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INSULATOR CONTOUR OPTIMIZATION USING BY FUZZY INFERENCE SYSTEM

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ABSTRACT

Development of efficient methods for optimum design of electrode and insulator in a high voltage apparatus has been an important area of research in the recent years. In this paper, optimized form of shuttle insulator has been determined by Fuzzy Inference System (FIS) to obtain uniform and lowest stress distribution along the electrode surface. A FIS is much simpler and less time consuming to implement compared to other optimization techniques presently available such as iterative approach and Neural Networks.

I. INTRODUCTION

In the high voltage technology, designing a cost-effective high voltage (HV) electrode system requires optimized electrode and insulator contour. Optimized insulator contour should give uniform stress distribution along the insulator surface, and keeping the electric field as low as possible. Obtaining uniform electric field distribution in any insulation is important for the reliability and life of electrical system. Otherwise, electric field is non-uniform and breakdown or partial discharge phenomena early become in the insulation. In order to have optimum contours with complex geometries, it is necessary to optimize electrode and insulator contour by means of electrical field calculation. In the determination of electric fields is used various methods as analytical, numerical or experimental methods.

Different methods have been developed for electrode and insulator contour optimization [1-6]. One of these methods, to obtain desired electric field distribution, contours are modified iteratively by linear interpolation. In these iterative methods, since the electric fields have to be computed for each iteration step, computation time is very long. Therefore, iterative methods are not useful for every problem. To overcome these difficulties, Neural Network (NN) based optimization methods have been used. But even NN based applications involve a huge computational burden and they are quite time consuming because each NN application requires a certain amount of training to achieve the desired accuracy.

In this study, contour optimization of a shuttle insulator in plane – plane electrode system to have a uniform field distribution along the insulator surface is performed by using Fuzzy Inference System (FIS) [6]. The advantage of using fuzzy system is that, it will eliminate any training time and speed up the process of optimization.

II. FUZZY INFERENCE SYSTEM

Fuzzy logic is a method to formalize the human capacity of imprecise reasoning or approximate reasoning. The basic difference between a fuzzy system and a classical or crisp set is that fuzzy sets do not have sharply defined boundaries. The transition from "belonging to a set" to "not belonging to a set" is gradual rather than sharp transition [7-9].

The collection of all possible objects or a variable is denoted as universe of discourse U. A fuzzy set A in the universe of discourse is characterized by collection of a number of objects x and their corresponding membership value of degree in set A, denoted by $\mu_A(x)$.

Membership Function (MF) type is chosen by designer depending on her/his experience and the structure of the system. There are several types of MFs some of them are shown in Figure 1.

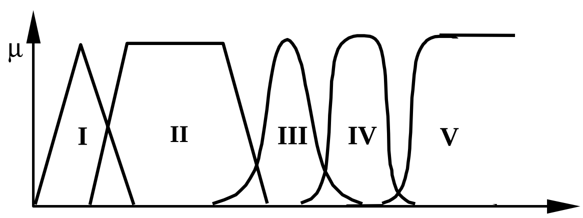


Figure 1. Types of the membership functions.
I: Triangular; II: Trapezoidal; III: Gaussian;
IV: Gaussianbell; V: Sigmoid.

Fuzzy modeling has some basic steps which are fuzzification of inputs, applying fuzzy operators, implication, aggregation and defuzzification. Fuzzification is the process of turning a crisp quantity into a fuzzy quantity, which is made by taking the inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via MFs. The inputs are always a crisp numerical value limited to the universe of discourse of the input variable and the output is a fuzzy degree of membership in the qualifying linguistic set (always the interval between 0 and 1). Once the inputs have been fuzzified, the degree to which each part of the antecedent has been satisfied for each rule. If the antecedent of a given rule has more than one part, the fuzzy operator is applied to obtain one number that represents the result of the antecedent for that rule. This number will then be applied to the output function. The input to the fuzzy operator is two or more membership values from fuzzified input variables. However, the aggregate of a fuzzy set encompasses a range of output values, and so must be defuzzified in order to resolve a single output value from the set. Defuzzification is the conversion of a precise quantity to a fuzzy quantity. The output of fuzzy process can be the logical union of two or more fuzzy MFs defined on the universe of discourse of the output variable [7-10].

III. AN INSULATOR TO BE OPTIMIZED

Figure 2 shows the schematic of a support insulator having a conical contour form. The cast resin insulator is a shuttle type insulator placed between plane – plane electrode system. It is considered that the magnitude of the potential difference as 1 kV which represents percent potential difference for studying the efficiency of FIS.

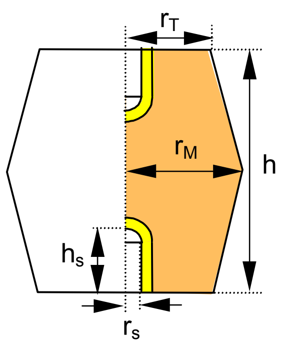


Figure 2. An axisymmetrical support insulator having a shuttle type.

Insulator profile is taken as linear as shown in Figure 2. For the axi-symmetric insulator, the values of r_M, and h are kept constant at r_M = 20 mm and h = 40 mm, which are radius of the insulator, and height of the insulator respectively. The radius (r_s) and the height (h_s) of screw socket using for connections are also kept constant during the calculations. The dimensions of the screw sockets are r_s = 3 mm, and h_s = 10 mm. In this study, by varying only one parameter, r – coordinate of the top point of the insulator (r_T), different contours are obtained.

For obtaining the different training and test patterns by means of field calculation, 110 different values of the top point of insulator are considered, e.g. 9 to 19.9 mm in steps of 0.1 mm. Hence, altogether 110 electric field data obtained from the results of calculations. The electric stresses are calculated at 45 different points on the surface of the insulator which have equal distance from each other for all cases.

Initially, two factors in electric field distribution, which are influenced mostly by variation of electrode contour dimensions are identified by performing a few trial field calculations using finite element method [11-12]. These factors are tangential electric field value at top-point which is also the maximum value of tangential electric field (E_{Top}), tangential electric field value at mid-point (E_{Middle}).

It is decided to construct two inputs, one output fuzzy system where the two inputs are E_{Top}, E_{Middle}, and the output variable is the r – coordinate of the top point of insulator (r).

IV. CALCULATION OF ELECTRIC FIELD

Although the differential equations of interest appear relatively compact, it is typically very difficult to get closed-form solutions for all but the simplest geometries. This is where finite element analysis comes in. The idea of finite elements is to discretize the problem down into large number regions, each with a simple geometry (e.g. triangles). The insulating region is divided into triangles. Over these simple regions, the true solution for the desired potential is approximated by a very simple function. If enough small regions are used, the approximate potential closely matches the exact solution [11].

The advantage of breaking the domain down into a number of small elements is that the problem becomes transformed from a small but difficult to solve problem into a big but relatively easy to solve problem. Through the process of discretization, a linear algebra problem is formed with perhaps tens of thousands of unknowns. However, algorithms exist that allow the resulting linear algebra problem to be solved, usually in a short amount of time. Specifically, FEM discretizes the problem domain using triangular elements. Over each element, the solution is approximated by a linear interpolation of the values of potential at the three vertices of the triangle. The linear algebra problem is formed by minimizing a measure of the error between the exact differential equation and the approximate differential equation as written in terms of the linear trial functions [11].

After approximation of the potential at desired region, electric fields can be easily calculated. Breaking down of the electrode system into triangular elements called discretization process is shown in figure 2.

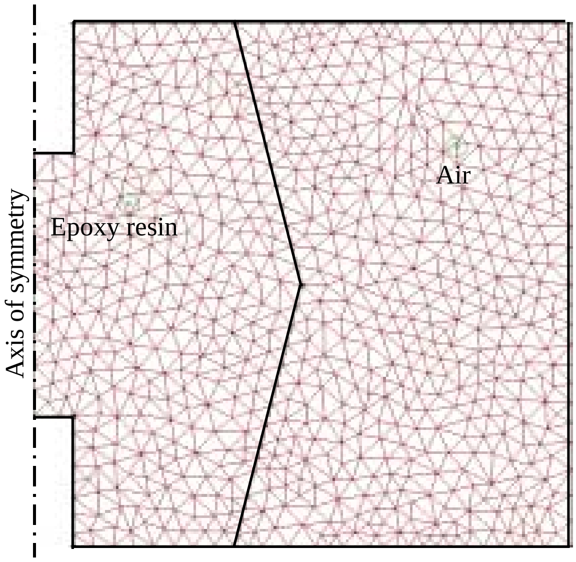


Figure 2. A finite element mesh used in solution for the shuttle insulator.

The region is divided into more than 10000 triangles for accurate solution. After solving the problem, electric field distribution curves can be obtained using FEMM 4.0 program. 110 sample cases for different configurations are determined on the basis of which the fuzzy system constructed [11-12, 6].

V. FUZZY MODEL OF THE SYSTEM

In this study, a Mamdani fuzzy model is used for decision-making process. Fuzzification of each of the three variables of input and output are carried out using Gaussianbell MFs and Sigmoid MFs as shown in Figure 3, all variables are fuzzified into seven fuzzy sets.

VVS: Very very small
VS: Very small
S: Small
M: Medium
L: Large
VL: Very large
VVL: Very very large

In this paper, the fuzzy logical operations are chosen as follows; AND operation: minimum, OR operation: maximum. The implication method for the problem is chosen as minimum. After implication, an aggregation method is applied which is chosen as maximum in order to combine all the rules. In the literature, many defuzzification methods are used to fuzzy modeling. In this study, Centroid method is used to defuzzification.

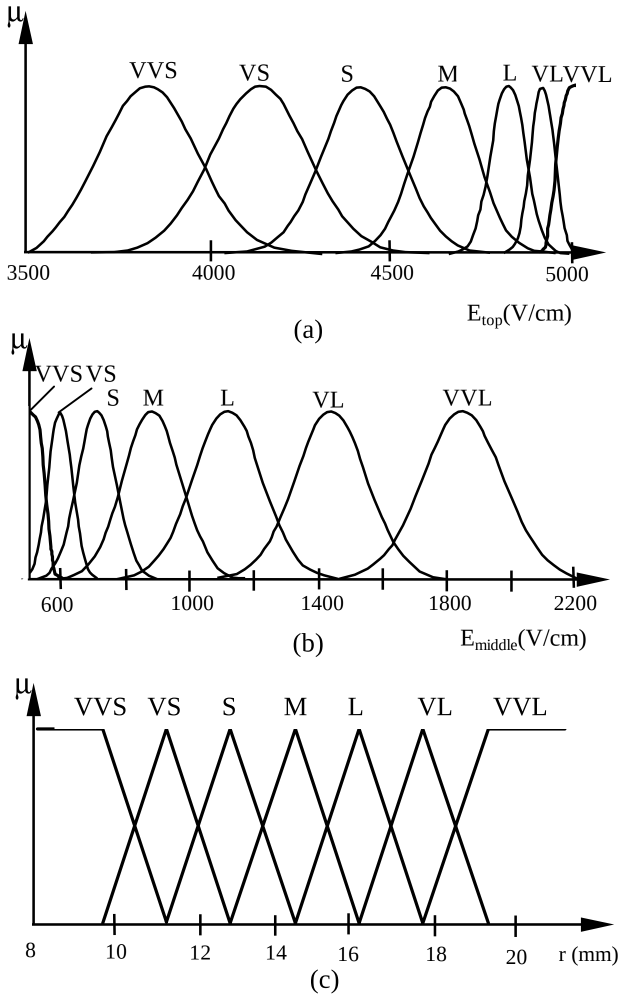


Figure 3. MFs of (a) Etop, (b) Emiddle, (c) r.

Fuzzy sets and fuzzy operators are the subjects and verbs of fuzzy logic. These if-then rule statements are used to formulate the conditional statements that comprise fuzzy logic. Fuzzy if-then rule assumes the form

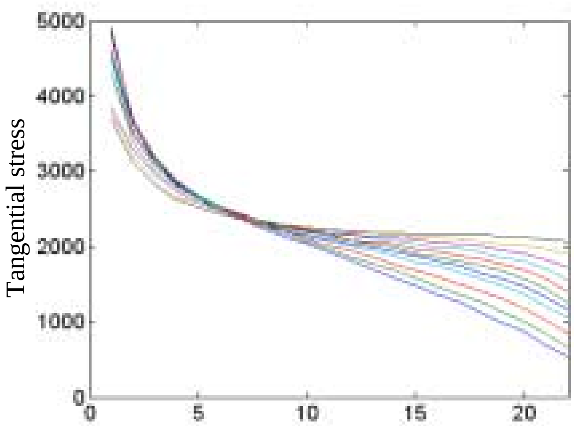
IF Etop is A AND Emiddle is B; THEN r is C

where A, B, C are linguistic values defined by fuzzy sets on the ranges (universes of discourse). The if-part of the rule is called the antecedent or premise, while the then-part of the rule is called the consequent or conclusion. The fuzzy rule bases constructed from input-output data set comprises of 32 rules, because all possibilities are not fired. The number of rule boxes to be activated depends on the input output data.

VI. OPTIMIZATION OF INSULATOR CONTOUR

Insulating materials under electric field are forced by this electric field. Electrical stresses may lead to partial discharges or breakdown in the insulation. In order the inputs are decrease these risks and to obtain high performance from the high voltage apparatus, insulating materials should be forced uniformly and stress distribution along the electrode surface should be homogen.

Electric field value at top point of the insulator and electric field value at mid-point of the insulator are calculated by FEM as mentioned above. 110 different cases are examined for the constructing the system. The field distributions of all cases are taken into account to determine optimized radius of the insulator. The field distribution is shown in Figure 4.



Equidistance 22 points on the insulator surface from top point to mid-point

Figure 4. The tangential electric field distributions for different insulators.

In order to have a uniform field distribution, the electric field value at the top point and the mid-point of the insulator should be as close as possible. From the Figure 4, the electric field value at the top point is chosen as 4000 V/cm, and at the mid-point 2000 V/cm to have optimum radius. When the desired inputs are applied to the fuzzy system, optimum value of the insulator radius can be determined as 16.3 mm.

VII. CONCLUSIONS

This paper presents a fuzzy inference system for optimization of a high voltage insulator. The insulator used in the study is an axisymmetric support insulator having a shuttle type. By using fuzzy system, it is possible to optimized the insulator surface easier than both traditional iterative approach and neural network based studies. The fuzzy system development less time consuming because it requires only one iteration to reach at a solution, and at the same time it eliminates the training phase required in developing neural network applications. The fuzzy system also provides an inherent feature of implementing a complex multidimensional mathematical mapping between inputs and outputs in much simpler manner. This simplicity of development, consumption of significantly less computation time, highly efficient output generation.

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