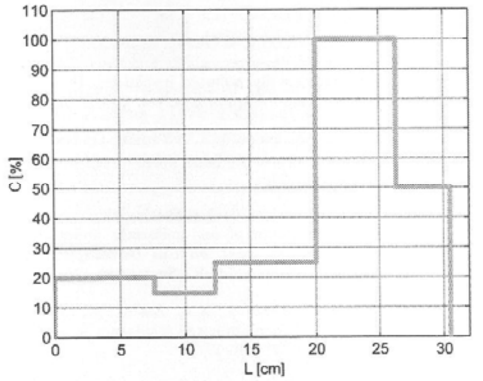

Figure 3. Distribution of the pollution layer $C_{\min} : C_{\max} =$ 15 : 100.

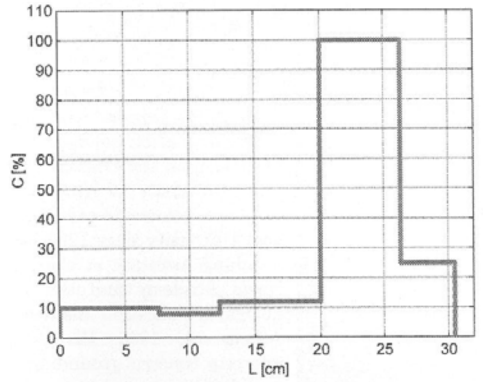

Figure 4. Distribution of the pollution layer $C_{\min} : C_{\max} =$ 1 : 12.5

The non-uniformly polluted insulator is divided into five parts; each one is considered to be uniformly contaminated. Three different distributions of the pollution layers are investigated in this work (Figs 2– 4) according to the measured values of the natural contamination, as measured by Rizk [9].

The ratio of the ESDD of each part to the one of the part with the maximum ESDD in the first case is C_1:C_2:C_3:C_4:C_5=25:20:30:100:70 (Fig. 2). The ratio in the second case is C_1:C_2:C_3:C_4:C_5= 20:15:25:100:50 (Fig. 3). The third one is C_1:C_2:C_3:C_4:C_5=25:20:30:100:70 (Fig. 4).

The first one of the above investigated cases represents the pollution of the insulator after a period of two years without cleaning. The second and the third distribution correspond to a decrease of 35% and 60% of the pollution, respectively, after cleaning by rain. Rizk [9] and El-Arabaty [10] have measured those distributions.

4. Results

The variation of the critical voltage U_c with the total salt deposit P on the insulator surface, or with the average ESDD $C_{a\nu}$, are shown in Figs. 5 and 6, respectively. The dependence of critical voltage U_c upon the ESDD C_4 of the most polluted part of the insulator is shown in Fig. 7.

It is obvious that the total pollution quantity is not the only critical parameter determining the dielectric behaviour of the insulator. The form of the distribution of the pollution layer is very important: the critical flashover voltage value U_c of the insulator under uniform distribution is lower than under a more non-uniform pollution. It must be noted that these critical values of the flashover voltage refer to the same total salt deposit P.

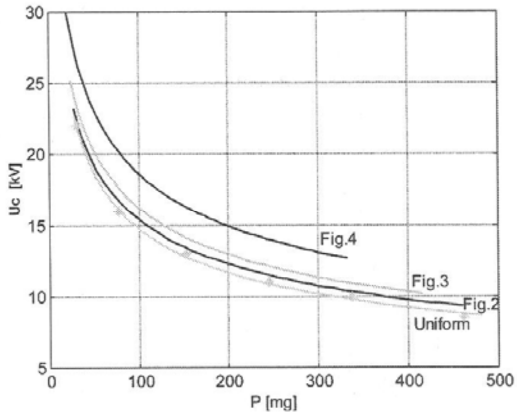

Figure 5. Critical voltage Uc versus total salt deposit P.

* Experimental results [1].

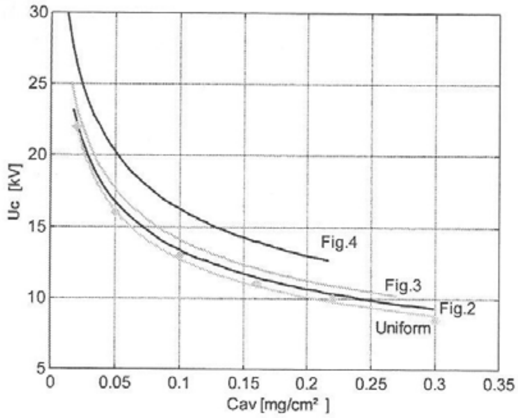

Figure 6. Critical voltage Uc versus the average ESDD C_{av}.

* Experimental results [1].

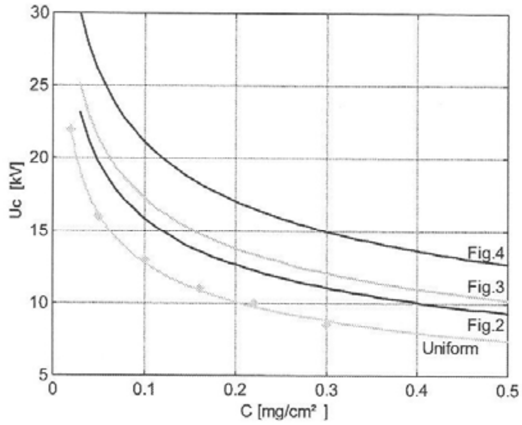

Figure 7. Critical voltage Uc versus $C_{\max}$ the most polluted parts of the insulator.

* Experimental results [1].

5. Conclusion

The aim of this article was to investigate the dielectric behaviour of non-uniformly polluted insulators by means of a computer model. This investigation was based on measurements of the natural pollution on the insulator surface, which has been performed by other researchers.

The computer results confirmed that the total pollution or the equivalent salt deposit density are not exclusively the critical parameters that determine the dielectric behaviour of the insulator. The uniformity, or even non-uniformity, of the pollution was also found to be very important.

The contribution of this work is the determination of the dielectric strength of the insulator under non-uniform pollution. It is hoped that expensive experiments required for the estimation of this behaviour can be drastically reduced or even eliminated. The information that can be obtained by means of the proposed method is very useful for insulation co-ordination of electric power overhead lines.

References

[1] F.V Topalis, I.F. Gonos, & I.A. Stathopulos, Dielectric behaviour of polluted insulators, *IEE Proc. Generation, Transmission and Distribution, 148*(4), July 2001, 269–275.

[2] G. Theodorakis, F.V. Topalis, & I.A. Stathopulos, Parameter identification of the polluted insulator model, *Proc. of Int. Symp. on Simulation and Modelling*, Lugano, Switzerland, 1989, 103–106.

[3] L.L. Alston & S. Zoledziowski, Growth of discharges on polluted insulation, *IEE Proceedings, 110* (7), 1963, 1260–1266.

[4] F.A.M. Rizk, Mathematical models for pollution flashover, *Electra, 78*, October 1981, 71–103.

[5] R.J. Xavier & Y.N. Rao, Study of surface conductivity and E.S.D.D. on contaminated porcelain insulating surfaces, *Proc. 5th Int. Symp. on High Voltage Engineering*, Vol. 2, Braunschweig, 1987.

[6] Zhang Renyu, Zhu Deheng, & Guan Zhicheng, A study on the relation between the flashover voltage and the leakage current of naturally or artificially polluted insulators, *Proc. 4th Int. Symp. on High Voltage Engineering*, Vol. 2, Athens, 1983.

[7] S.A. Suflis, I.A. Stathopulos, & F.V. Topalis, On the dielectric behavior of non-uniformly polluted insulators, *Greek CIGRE*, Athens, November 1995.

[8] F.V. Topalis, N. Leontides, & I.A. Stathopulos, Investigation of the dielectric behavior of non-uniformly polluted insulators, *Proc. of 10th Int. Conf. on Gas Discharges and their Applications*, Vol. 2, Swansea, U.K., September 1992, 564–567.

[9] F.A.M. Rizk, A.A. El-Sarky, A.A. Assad, & M.M. Awad, Comparative tests on contaminated insulators with reference to desert conditions, *CIGRE*, 1972.

[10] A. El-Arabaty, A. Nosseir, S. El-Debeiky, A. El-Awady, E. Nasser, & A. El-Sarky, Effects of insulator shape, dimensions and material on its flashover characteristics, *Proc. 4th Int. Symp. on High Voltage Engineering*, Vol. 2, Athens, 1983.

Biographies

Ioannis F. Gonos received his diploma of electrical engineering in 1993 from the National Technical University of Athens. He has been a doctoral candidate at that University since 1996, and a Teaching Assistant at the Greek Naval Academy and the Technological Education Institute of Athens since 1996. His research interests concern grounding system, insulators, and high-voltage measurements.

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