COMPUTER METHODS FOR THE DETERMINATION OF THE CRITICAL PARAMETERS OF POLLUTED INSULATORS

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ABSTRACT

The aim of this paper is the investigation of the dielectric behaviour of polluted insulators using experimental data and computer methods. A computer programme was developed based on a mathematical model, introduced by the authors, which was presented in previous papers. The model allows the determination of the critical parameters (voltage, current and voltage gradient) for the flashover of the insulator, using only the geometrical characteristics of the insulator and the equivalent salt deposit density of the pollution layer over the surface of the insulator. Different types of insulators were investigated (cap and pin, pin type and stab type) and the variation of the critical parameters upon the density of the pollution layer was determined. The influence of the geometrical dimensions and the shape of insulator to the critical parameters were also investigated. Analytical relations between the critical parameters of the insulators and the salt deposit density were defined using the computed results by means of curve fitting methods. A similar procedure allowed the definition of analytical relations between the critical parameters and the dimensions, the shape and the type of the insulator.

1. 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 results of those experiments [1, 2] permitted the evaluation of the arc constants of the insulator with a quite high accuracy, by means of a mathematical procedure, presented in [3]. It has been proved that, the computed values of the arc constants are independent of the insulator type and the kind of pollution. The definition of the arc constants allowed the formulation of a generalised model for the dielectric behaviour of polluted insulators, independently of the type of the insulator and the kind of pollution [3-5].

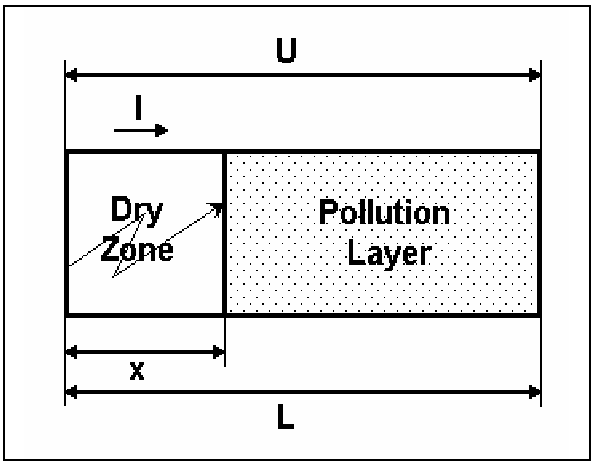
A computer programme was developed, based on that model, for the calculation of the critical parameters of polluted insulators. Comparisons show a very good agreement between the computed parameters and the measured ones, presented in [1, 2].

The computations of this paper aim to the determination of analytical relations between the critical parameters of the flashover and the geometrical characteristics of the insulator as well as the salt deposit density of the pollution layer on the surface of the insulator.

The determination of analytical relations which define the dependence of the critical values of the flashover upon the known parameters of the insulator, provides a useful tool for the design of insulators and for the insulation co-ordination of overhead lines.

2. GENERALISED MODEL OF THE POLLUTED INSULATOR

The most simple model for explanation and evaluation of the flashover process [6, 7] 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).



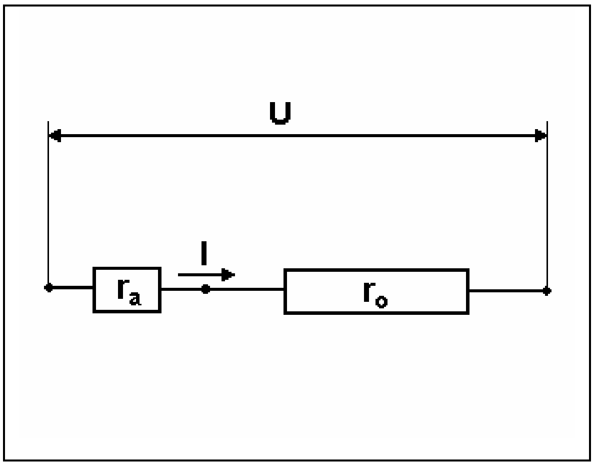


Fig. 1: Equivalent circuit of polluted insulator.

The applied voltage U should satisfy [6] the following equation:

$$U = I \cdot r_\alpha \cdot x + I \cdot r_0 \cdot (L - x) \tag{1}$$

where x is the length of the arc, L is the crepage distance of the insulator and I is the leakage current. r_0 is the resistance per unit length of the pollution layer defined by the formula:

$$r_0 = \frac{1}{\pi \cdot D_d \cdot X_s} \tag{2}$$

D_d is the equivalent diameter of the polluted insulator and X_s is the surface conductivity. The value of X_s is given as a function of the equivalent salt deposit density C. X_s is obtained in Ω^{-1} and r_0 in Ω/cm, for C expressed in mg/cm^2 and D_d in cm [2, 3].

r_a is the resistance per unit length of the arc [7]:

$$r_a = A \cdot I^{-(n+1)} \tag{3}$$

where A and n, are the arc constants. The values of A and n were determined through a mathematical procedure and experimental tests, carried out by the authors of this paper in [3]. Those values were found to be A=131.5 and n=0.374 for cap and pin, stab type and pin type insulators independently of the kind of pollution and the geometrical dimensions of the investigated insulators.

The critical condition for developing a partial arc into a complete flashover is $\frac{di}{dx} > 0$. An equivalent expression is that the resistance per unit length of the arc must be less than or equal to the resistance per unit length of the pollution layer $\left(r_a \leq r_0\right)$. At the critical condition, when the partial arc has already developed into a complete flashover, the current I obtains its critical value I_c which is given [8] by the formula:

$$I_c = \left(\frac{D_r}{D_d} \cdot \frac{A}{r_0}\right)^{\frac{1}{n+1}} \tag{4}$$

where D_r is the diameter of the insulator disk.

The critical voltage U_c is given [2, 3] by the following formula:

$$U_c = \frac{A}{n+1} \cdot \left(L + \pi \cdot n \cdot D_r \cdot K_s \cdot K\right) \cdot \left(\pi \cdot A \cdot D_r \cdot X_s\right)^{-\left(\frac{n}{n+1}\right)} \tag{5}$$

This equation provides the value of U_c as a function of the geometrical characteristics L and D_r of the insulator, the constants A and n and the surface conductivity X_s (pollution). K_s is the coefficient of the shape of the insulator which is a function of the geometrical parameters of the insulator. K is the modified coefficient of the pollution layer resistance with consideration of the current concentration at the arc foot point [8] which is also function of the above known parameters.

The critical voltage gradient E_c is calculated dividing the critical voltage by the creepage length of the insulator. It is given by the following formula:

$$E_c = \frac{U_c}{L} \tag{6}$$

3. RESULTS

The first part of this investigation was the application of the developed mathematical model to 17 different types of insulators and the calculation of the critical voltage, critical current and critical voltage gradient of the insulators. Thereafter, curve fitting methods were applied in order to determine simplified analytical expressions of the critical parameters versus the equivalent salt deposit density C.

The first 9 insulators of this investigation are of cap and pin type, the next one is of pin type and the last 4 insulators are of stab type. The characteristics of these insulators are presented in Table 1. The insulators were considered to be uniformly contaminated. The critical voltage, critical current and critical voltage gradient were determined by means of the procedure which is described above and using the values of the arc constants A=131.5 and n=0.374 [3].

Ins.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Dr	26.77	26.77	25.40	25.40	25.40	25.40	29.21	27.94	32.07	25.40	28.00	25.40	20.00	18.00	20.00	15.00	15.00
H	15.87	15.87	16.51	14.60	14.60	14.60	15.87	15.56	17.78	14.60	17.00	14.50	16.50	29.00	32.00	24.80	29.40
L	33.02	40.64	43.18	27.94	43.18	31.75	46.99	36.83	54.61	30.50	37.00	30.50	40.00	60.50	96.00	37.00	40.00
$\mathbf{D_d}$	13.30	15.04	15.27	13.00	15.00	14.12	16.22	15.48	18.16	13.95	14.72	13.12	9.87	13.46	14.97	11.16	11.20
$\mathbf{K_s}$	0.790	0.860	0.900	0.684	0.916	0.716	0.922	0.757	0.957	0.696	0.800	0.740	1.290	1.430	2.040	1.060	1.140

Table 1: Characteristics of the investigated insulators.

The computations show that the variation of critical parameters U_c, I_c and E_c upon the equivalent salt deposit density C follow the analytical expression of the power function: $f(C) = k_1 \cdot C^{k_2}$. A typical computation of U_c, I_c and E_c is presented in Figures 2, 3 and 4 respectively.

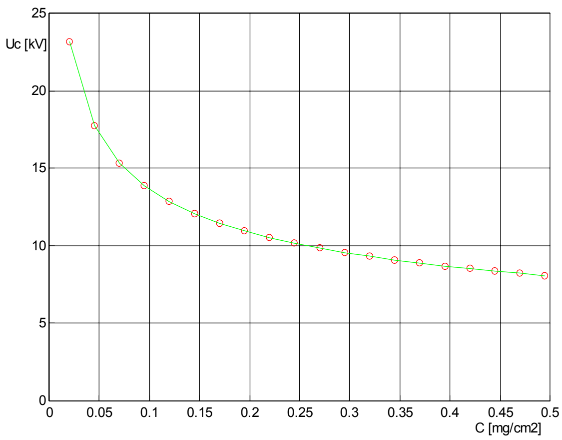


Fig. 2: Critical voltage U_c of the insulator No. 1 vs. the equivalent salt deposit density C.

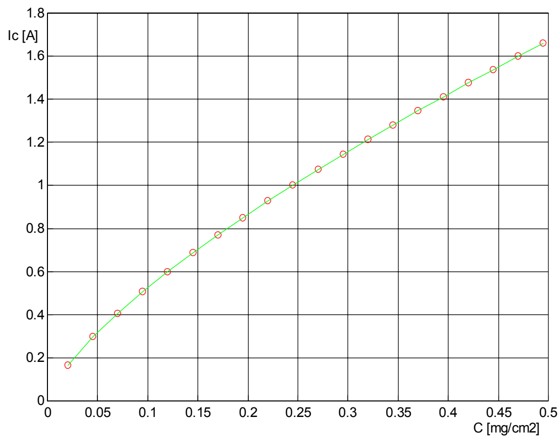


Fig. 3: Critical current I_c of the insulator No. 1 vs. the equivalent salt deposit density C.

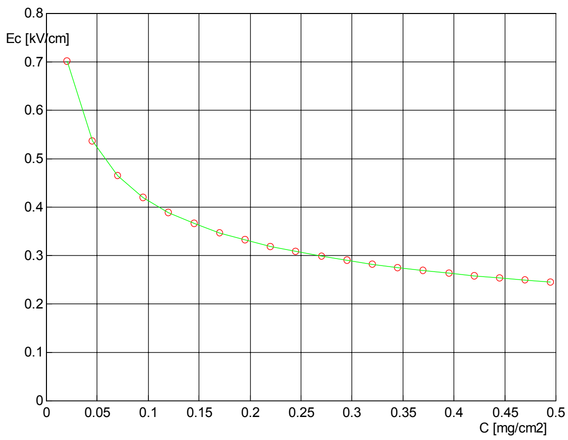


Fig. 4: Critical voltage gradient E_c of the insulator No. 1 vs. the equivalent salt deposit density C.

The application of curve fitting methods resulted in the following forms of the critical parameter U_c, I_c and E_c:

$$U_c = a \cdot C^{-b} \tag{7}$$

$$I_c = e \cdot C^{f} \tag{8}$$

$$E_c = \frac{a}{L} \cdot C^{-b} \tag{9}$$

where:
C is the equivalent salt deposit density and L the crepage distance of the insulator.
The values of the coefficients ***a***, ***b***, ***e*** and ***f*** are always positive.

Further investigation shows that the values of the coefficients a and e of U_c and I_c respectively are functions of the geometrical characteristics L, D_r and K_s of the insulator (Figures 5, 6 and 7) and therefore of the type of the insulator.

On the contrary, the exponent b of U_c seems to be independent of the dimensions, changing its value only with the type of the insulator. Its value lies between 0.32-033 for cap and pin insulators, 0.35-036 for stab type insulators and 0.31-0.32 for pin type insulators.

The exponent f of I_c seems to be constant and independent of all the dimensions and even the type of the insulator. Its value was found equal to 0.719.

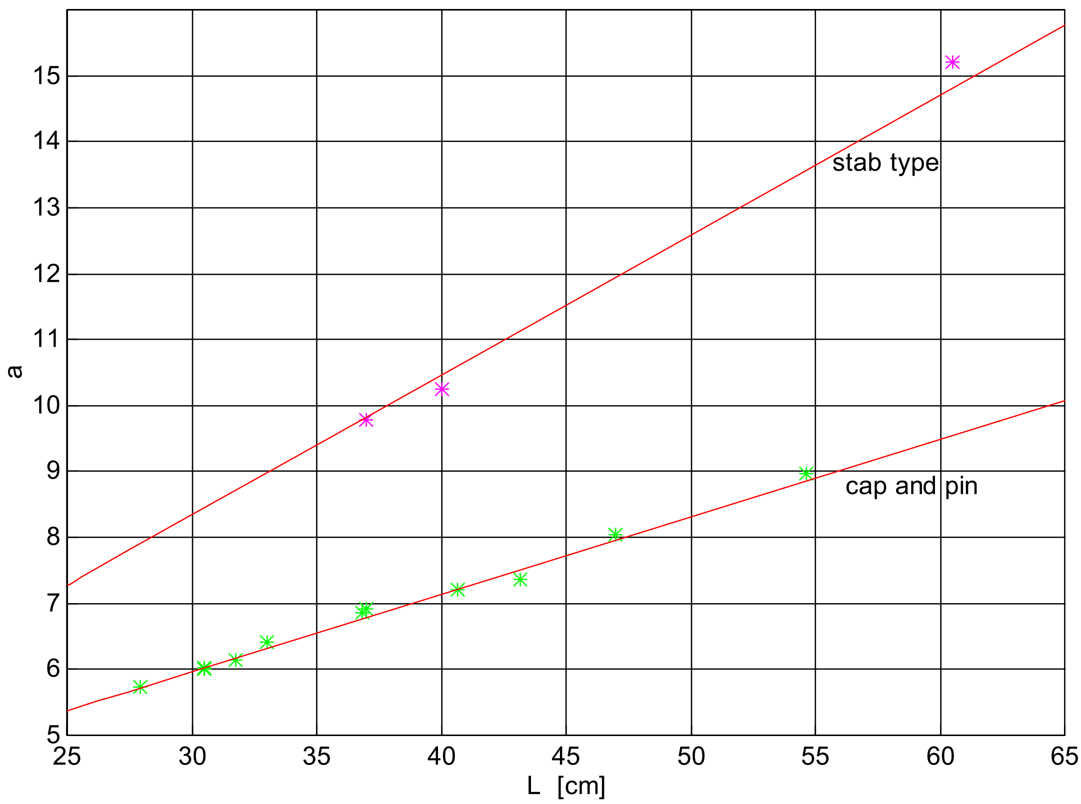


Fig. 5: Critical voltage coefficient ***a*** ($U_c = a \cdot C^{-b}$) vs. the crepage distance L of the insulator.

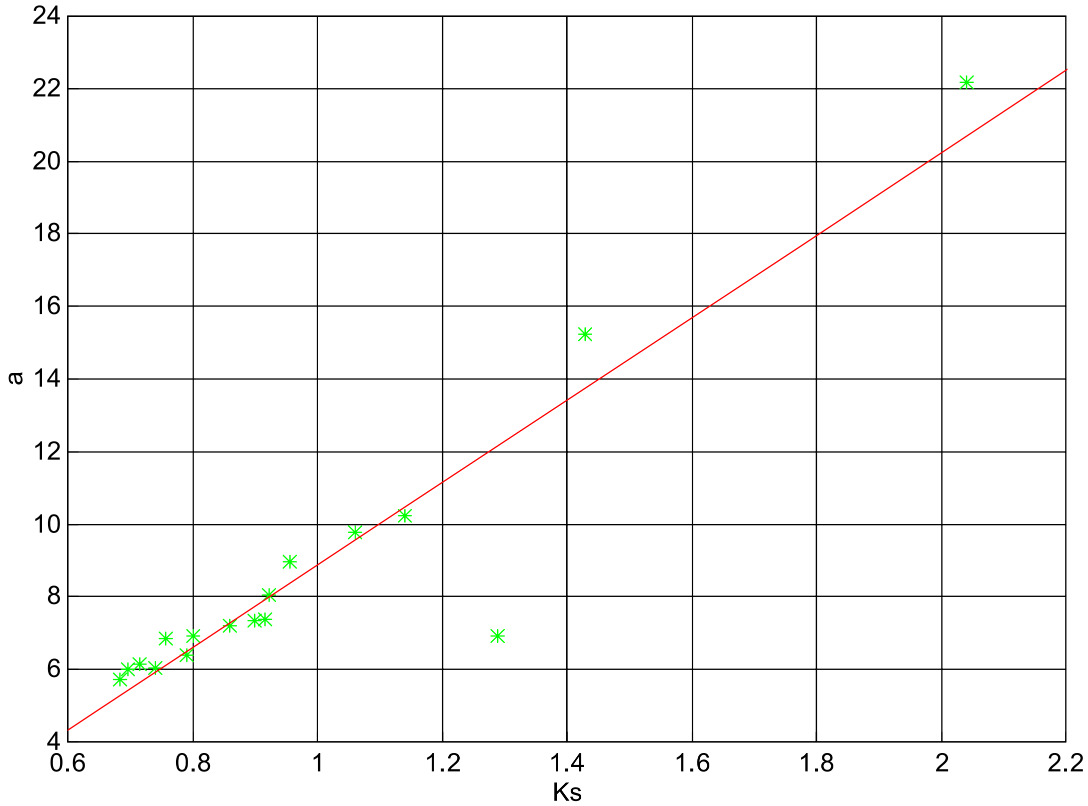


Fig. 6: Critical voltage coefficient ***a*** ($U_c = a \cdot C^{-b}$) vs. the coefficient K_s of the insulator shape.

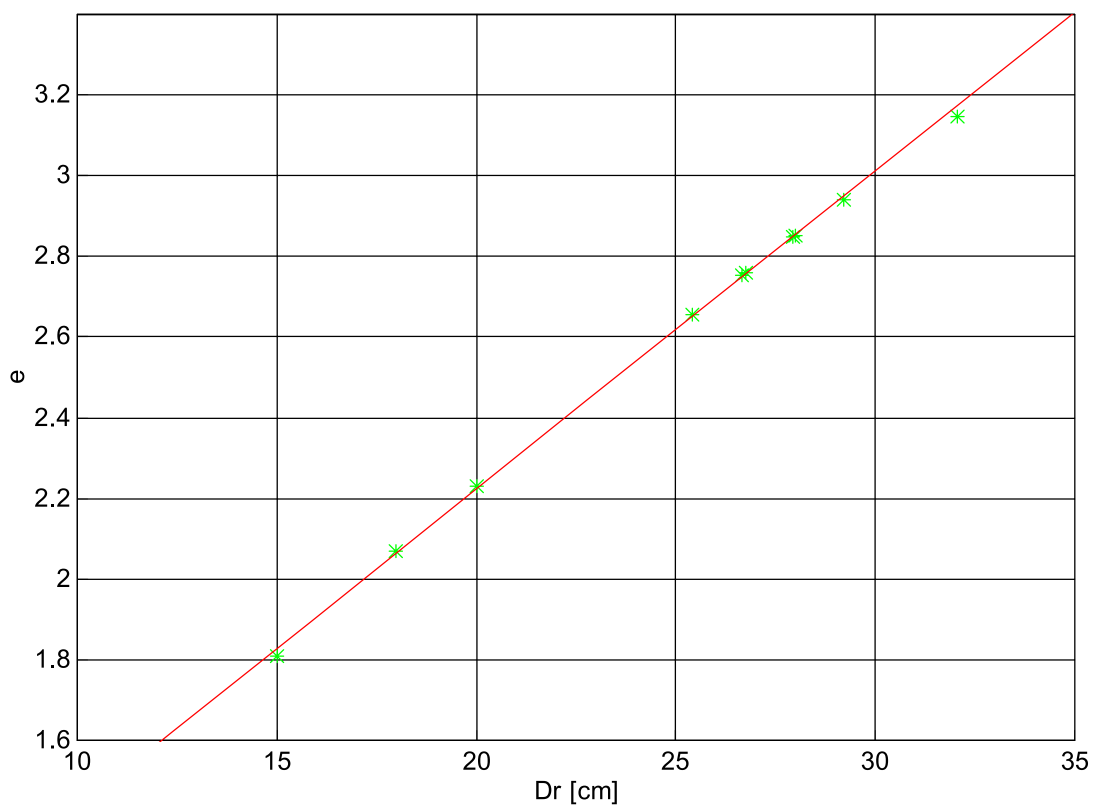


Fig. 7: Critical current coefficient ***e*** ($I_c = e \cdot C^{f}$) vs. the diameter D_r of the insulator disk.

Moreover, the use of curve fitting methods allow the determination of the following relationships between the coefficient ***a*** of U_c and the creepage distance L:

$$a = 0.117 \cdot L + 2.437 \qquad \text{(cap and pin)} \qquad (10.a)$$

$$a = 0.212 \cdot L + 1.975 \qquad \text{(stab type)} \qquad (10.b)$$

A similar relations between the exponent ***a*** of U_c and the coefficient K_s of insulator shape for any type of insulator was found to be:

$$a = 11.352 \cdot K_s - 2.481 \qquad (11)$$

The respective relation between the exponent ***e*** of I_c and the diameter D_r of insulator for any type of insulator is:

$$e = 0.079 \cdot D_r + 0.643 \qquad (12)$$

The above equations lead to the conclusion that the critical value of the voltage increases linearly with the increase of the creepage distance or/and the coefficient of the insulator shape where as the critical value of the current increases linearly with the increase of the diameter of the insulator. Only the critical voltage behaviour of the pin type insulator deviates from the linearity.

4. CONCLUSIONS

The developed simulation model and the computations presented in this paper lead to the conclusion that the critical parameters U_c, I_c and E_c of the investigated types of insulators follow the analytical form of the power function.

This power function is defined using only the geometrical characteristics of the insulator. Experimental tests on some types of the investigated insulators show a very good agreement between the measured values and the computed ones.

The validity of these equations, independently of the insulator type, renders the determination of the critical parameters using only the geometrical characteristics of the insulator and the distribution of the pollution layer. The distribution of contaminants and consequently, the evaluation of local layer conductivities can be obtained by means of simple measurements.

Another conclusion of the paper is that some geometrical characteristics of the insulator (creepage distance and insulator shape) affect linearly the critical voltage where as other characteristics (diameter) affect linearly the critical current.

On the other hand, the type of the insulator seems to affect exponentially only the critical voltage keeping the value of the current constant when the other dimensions are not changed.

References

[1] G. Atsonios, G. Katsibokis, G. Panos, I. Stathopulos: "Salt Fog Tests on Pin Type Insulators in the PPC Research Center". Proc of Int. Symp. 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". Proc. of 5th Int. Symp. on High Voltage Engineering, Vol. II, Paper No. 52.13, Braunschweig, 1987.

[3] G. Theodorakis, F. Topalis, I. Stathopulos: "Parameter Identification of the Polluted Insulator Model". Proc. of Int. Symp. on Simulation and Modelling, pp. 103-106, Lugano, 1989.

[4] S. A. Suflis, I. A. Stathopulos, F. V. Topalis: "On the Dielectric Behavior of Non-Uniformly Polluted Insulators". in Greek., CIGRE, Greek Committee, Athens, November 1995.

[5] S. A. Suflis, I. F. Gonos, F. V. Topalis: "Computation Methods in Simulation of the Dielectric Behavior of Non-Uniformly Polluted Insulators". Proceedings of the IMACS International Symposium on Soft Computing in Engineering Applications (EURISCON '98), Athens, June 22 - 25, 1998.

[6] F. Obenhaus: "Fremdschichtueberschlag und Kriechweglaenge". Deutche Elektrotechnik, H. 4, S. 135-137, 1958.

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

[8] 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.