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Electrode 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 electrode 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.

Key-Words: - High-voltage, Electrode contour optimization, Fuzzy inference system, Fuzzy logic, Numerical method

1 Introduction

In the high voltage technology, designing a cost-effective high voltage (HV) electrode system requires optimized electrode and insulator contour. Optimized electrode contour should give uniform stress distribution along the electrode 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 [1-3]. 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 at every 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, to obtain a uniform electric field distribution along a rod electrode used in gas insulated system, fuzzy system is used for design of optimized electrode contours [3]. The advantage of using fuzzy system is that, it will eliminate any training time and speed up the process of optimization.

2 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 [4-6].

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.

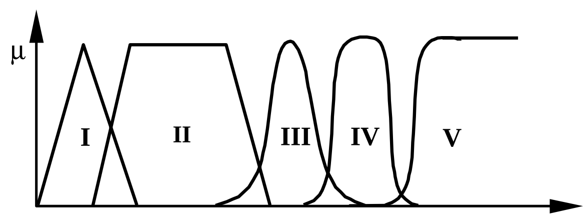

Figure 1. Types of the membership functions.
I: Triangular; II: Trapezoidal; III: Gaussian;
IV: Gaussianbell; V: Sigmoid.

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 [4-7].

3 A High Voltage Electrode System to be Optimized

Figure 2 shows a typical axisymmetric, gas insulated system (GIS) bus termination as an example of a high voltage electrode system.

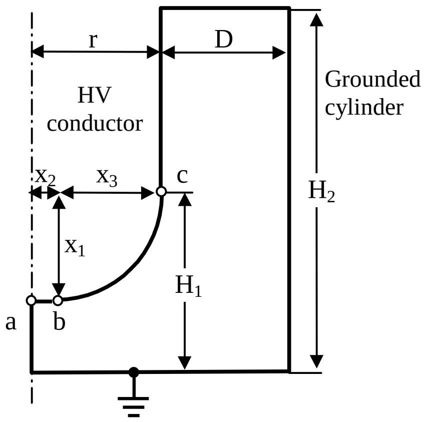

Figure 2. An axisymmetrical HV electrode configuration.

In figure 2, H_1 is the height of the point c above which the high voltage conductor dimension is assumed to remain fixed, H_2 is the height above which the field assumed to be constant, r is the radius of the high voltage conductor, and D is the radial distance between high voltage conductor surface and the grounded cylinder.

The purpose is to find an optimized ellipse configuration for the termination region so that the electric field distribution on the optimized single phase GIS bus termination is as uniform as possible and the maximum stress value should be as low as possible [1-4]. x_1 is the semi axis along y, and x_3 is the semi axis along x of the quarter ellipse bc. x_2 is the offset of the quarter ellipse or quarter circle and it is perpendicular to the central axis. The potential of the high voltage conductor is assumed to be 1.0, other physical dimensions are assumed as follows: H_1 = 1.4 units, r = 1.0 units, D = 1.0 units, H_2 = 3.0 units.

Initially, three 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 [9-10]. These factors are electric field value at point a (Ea), electric field value at point c (Ec) and maximum value of electric field (Emax).

It is decided to construct 3 input, 2 output fuzzy system where the 3 inputs are Ea, Ec and Emax. Two output variables are x_1 (semi axis along the y axis of the ellipse or circle), and x_2 (offset). Semi axis of the quarter circle along the x_3 gets fixed automatically for each case as $x_2 + x_3 = r = 1.0$ unit.

4 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 [8].

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 [8].

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. The region is divided into more than 1000 triangles for accurate solution. After solving the problem, electric field distribution curves can be obtained using FEMM 4.0 program. 21 sample cases for different circular and elliptic configurations are determined on the basis of which the fuzzy system constructed [8-9, 3].

5 Fuzzy Model of the Electrode System

In this study, a Mamdani fuzzy model is used for decision-making process. The process can be divided into five parts: fuzzification of the input variables, application of the fuzzy operator (AND or OR) in the antecedent, implication from the antecedent to the consequent, aggregation of the consequents across the rules, and defuzzification [3-7].

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 membership functions. 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). Fuzzification of each of the five input and output variables are carried out using triangular MFs and trapezoidal MFs as shown in Figure 3, all variables are fuzzified into four fuzzy set.

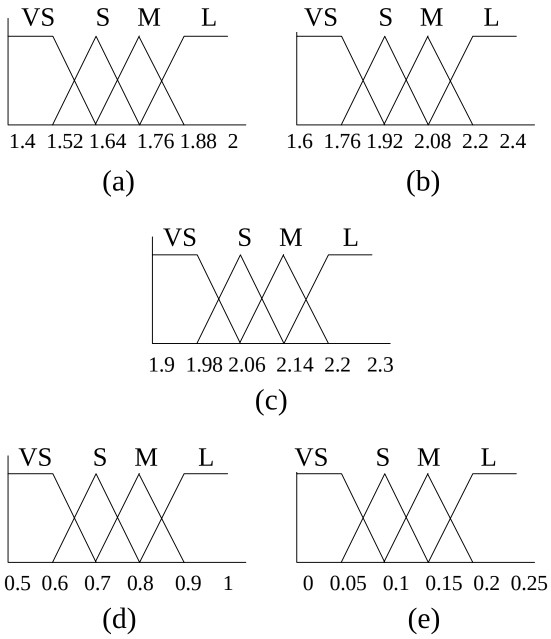

Figure 3. MFs of (a) Ea, (b) Ec, (c) Emax, (d) x_1, (e) x_2

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 In this paper, the fuzzy logical operations are 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.

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 membership functions defined on the universe of discourse of the output variable. In the literature, many defuzzification methods are used to fuzzy modeling. In this study, Centroid method is used to defuzzification.

Each of the input and output variables are fuzzified into four fuzzy sets. 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 Ea is A AND Ec is B AND Emax is C; THEN x_1 is D AND x_2 is E.

where A, B, C, D, E 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 17 rules, because all possibilities are not fired. The number of rule boxes to be activated depends on the input output data.

6 Optimization of Electrode 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 to 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.

Maximum electric field should occur in the middle of the circular part of the electrode, and Ea, Ec, and

Emax should be as close to each other so that the field distribution is ideally as uniform as possible. Under this consideration, input variable for the system should be as follows: Ea = 1.9; Ec = 1.9; Emax = 2.2. Optimized values of x_1 and x_2 can be determined by using the fuzzy inference system. With these optimized values of x_1 and x_2, the electric field computations are carried out by finite element method to find out the actual field distributions along the electrode contour. Figure 4 shows the resulted electric field distribution curve obtained for the electrode system, with optimized set of x_1 = 0.819 and x_2 = 0.191.

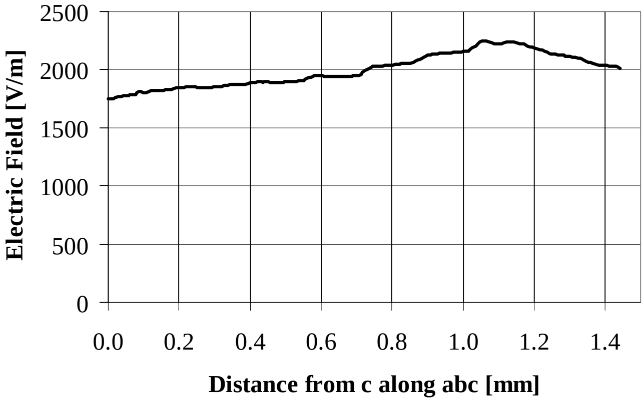

Figure 4. Electric field distribution for optimized electrode.

Figure 4 clearly shows that, electric field distribution along the electrode surface is very close to uniform distribution.

7 Conclusion

This paper presents a fuzzy inference system for optimization of a high voltage electrode system. The electrode system is an axisymmetrical gas insulated system with rod electrode in a grounded cylinder. By using fuzzy system, it is possible to optimized the rod electrode surface easier than both traditional iterative approach and neural network based studies. The fuzzy system development less time consuming because it does not require more than 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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