COMPUTATION METHODS IN SIMULATION OF THE DIELECTRIC BEHAVIOR OF NON UNIFORMLY POLLUTED INSULATORS

S. A. SUFLIS I. F. GONOS F. V. TOPALIS
NATIONAL TECHNICAL UNIVERSITY OF ATHENS
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
Electric Power Division
Tel. +30-1-7723506, Fax. +30-1-7723628, E-mail: Topalis@softlab.ntua.gr
42 Patission Str., GR 106 82 Athens GREECE

Abstract

This chapter deals with the dielectric behavior of non-uniformly polluted insulators by means of a mathematical procedure based upon well known models, a model developed by the authors of the chapter and using available own experimental data. The surface of the insulator is considered to be non-uniformly contaminated, since the pollution layer is treated to follow different functions of distribution.

The distribution of the pollution layer is determined according to two methods :
i) the insulator is divided into two major parts, each one considered to be uniformly contaminated and
ii) the pollution layer of the insulator is considered to be distributed across the creepage distance according to a mathematical function.

Thereafter, the critical voltage of the insulator is defined under the specified distribution of the pollution, by means of the above mentioned procedure and using only the geometric dimensions of the insulator, the arc constants and the pollution severity.

In this chapter is presented the dependence of the critical voltage upon the distribution of the pollution layer and the total deposit on the insulator. Furthermore a curve fitting procedure is developed in order to determi

ne a simple analytical correlation between the critical voltage and the distribution of the pollution layer as well as the total deposit of the insulator. Diagrams show the variation of the coefficients of the curve fitting formula upon basic insulator characteristics.

Introduction

A major problem of the insulation systems is the accumulation of airborne pollutants due to natural, industrial, or even mixed pollution, during the dry weather period and their subsequent wetting, mainly by high humidity. This problem was the motivation for the installation of a test station in order to perform laboratory tests on artificially polluted insulators.

The experiments carried out, using either the salt fog method or the solid layer cool fog method, provided us with numerous experimental data (maximum withstand voltage versus pollution, ratio between creepage distance and minimum flashover voltage versus pollution, maximum withstand salinity at a given applied voltage, leakage current, etc.) for several insulator types.

The above experimental results permitted the evaluation of the arc constants A, n and of the surface conductivity X_s of the insulator with a quite high accuracy, by means of a mathematical procedure. It has been proved that, the computed values of A, n and X_s are independent of the insulator type and the kind of pollution.

In this chapter, the dielectric behavior of stab - type insulators is investigated, by means of a computer model described below and using the calculated values of A, n and X_s.

Generalised Model of the Polluted Insulator

The most simple model for explanation and evaluation of the flashover process of a polluted insulator consists of a partial arc spanning over a dry zone and the resistance of the pollution layer in series (Fig. 1).

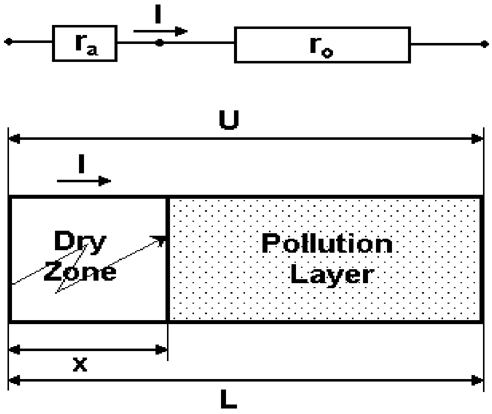

Fig. 1: Equivalent circuit of polluted insulator.

The applied voltage U should satisfy the following equation :

$$U = I \cdot \left(r_a \cdot x + r_0 \cdot (L - x) \right)$$

where x is the length of the arc, L is the creepage distance of the insulator and I is the leakage current. r_a is the resistance per unit length of the arc:

$$r_a = A \cdot I^{-(n+1)}$$

where A and n, are the arc constants, which has been determined with a quite high accuracy. The values of A, n were found to be :

$A = 131.5$, $n = 0.374$

independently of the type of insulator and the kind of pollution.

r_0 is the resistance per unit length of the pollution layer defined by the formula:

$$r_0 = \frac{1}{\pi \cdot D_d \cdot X_s}$$

where X_s is the surface conductivity and D_d is the equivalent diameter of the polluted insulator. X_s is given versus the equivalent salt deposit density C (ESDD), by the formula:

$$X_s = (369.05 \cdot C + 0.42) \cdot 10^{-6}$$

X_s is obtained in $Ù^{-1}$ and r_0 in Ù / cm, for C expressed in mg / cm^2 and D_d in cm.

The equivalent diameter D_d of the insulator is defined as follows:

$$D_d = \frac{L}{\pi \cdot K_s}$$

where K_s is the coefficient of the insulator shape :

$$K_s = \int_0^L \frac{dl}{\pi \cdot D(l)}$$

D(l) is the diameter of the insulator, varying across its creepage distance L.

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

$$I_c = \left(\frac{D_r \cdot A}{D_d \cdot r_0} \right)^{\frac{1}{n+1}}$$

where D_r is the diameter of the insulator disk. The respective critical value I_c of the arc length x is given as follows:

$$I_c = \frac{L}{n+1}$$

At the critical condition, the first equation becomes :

$$U_c = I_c \cdot \left(r_a \cdot l_c + K \cdot r_0 \cdot \left(L - l_c \right) \right)$$

where K is the modified coefficient of the pollution layer resistance with consideration of the current concentration at the arc foot point. In the case of stab - type insulators K is defined as follows :

$$K = \frac{N \cdot (n+1)}{2 \cdot \pi \cdot n \cdot K_s} \cdot \left(\ln\left(\frac{4L}{\pi \cdot N \cdot R} \right) - \ln\left(\tan \frac{\pi \cdot N}{2 \cdot (n+1)} \right) \right)$$

where N is the number of sheds which is equal to 4 in the case of the investigated insulator and R is the radius of the arc foot, given by the formula:

$$R = 0.469 \cdot \left(\frac{D_r \cdot A}{D_d \cdot r_0} \right)^{\frac{1}{2 \cdot (n+1)}}$$

Substituting the values of r_a, r_0, D_d, I_c, l_c in equation for U_c, results the following formula of the critical voltage U_c :

$$U_c = \frac{A}{n+1} \cdot \left(L + \pi \cdot n \cdot D_r \cdot K_s \cdot K \right) \cdot \left(\pi \cdot A \cdot D_r \cdot X_s \right)^{-\left(\frac{n}{n+1} \right)}$$

This equation provides the value of U_c versus only the known geometrical characteristics of the insulator, the constants A, n and the pollution C, since X_s, K_s and K are also functions of the same parameters:

$U_c = f(A, n, L, D_r, C)$

Non - Uniformly Polluted Insulator

In the case of non - uniform distribution of the pollution layer, the insulator is divided into m parts across its creepage distance L. The equivalent salt deposit density C_i of each part is considered to be constant, therefore its surface conductivity will be:

$$X_{si} = \left(369.05 \cdot C_i + 0.42 \right) \cdot 10^{-6}$$

The coefficient of the insulator shape, is:

$$K_s = \sum_{i=1}^{m} \frac{l_i}{\pi \cdot D_m(l_i)}$$

where $D_m(l_i)$ is the mean diameter of part i. Each term of the above sum corresponds to the shape coefficient K_{si} of part i:

$$K_{si} = \frac{l_i}{\pi \cdot D_m(l_i)}$$

Hence, the shape coefficient of the total insulator is :

$$K_s = \sum_{i=1}^{m} K_{si}$$

Finally, the surface conductivity of the total pollution layer will be given from the following relation:

$$X_s = \frac{K_{si}}{\sum_{i=1}^{m} \frac{K_{si}}{X_{si}}}$$

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

$$P_i = \pi \cdot l_i \cdot D_{mi} \cdot C_i$$

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

$$P = \sum_{i=1}^{m} P_{si} = \sum_{i=1}^{m} \pi \cdot l_i \cdot D_{mi} \cdot C_i$$

Computation methods

For the purposes of the present investigation, each shed of the insulator is simulated by 12 elements. Hence, the insulator (which consists of 4 sheds) is simulated by 48 elements (m=48). The insulator is divided into 2 major parts, each one considered to be uniformly contaminated. The simulation method of the two major, uniformly polluted parts, is carrying out by means of three procedures:

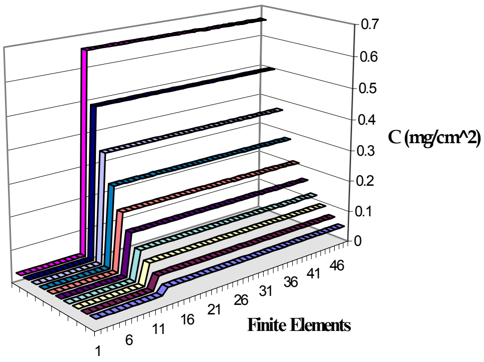

Fig. 2: Dependence salt deposit density

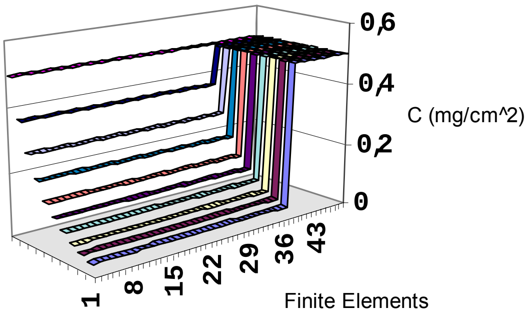

Fig. 3: Dependence salt deposit density

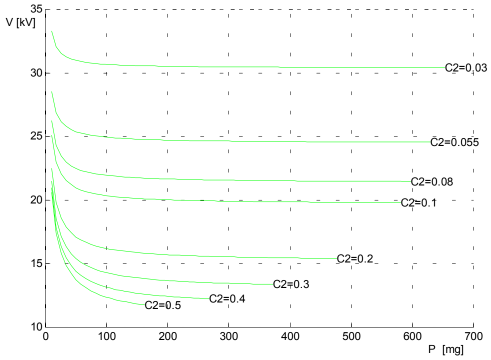

Fig. 4: Dependence of Uc versus salt deposit P, 1-3.

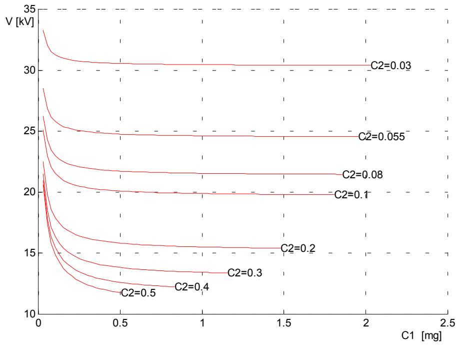

Fig. 5: Dependence of Uc versus salt deposit density C, 1-3.

$$U_c = A - B \cdot e^{-C/C_1}$$

Pc1Uc

User-Defined Model:
Uc=a-13,5*exp(-b/Pc)

C2	a	b
0,030	43,36198	2,4355151
0,055	37,480629	3,5801608
0,080	34,365457	4,5316201
0,100	32,683272	5,2051926
0,200	28,198039	7,9031182
0,300	26,039645	9,9570449
0,400	24,700365	11,610612
0,500	23,776485	12,945191

C1Uc

User-Defined Model:
Uc=a-13,5*exp(-b/C1)

C2	a	b
0,030	43,361980	0,0075639574
0,055	37,480629	0,011118874
0,080	34,365458	0,014073816
0,100	32,683273	0,016165726
0,200	28,198040	0,024544657
0,300	26,039648	0,030923526
0,400	24,700369	0,036058982
0,500	23,776489	0,040203810

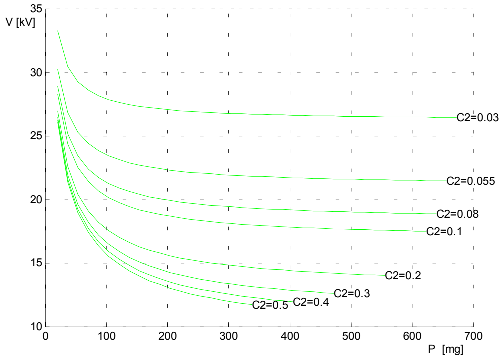

Fig. 6: Dependence of Uc versus salt deposit P, 2-2.

$$U_c = A - B \cdot e^{-C/P}$$

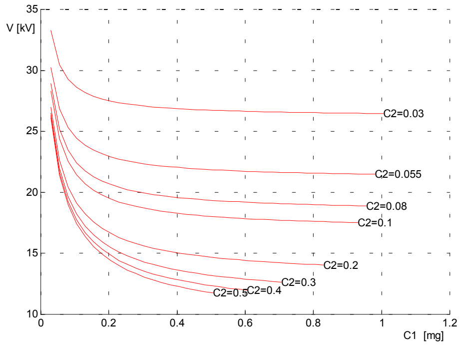

Fig. 7: Dependence of Uc versus salt deposit density C, 2-2.

Pc1Uc

User-Defined Model:
y=a-18*exp(-b/x)

C2	a	b
0,030	44,203868	10,016861
0,055	39,109162	14,274882
0,080	36,428441	17,618236
0,100	34,990695	19,883933
0,200	31,225501	28,145378
0,300	29,506271	33,393934
0,400	28,511835	36,88216
0,500	27,898769	39,049297

C1Uc

User-Defined Model:
y=a-18*exp(-b/x)

C2	a	b
0,030	44,203868	0,014962816
0,055	39,109162	0,021323292
0,080	36,428441	0,026317463
0,100	34,990695	0,02970188
0,200	31,225502	0,042042518
0,300	29,506272	0,049882604
0,400	28,511831	0,055093273
0,500	27,898759	0,058330552

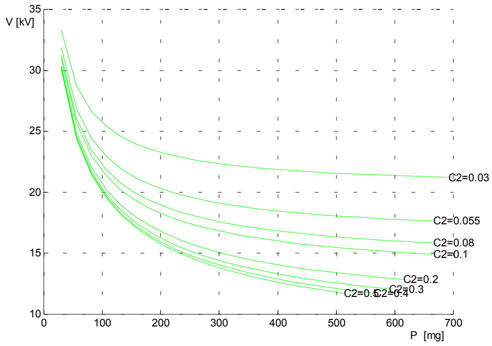

Fig. 8: Dependence of Uc versus salt deposit P, 3-1.

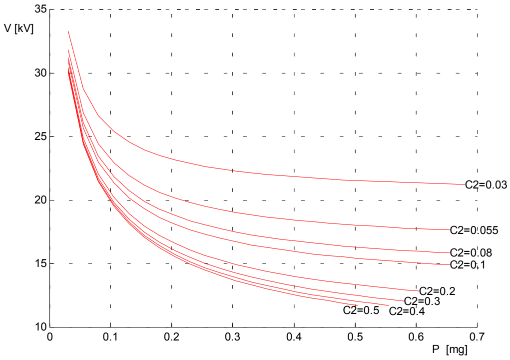

Fig. 9: Dependence of Uc versus salt deposit density C, 3-1.

Pc1Uc

User-Defined Model:
y=a-22*exp(-b/x)

C2	a	b

0,030	42,433592	26,956751
0,055	38,570185	36,159985
0,080	36,593732	42,651482
0,100	35,561316	46,684005
0,200	33,062657	58,44959
0,300	32,048301	64,112936
0,400	31,519783	67,15008
0,500	31,271577	68,196743

C1Uc

User-Defined Model:
y=a-22*exp(-b/x)

C2	**a**	**b**
0,030	42,433594	0,026508404
0,055	38,570187	0,035558586
0,080	36,593733	0,041942131
0,100	35,561318	0,045907581
0,200	33,062658	0,057477496
0,300	32,048303	0,063046628
0,400	31,519821	0,066032737
0,500	31,271506	0,067063566

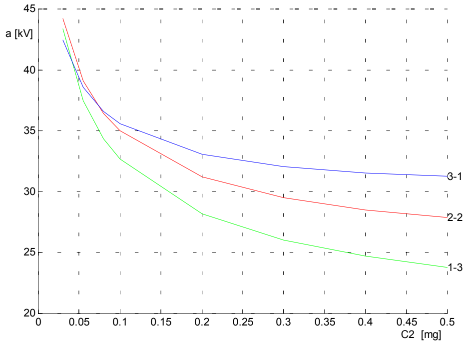

Fig. 10: Dependence of a versus salt deposit density C_2.
a(C2) - Uc(Pc1), Uc(C1)

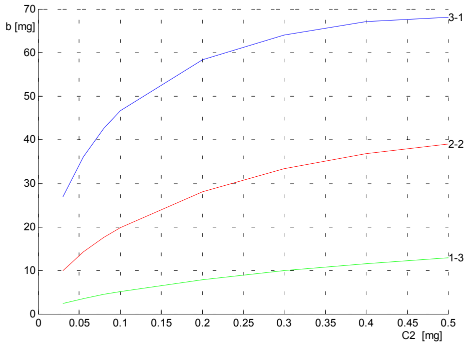

Fig. 11: Dependence of b versus salt deposit density C_2.
b(C2) - Uc(Pc1)

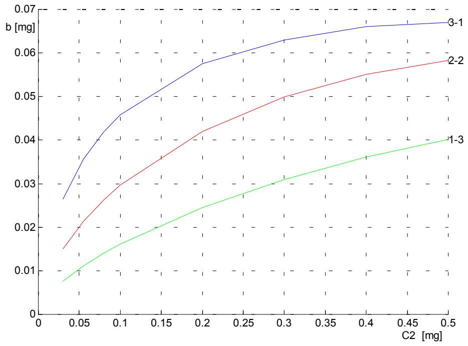

Fig. 12: Dependence of b versus salt deposit density C_2.
b(C2) - Uc(C1)

References

1. G. Atsonios, G. Katsibokis, G. Panos, I. Stathopulos: «Salt Fog Tests on Pin Type Insulators in the PPC Research Center». Proceedings of International Symposium High Technology in the Power Industry, pp. 72-76, Lugano, 1987.
2. K. Ikonomou, G. Katsibokis, A. Kravaritis, I. Stathopulos: «Cool Fog Tests on Artificially Polluted Insulators». Proceedings of 5th International Symposium on High Voltage Engineering, Vol. II, Paper No. 52.13, Braunschweig, 1987.
3. G. Theodorakis, F. Topalis, I. Stathopulos: «Parameters Identification of the Poluted Insulator Model». Proceedings of International Symposium High Technology in the Power Industry, pp. 103-106, Lugano, 1989.
4. F. Topalis, N. Leontidis, I. Stathopulos: «Invastigation of the Dielectric Behavior of Non-Uniformly Polluted Insulators».
5. S. Suflis, I. Stathopulos, F. Topalis: «On the Dielectric Behavior of Non-Uniformly Polluted Insulators», in Greek.
6. Obenhaus: "Fremdschichtueberschlag und Kriechweglaenge". Deutche Elektrotechnik, 1958, H. 4, S. 135-137.

7. Alston, S. Zoledziowski: “Growth of Discharges on Polluted Insulation”. Proc. IEE, Vol. 110 (1963), No. 7, pp. 1260-1266.
8. Wilkins: “Flashover Voltage of High Voltage Insulators with Uniform Surface Pollution Films”. Proc. IEE, Vol. 116 (1969), No. 3, pp. 457-465.
9. Rizk: “Mathematical Models for Pollution Flashover”. Electra, No. 78, pp. 71-103, October 1981.
10. Xavier, Y.N. Rao: “Study of Surface Conductivity and E.S.D.D. on Contaminated Porcelain Insulating Surfaces”. Proc. of 5th Int. Symp. on High Voltage Engineering, Vol. II, Paper No. 51.12, Braunschweig, 1987.
11. 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. of 4th Int. Symp. on High Voltage Engineering, Vol. II, Paper No. 46.01, Athens, 1983.
12. Streubel: “The Influence of Nonuniform Contamination on the Flashover Voltage of Insulators”. Proc. of 4th Int. Symp. on High Voltage Engineering, Vol. II, Paper No. 46.10, Athens, 1983.