XIIIth International Symposium on High Voltage Engineering, Netherlands 2003, Smit (ed.)
 ISBN 90-77017-79-8

Study of the dielectric behaviour of non-uniformly polluted insulators

S. A. Suflis I. F. Gonos F. V. Topalis I. A. Stathopulos
National Technical University of Athens, Greece
School of Electrical and Computer Engineering, Electric Power Department, High Voltage Laboratory

Abstract: The aim of this paper is to investigate the dielectric behaviour of polluted insulators. For the purposes of this investigation a mathematical model has been developed that is suitable for calculations under uniform pollution as well as under non-uniform one. Three types of porcelain insulators are examined. Two of them are cap-and-pin suspension insulators and the last one is of fog-type. The flashover process is simulated by means of a computer program, which uses as data experimental results from other researchers. The pollution layer across the surface of the insulator is simulated using measurements of the natural pollution distribution on insulators, being installed in overhead lines. On the other hand, valuable measurements of the flashover voltage of insulators under artificial uniform pollution are used in order to determine the parameters of the arc. The model simulates the surface of the insulator by means of finite elements, uniformly contaminated, across the creepage length. Other data are not required, except the dimensions of the insulator, since the model computes the distribution of the pollution layer and the arc constants from the available experiments. Finally, the critical voltage of the insulator is defined under various distributions of the pollution and under the respective total pollutant deposits on the insulator surface.

1. Introduction

The importance of the research on insulator pollution has been increased considerably with the rise of the voltage of transmission lines. The performance of insulators under polluted environment is one of the guiding factors in the insulation co-ordination of high voltage transmission lines. On the other hand, the flashover of polluted insulators can cause transmission line outage of long duration and over a large area. Flashover of polluted insulators is still a serious threat to the safe operation of a power transmission system. It is generally considered that pollution flashover is becoming ever more important in the design of high voltage transmission lines.

Research on insulator pollution is directed primarily to understanding the physics of the growth of discharge and to develop a mathematical model, which can predict accurately the critical flashover voltage and critical current. A common feature of all the mathematical models proposed by researchers [1-4] is a representation of a propagating arc consisting of a partial arc in series with the resistance of the unbridged section of the polluted layer. Alston [3] and Wilkins [4] proposed mathematical models for the prediction of critical flashover voltage taking into consideration the effects of different physical parameters.

The flashover of polluted insulators was the motivation for the installation of a test station in order to perform laboratory tests on artificially polluted insulators. Although the mentioned tests are indispensable for the study of the insulator behaviour under pollution, they are of long duration. The cost of the equipment that is necessary for these experiments is very high. For the above reasons, it seems to be very 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 energised. The experiments carried out [5-7] using either the salt fog method or the solid layer cool fog method [8]. Numerous experimental data were obtained (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. These data were used for the determination of the arc constants [9, 10] and the development of a generalised model for the dielectric behaviour of polluted insulators. The application of this model for non-uniformly polluted insulators is presented in this paper.

2. Mathematical model

The flashover process over polluted insulators is described by well-known analytical equations, published by various scientists, mainly Obenhaus [2] and Alston [1]. These procedures were used for the formulation of a mathematical model that permits determination of the parameters of the flashover under pollution of the insulator.

The most known model for the explanation and evaluation of the flashover process [3] and [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 critical voltage U_c is given [7] by the following formula:

$$U_c = \frac{A}{n+1}\left(L + \pi D_r FKn\right)\left(\pi D_r \sigma_P A\right)^{\frac{-n}{n+1}} \quad (1)$$

where D_r is the diameter of the insulator and *A, n* the arc constants. Their values *A=124.8*, *n=0.409* have been determined using a complex optimisation method [10] based on genetic algorithms. It has been found experimentally that the value of the flashover voltage of a polluted insulator is not constant even under identical conditions. This is mainly due to random arc phenomena on the polluted surface. Such phenomena are the arc bridging between sheds or ribs, the arc drifting away from the surface of an insulator as well as the number of consecutive arcs before flashover. These random arcs will certainly affect the flashover.

The coefficient *K* of Eq.(1) was introduced by Wilkins [4] in order to modify the resistance of the pollution layer at the critical instant of the flashover, considering the current concentration at the arc foot point. A simplified formula [11] for the calculation of *K* for cap-and-pin insulators is:

$$K = 1 + \frac{L}{2\pi F\left(L - x_c\right)} \ln\left(\frac{L}{2\pi F\sqrt{\frac{\left(\pi D_r \sigma_P A\right)^{\frac{1}{n+1}}}{1.45\pi}}}\right) \quad (2)$$

F is the form factor of the insulator that is given as follows:

$$F = \int_0^L \frac{1}{\pi D(l)} dl \quad (3)$$

D(l) is the diameter of the insulator that varies across the leakage path. The conductivity σ_p of the pollution layer is:

$$\sigma_P = \frac{1}{R_P} F \quad (4)$$

where R_P is the resistance per unit length of the pollution layer.

In case of non-uniform distribution of the pollution layer, the insulator is divided into m parts across its creepage distance *L* [11, 12]. The equivalent salt deposit density C_i (ESDD) of each part is considered to be constant, therefore the surface conductivity of the i-th part will be:

$$\sigma_{Pi} = (369.05C_i + 0.42)10^{-6} \quad (5)$$

The coefficient of the insulator shape, according Eq. (3) will be [9]:

$$F = \sum_{i=1}^{m} F_i = \sum_{i=1}^{m} \frac{1}{\pi D(l_i)} l_i \quad (6)$$

where $D(l_i)$ is the mean diameter of part *i* and l_i is the leakage length of the part *i*.

Finally, the surface conductivity σ_P of the total pollution layer will be given from the following relation [11,12]:

$$\sigma_P = \frac{F_i}{\sum_{i=1}^{m} \frac{F_i}{\sigma_{Pi}}} \quad (7)$$

The total salt deposit P_i of each part is given by the following equation [11, 12]:

$$P_i = \pi l_i D_i C_i \quad (8)$$

Therefore, the total salt deposit *P* of the insulator surface can be calculated as follows [11, 12]:

$$P = \sum_{i=1}^{m} P_i = \sum_{i=1}^{m} \pi l_i D_i C_i \quad (9)$$

The average ESDD C_{av} of the insulator is given as follows [11]:

$$C_{av} = \frac{P}{S} \quad (10)$$

where *S* is the surface of the insulator disk.

The meaning of the Eq.(1) is that, if the values of the arc constants are known, the model of the polluted insulator can be used not only to conclude about the flashover mechanism qualitatively, but also quantitatively about it: 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 exactly predicted and, eventually, the relevant expensive and time consuming experimental tests can be omitted, or, at least, limited in the absolutely indispensable number.

3. Investigated insulators

This paper uses experimental data from three different types of cap-and-pin insulators that have been tested experimentally [5, 6]. The technical characteristics of them are presented in Table 1.

	Fog type	Cap and pin 1	Cap and pin 2
Maximum diameter Dr	254 mm	254 mm	254 mm
Distance between centres	146 mm	146 mm	146 mm
Creepage distance L	431 mm	305 mm	279 mm
Form factor F	0.916	0.696	0.684

Table 1: Dimensions of the investigated insulators

The first insulator is of fog-type. The other two are cap-and-pin suspension insulators. They have been tested using the solid layer-cool fog method according

[8]. The surface conductivity of the pollution layer varies from 8 μΩ^{-1} to 110 μΩ^{-1} for the fog type and the first cap and pin insulator [5] and from 50 μΩ^{-1} to 200 μΩ^{-1} for the last one (cap and pin type insulator) [6]. The higher values correspond to industrial pollution in heavily polluted areas.

4. Simulation Method

The developed model simulates the flashover process over the surface of the three types of insulators of Table 1. The non-uniformly polluted insulator is divided into five parts. Each part is considered to be 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 distribution of the pollution layer is determined according to measurements of the natural contamination, which have been performed by Rizk [13]. The ratio of the ESDD of each part to the one of the part with the maximum ESDD is shown in Fig. 1. This case represents the pollution of the insulator after a period of two years without cleaning.

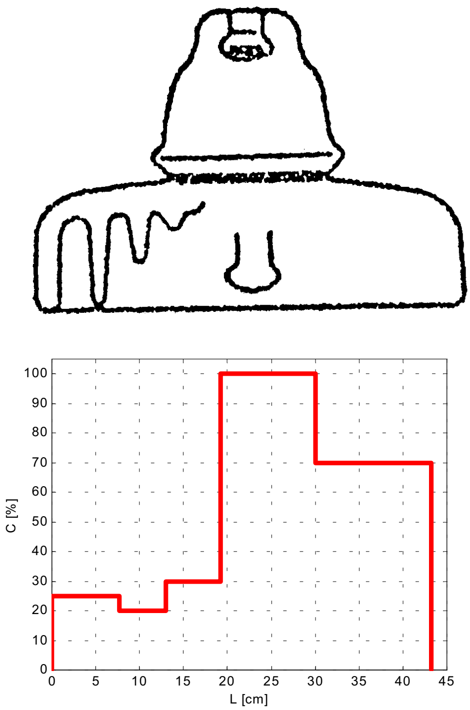

Figure 1: Distribution of the pollution layer

5. Results

The more important quantity in the experimental process is the critical voltage, i.e. the value of the supply voltage at the time just before the flashover. The variation of the critical voltage U_c with the average ESDD, for the above mentioned three cases of insulators, are shown in Figs. 2, 3 and 4, respectively.

It is obvious that the ESDD 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. As it is shown in Figures 2-4, the critical flashover voltage value U_c for each insulator under uniform distribution is lower than under a non-uniform pollution, which its most contaminated part has the same ESDD with the respective value of the uniform polluted insulator. The other parts of the non-uniform polluted insulator have lower ESDD than the uniform ones.

For the uniform polluted insulator the experimental results [5-7] (which is shown with circular symbol in Figures 2-4) have a very good agreement with the theoretical ones.

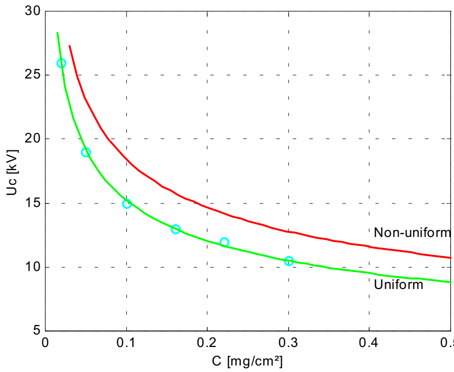

Figure 2: Critical voltage U_c versus ESDD C
(Fog type insulator)

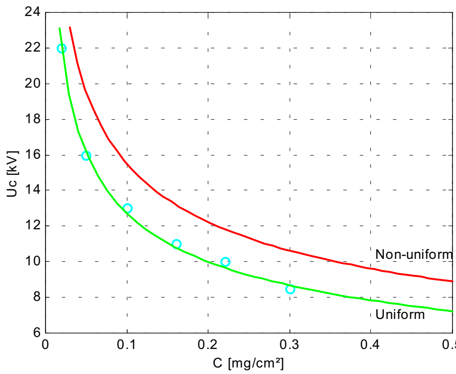

Figure 3: Critical voltage U_c versus ESDD C
(Cap and pin 1 type insulator)

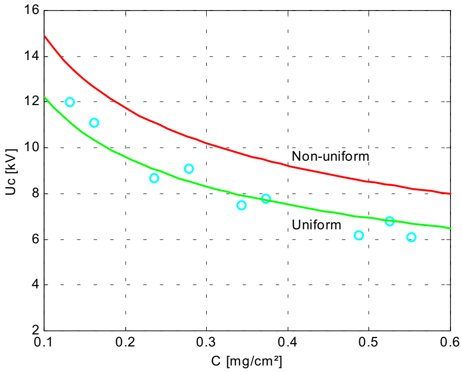

Figure 4: Critical voltage U_c versus ESDD C
(Cap and pin 2 type insulator)

6. Conclusions

The flashover process over polluted insulators is described by analytical equations, published by various investigators. These procedures where used for the formulation of a mathematical model that permits the determination of the flashover parameters under uniform or non-uniform pollution of the insulator. The calculated values for the uniform pollution were found to be in good 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.

The advantage of the presented model is that it uses these measurements as well as that it is applied on similar insulators to the ones of Rizk. Another advantage of the presented methodology is that it requires very few parameters: the dimensions of the insulator, the arc constants and the distribution of the pollution.

7. References

[1] F. A. M. Rizk: "Mathematical Models for Pollution Flashover", Electra, No. 78, pp. 71 - 103, October 1981.

[2] H. Boeme, F. Obenhaus: "Pollution Flashover Tests on Insulators in the Laboratory and in Systems and the Model Concept of Creepage - path Flashover", CIGRE, 1458.11, Paper No. 407, June 1966.

[3] L. L. Alston, S. Zoledziowski: "Growth of Discharges on Polluted Insulation", Proc. IEE, Vol. 110, No. 7, pp. 1260 - 1266, 1963.

[4] R. Wilkins: "Flashover Voltage of HV Insulators with Uniform Surface Pollution Film", Proc. IEE, Vol. 116, No. 3, pp. 457 - 465, March, 1969.

[5] K. Ikonomou, G. Katsibokis, A. Kravaritis, I. Stathopulos: "Cool Fog Tests on Artificially Polluted Insulators", Proceedings of 5th Int. Symposium on High Voltage Engineering, Vol. II, Paper No. 52.13, Braunschweig, 1987.

[6] G. Zhicheng, Z. Renyu, "Calculation of DC and AC flashover voltage of polluted insulators", IEEE Trans. Electr. Insul., Vol. 25, No. 4, pp. 723 - 729, 1990.

[7] F. V. Topalis, I. F. Gonos, I. A. Stathopulos, "Dielectric behaviour of polluted insulators", Proc. IEE - Gener. Transm. Distrib., Vol. 148, No. 4, pp. 269 - 274, 2001.

[8] International Electrotechnical Commission, "Artificial pollution tests on high - voltage insulators to be used on AC systems", IEC 60507: 1991 - 04, Switzerland, 1991.

[9] G. Theodorakis, F. Topalis, I. Stathopulos: "Parameter Identification of the Polluted Insulator Model", Proceedings. of International Symposium. on Simulation and Modelling, pp. 103 - 106, Lugano, 1989.

[10] I. F. Gonos., F. V. Topalis, I. A. Stathopulos, "Genetic algorithm approach to the modelling of polluted insulators", Proc. IEE - Gener. Transm. Distrib., Vol. 149, No. 3, pp. 373 - 376, May, 2002.

[11] I. F. Gonos., F. V. Topalis, I. A. Stathopulos, "A model for the flashover process on non uniformly - polluted insulators", International Journal of Modelling and Simulation, Vol. 22, No. 3, pp. 137 - 141, 2002.

[12] S. A. Suflis, I. A. Stathopulos, F. V. Topalis: "On the dielectric behaviour of non - uniformly polluted insulators", Greek CIGRE, Athens, November 1995.

[13] 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.

Authors address:
National Technical University of Athens,
School of Electrical and Computer Engineering,
Electric Power Department, High Voltage Laboratory,
9, Iroon Politechniou Str., 157 80 Zografou, Athens, GREECE,
Email: suflis@ieee.org, igonos@ieee.org,
topalis@ieee.org, stathop@power.ece.ntua.gr