Application of a genetic algorithm for calculating the capacitances on an insulator string

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Abstract: - The aim of this paper is the study of the distribution of the voltage along an insulator string. Insulator strings are used for the suspension of overhead transmission lines. This paper presents a method for the calculation of the capacitances on an insulator string using genetic algorithm. The simulation results have been compared with experimental results, which have been obtained in the High Voltage Laboratory of the National Technical University of Athens. The good agreement between experimental and computed results is a very strong indication for the validity and the correctness of the developed model.

Key words: - Insulator string, genetic algorithm, stray capacitance, cap-and-pin type porcelain insulator

1 Introduction

Insulator strings are used for the suspension of overhead transmission lines. Every insulator has an equivalent capacitance, which is equal for all the same insulators of the string. But the stray capacitances of each insulator to the high voltage conductor as well as to earth have different values for different positions of the insulator in the string.

The stray capacitance is the reason of the non-uniform distribution of the voltage across the string. Owing to the capacitances existing between the discs, conductor and ground the distribution of the voltage along the insulator is not uniform, the discs nearer the conductor being more highly stressed.

In recent years there is a rapidly growing interest in the mechanism of development of electrical arc in polluted insulators. Polluted insulators can trigger under certain circumstances the development of electrical arcs, which could cause serious disturbances in the proper operation of networks. This phenomenon that is called pollution flashover is still not completely clear. A great number of projects are carried out and many studies have been published all over the world concerning this phenomenon. In spite of these significant efforts it has become evident that there is not a fully acceptable explanation of the pollution flashover mechanism and that is the reason why there isn't still a general and efficient method in facing the problem.

Airborne pollutants due to natural or industrial or even mixed pollution cover the surface of the insulators. As the surface becomes moist because of rain, fog or dew, the pollution layer becomes conductive because of the presence of ionic solids. A leakage current flows through the conducting surface film generating heat, which tends to increase the film temperature most rapidly at those points where the current density is greatest, i.e. at narrow sections of the insulator, such as the area around the pin of the insulator. Eventually, the temperature in these areas approaches boiling point, and rapid evaporation of the moisture occurs producing dry areas.

2 Experimental apparatus and test results

The examined cap-and-pin type insulator is used in insulator strings for the suspension of 150 kV overhead transmission lines crossing coastal and industrial areas, with remarkably high pollution. The geometrical characteristics of the investigated insulator are the diameter, which is 254 mm, the height, which is 146 mm, and the creepage distance, which is 305 mm.

The aim of our experiments was the study of the distribution of the voltage across an insulator string. The test arrangement is shown in Fig. 1. It includes a 230 V self-transformer frequently found in industrial environments. Through this self-transformer, a 110V/55kV transformer is fed. The voltage is measured by two methods. The first method is using the voltmeter V_1 in the primary part of the transformer and then transforming the low voltage U_l in high voltage multiplying by the voltage transformer ratio a. The second method is using an electrostatic voltmeter E_v and measuring the high voltage U_2 in the secondary part of the transformer [1, 2]. The average U_{ti} of the two values is the voltage applied across the ten-insulator string:

$$U_{ti} = \frac{U_{1i} \cdot a + U_{2i}}{2} \tag{1}$$

The insulator string consists of ten individual insulators. In parallel with i-insulator is connected a sphere gap. The capacitance of the sphere gap is very small compared with the capacitance of the insulator, so it can be neglected.

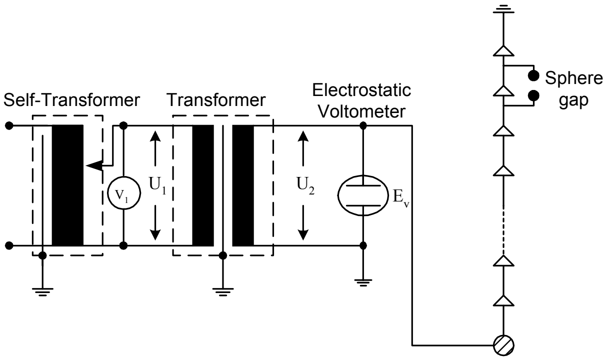

Fig. 1: Experimental set-up.

Increasing the voltage U_t, which is applied to the insulator string, the sphere gap critical voltage U_d is being reached. The rate of the voltage P_i, which is applied in the i-insulator, is given by

$$P_i = \frac{U_d}{U_{ti}} \cdot 100\% \tag{2}$$

The stray capacitances are the reason that the distribution of the voltage in each insulator is not uniform. Moving the sphere gap in each of the ten insulators and calculating the rates P_i for each insulator the critical voltage of the sphere gap is calculated by the equation

$$\sum_{i=1}^{10} P_i = U_d \cdot \sum_{i=1}^{10} \frac{1}{U_{ti}} = 1 \tag{3}$$

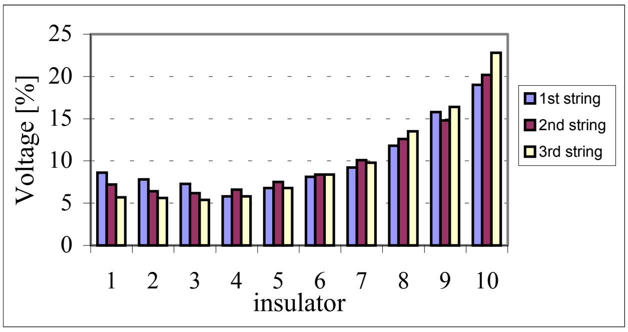

Fig. 2: The percentage voltage in each insulator.

The experiment has been repeated for several different insulator strings, which are consisting of ten discs with the same geometrical characteristics. The experimental results for three of the investigated strings are shown in Fig. 2. One edge of the insulator string (1st insulator) is grounded and the other edge (10th insulator) is connected with the transmission line. The insulator's number, in Fig. 2, shows the position of the insulator at the string.

3 Genetic Algorithm

Genetic algorithms were first introduced by John Holland for the formal examination of the mechanisms of natural adaptation [3], but since then the algorithms have been modified to solve computational problems in research. Modern genetic algorithms deviate greatly from the original form proposed by Holland, but their lineage is clear. Genetic algorithms are now widely applied in science and engineering as adaptive algorithms for solving practical problems. Certain kinds of problems are particularly suited to being tackled using a genetic algorithm approach. The general acceptance is that genetic algorithms are particularly suited to multidimensional global problems where the search space potentially contains multiple local minima. Unlike other methods, correlation between the search variables is not generally a problem. The basic genetic algorithm does not require extensive knowledge of the search space, such as solution bounds or functional derivatives. A task to which simple genetic algorithms are not suited is rapid local optimization; however, coupling the genetic algorithm with other techniques to overcome this problem is trivial. Whenever multidimensional systematic searching is the technique of choice, despite the fact that the large number of comparisons makes that approach intractable, a genetic algorithm should be considered the best choice for the reasons outlined in the sections below [3, 4].

This paper proposes a methodology, which uses the developed genetic algorithm for the calculation of the capacitances and the voltage distribution of an insulator string. This genetic algorithm has been developed using the software package Matlab. This genetic algorithm produces excellent results in several optimization problems [5-8]. It has been applied for minimization in multidimensional systems [5, 6], calculation of arc parameters for polluted insulators [7] and computation of the parameters of the ground structure [8]. The operation of genetic algorithm, which has been developed, is described in the flow chart of Fig. 3.

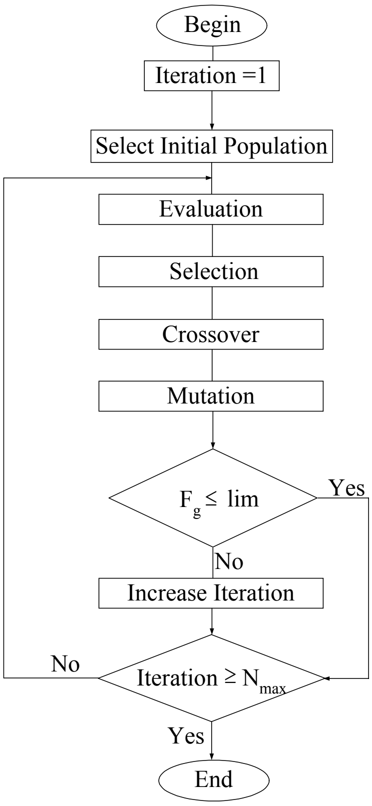

Fig. 3. The flow chart of our Genetic algorithm

4 Calculation of capacitance

The calculation of the parameters of an insulator string is an optimization problem. For the computation of the three parameters (capacitance of each insulator C, stray capacitance to earth C_e and stray capacitance to the high voltage conductor C_h as they are shown in Fig. 4), the minimization of the function F_g is necessary:

$$F_g = \sum_{i=1}^{N} \frac{\left| P_i^m - P_i^c \right|}{P_i^m} \tag{4}$$

where P_i^m is the *i-th* measurement value of the rate of voltage, which is applied in the i-insulator, while P_i^c is the computed one. The computed value P_i^c is calculated using the equations (5-7) [9-11]:

$$P_i^c = \frac{100}{1+m} \left\{ 1 + m \cdot \frac{\sinh(i \cdot \gamma)}{\sinh(n \cdot \gamma)} - \frac{\sinh((n-i) \cdot \gamma)}{\sinh(n \cdot \gamma)} \right\} \tag{5}$$

$$\gamma = \sqrt{\frac{C_e + C_h}{C}} \tag{6}$$

$$m = \frac{C_e}{C_h} \tag{7}$$

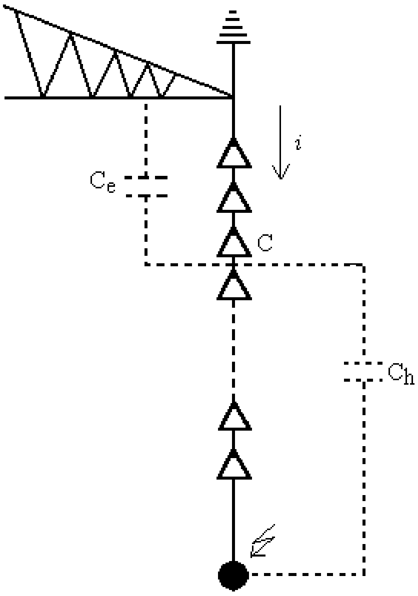

Fig. 4. The capacitances of the insulator string

The application of the genetic algorithm for the experimental results of string 2 (Fig. 2) with number of parents P_s=20, bit of binary number (size of chromosome) t=16, variables m=3, number of children N_c=4, parts for crossovers N_p=6, maximum number of iterations N_{max}=40 and probability of mutation P_m =5%. The application results finally converge to the optimum values C=148.96 pF, C_e=8.324 pF and C_h= 1.560pF as the number of iterations increases (Fig. 5).

The whole procedure is shown in Fig. 5, where it becomes obvious that the algorithm converges rapidly to these values. The next step is to verify the validity of the genetic algorithm by applying the computed values of the capacitances to the experimental results of Fig. 2. The utilisation of the optimum values of the capacitances (Table 1) in the mathematical model results to the curves of the rate of the voltage P_i, which is applied in the i-insulator (Fig. 6). In this figure the results from other experiments (string 1 and string 3) are also presented. It may be pointed out that the computed values agree well with the experiments.

Table 1. Results of GA

	F_g	C [pF]	C_e [pF]	C_h [pF]
String 1	0.1916	109.219	6.117	1.149
String 2	0.1905	148.965	8.324	1.560
String 3	0.1901	130.586	7.293	1.364

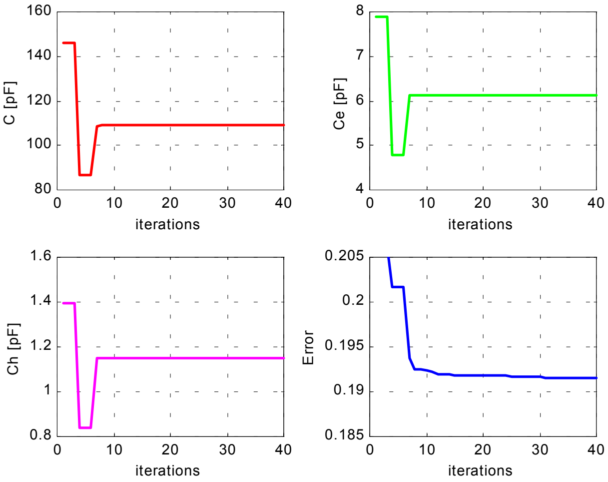

Fig. 5. The converges of the GA results

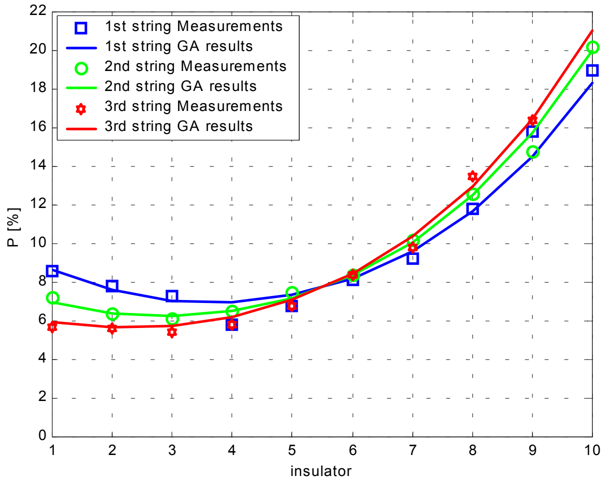

Fig. 6. Comparison between experimental and simulation results

5 Conclusions

The aim of this paper is the study of the distribution of the voltage across an insulator string. A method for the calculation of the capacitances on an insulator string using genetic algorithm is presented. The good agreement between experimental and computed results is a very strong indication for the validity and the correctness of the developed model and allow the limitation or even the elimination of the experiments needed for the calculation of voltage distribution across the insulator string. The limitation or elimination of experiments seems to be very significant since the execution of such experiments is time and money consuming and has as presupposition the availability of expensive equipment.

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