Corona Ring Optimization for Different Cases of Polymer Insulators Based on its Size and Distance

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ABSTRACT

This paper describes the impact of the distance and the size of the corona ring, on the magnitude and distribution of electrical potential across the polymer insulators. The procedure is based on finite element method numerical analysis and stochastic optimization algorithm of differential evolution (DE). The optimal selection of corona ring has a significant impact on the control of potential and, consequently, on dielectric strengths, both inside and outside the insulator. This method is used for optimized determining of the size and the distance of corona ring from polymer insulators in existing structures.

KEYWORDS: Corona, electrical field, FEM, optimization, polymer, size.

1. INTRODUCTION

POLYMER insulators, which are being used increasingly for outdoor applications, have better characteristics than porcelain and glass types: they are lighter, have better contamination performance due to their surface hydrophobicity, possess higher impact strength, and so on [1].

The electric field (E-field) distribution on transmission class composite nonceramic insulators, alternatively called polymer or nonceramic insulators (NCIs), affects both the long and short term performance. In order to design and apply composite insulators effectively, a fundamental understanding of the E-field distribution and its effect on the insulator performance is needed [2]. So calculation of the electric field is required in the insulation design of HV electric power apparatus in order to reduce the size and to enhance the space utilization efficiency. In particular, electric field calculation and electric field optimization have become indispensable tools. In [3] a personal computer (PC) based electric field calculation system combined with CAD has been developed

The document [2] intended to provide an overview of the E-field distribution of composite insulators and the related issues.

It was not intended to provide guidance on the design, selection and application of corona rings. Hongwei Mei [4] investigated installing insulation jackets with different lengths on transmission line conductors to reduce the electric field strength on composite insulators. That paper presents the latest researches about field distribution for polymer insulators but unfortunately that is not complete and so there is a need for further investigation about this issue with respect to optimization methods.

This strengthens the requirements for higher reliability, compatibility, safety, long life, and minimal maintenance. All these requirements can be fulfilled by optimization algorithm. The key role in every electrical element is played by the insulation elements. Ageing of their material and, consequently, their lifetime depend mainly on the magnitudes of electric field they are exposed to [5].

For this reason, the presented study focuses on optimization of corona ring for existing types of polymer insulators with respect to the magnitudes and the distribution pattern of electrical field.

2. ELECTRICAL FIELD ISSUES

The E-field distribution on the surface of, and within composite insulators is a function of numerous parameters including applied voltage, insulator design, tower configuration, corona ring and hardware design, phase spacing, etc. The following discussion will provide generalized information that relates to the E-field distribution of most electrical applications.

There are three main regions of interest when considering the E-field distribution of composite insulators [2].

1) On the surface of, and in the air surrounding, the polymer weather-shed surface and surrounding the end-fitting seal.

2) Within the fiberglass rod and polymer rubber weather-shed material, as well as at the interfaces between these materials and the metal end fitting.

3) On the surface of, and in the air surrounding the metallic end fittings and attached corona rings.

If the E-field magnitude in any of these three regions exceeds critical values, excessively large magnitudes of, discharge activity can ensue, and the long or short term performance of the insulator may be affected. There is a direct relationship between the E-field distribution and the resulting discharge activity on and within composite insulators. The presence, location and magnitude of discharges are a function of the magnitude and direction of the local E-field.

In general, the E-field magnitudes are larger close to the energized and grounded ends of a composite insulator. Typically the energized end is subjected to the highest field magnitudes. In some cases the position of highest E-field occurs adjacent to the end fittings, while in other cases it may occur within a short distance of the end fitting.

Numerous field observations and results from accelerated aging tests have shown that E-fields play a significant role in the degradation of polymer material. As such, the E-field is recognized as a significant factor in the aging mechanisms of NCIs [6].

The application of a corona ring may result in the highest E-field magnitude occurring a short distance away from the end fitting rather than adjacent to it. The presence of the corona rings results in a shift of the position of highest E-field to a location 3 sheds away from the live end fitting. On insulator assemblies utilizing corona rings, the location of the highest E-field is a function of the size and location of the corona ring [2]. So in this paper the size and location of corona ring for several cases of polymer insulator will be optimized using the proposed optimization algorithm.

3. OPTIMIZATION ALGORITHM

The basic algorithm (Fig. 1) consists of an entire parametrically written model of the insulator (P_1, P_2, P_3), mesh generator, solver of the Electromagnetic Field Analysis Tools program package, and differential evolution (DE) optimization algorithm [7].

```
Begin
  Initial parametric model geometry and materials with x_n parameters
  Create initial population of size NP (i=1,...,NP)
  k=1
  Evaluate members of the population with regard to the objective
  function f_i^(k)(x)
  While the stopping criterion is not reached Do
    For i=1 to NP Do
        k=k+1
        Create vector of mutated descendants v_i^(k+1)
        Execute differential crossover x_i^(k+1)
        If (|(x_i^(k+1) - x_i^(k)| > max_difference) Then
          Meshing of geometry (specially for switchgear)
        else
          re-distribution of existing finite elements
        Endif
        Preparation of the model in the pre-processor
        FEM solver of the EleFAnT program package
        Calculation electrical field strength
        Evaluate quality f_i^(k+1)(x) with regard to the objective function
        If ( f_i^(k+1)(x) < f_i^(k)(x)) Then
          Descendant becomes new parent x_i^(k+1)= x_i^(k+1)
        else
          Descendant is covered by the parent x_i^(k+1)= x_i^(k)
        Endif
    End
  End
```

Fig. 1. Pseudocode of the entire optimization algorithm for the design of insulation elements.

A parametrical description of the insulator's geometry in connection with the newly developed mesh generator is applied, since it enables larger possible changes in geometry that require new meshing of the model to finite elements. The mesh generator has been optimized to be used for the modeling of the polymer insulator units. It recognizes the most heavily loaded parametrically given, geometrical structures and ensures optimum distribution of the finite elements. The mesh generator has been specially adapted to various applied optimization algorithms so that, with regard to the objective function, it enables a choice between changing the geometry by re-distribution of existing finite elements and making a completely new mesh representation of the geometric structure with finite elements. In such a way, this adaptive meshing algorithm ensures lower numerical errors and a stable performance of the optimization algorithm. In the design process, it was necessary to fulfil three criteria. Each of them was analytically described by a function using bell-shaped fuzzy sets. Where, f_E evaluates the magnitudes of electric field strength, f_M describes the uniformity of the electric field at the boundaries. The weighted sum method is used for solving the multi-objective optimization problem (MOOP).

(1) describes how the functions $f_E(x)$, and $f_M(x)$ are united into a uniform objective function $f(x)$.

$$f(x) = w_E f_E(x) + w_M f_M(x) \tag{1}$$

Where w_E, and w_M are the weights of the individual quantities. Evaluation of the objective function $f(x)$ is the basis of the selection, where each descendent $x_i^{(k+1)}$ is selected in the next generation only when its valuation is lower than the valuation of its parent, otherwise it is replaced by its parent:

$$x_i^{(k+1)} = \begin{cases} x_i^{(k+1)}, \; if\; f\left(x_i^{(k+1)}\right) < f\left(x_i^{(k)}\right) \\ x_i^{(k)}, \; otherwise \end{cases} \tag{2}$$

The weighted sum method requires special attention being paid to selecting the weights of objective functions, which enable transformation to optimization with a composed single objective function. This method also requires a good knowledge of the applicative problem.

4. CASE STUDY

Two polymer insulator-type specimens, having straight and alternate sheds, as typical samples from case studies were presented in Figs 2, 3.

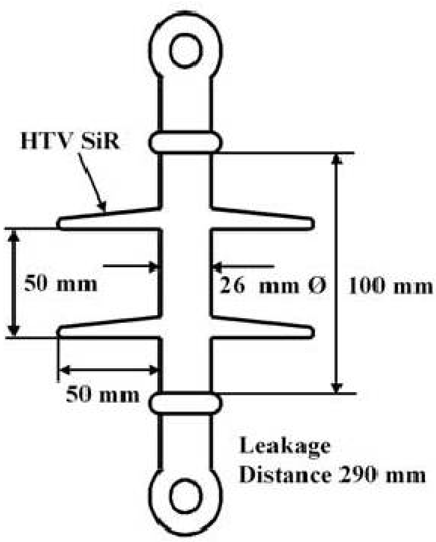

Fig. 2. Straight shed mode for polymer insulator that has been selected for optimization of its corona ring as 1th case study.

All the specimens were made of high-temperature vulcanized silicone rubber (HTV SiR) with alumina trihydrate (ATH: Al2O3•3H2O) filler contents of 50 parts per 100 by weight (pph). HTV SiR sheaths onto fiber-reinforced plastic (FRP) rods. Graphite discs, 31 mm in diameter and 5 mm in thickness, were screwed to both ends of each rod-type specimen using stainless steel hook screws. The insulator-type specimens were prepared by moulding HTV SiR onto the FRP rods. Moulding lines or parting lines were found on these insulator-type specimens. Each two pieces for individual specimen types were used in this investigation. These instances have been taken from [1]. But for further investigation, other models of polymer insulator have been chosen from [8] to extend the research for polymer insulator in a fog chamber (Fig. 4).

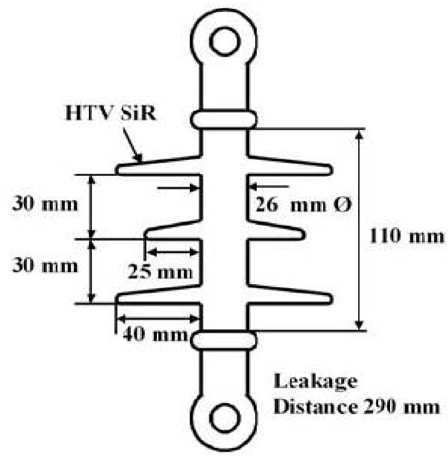

Fig. 3. Alternate shed mode for polymer insulator that has been selected for optimization of its corona ring as 2th case study.

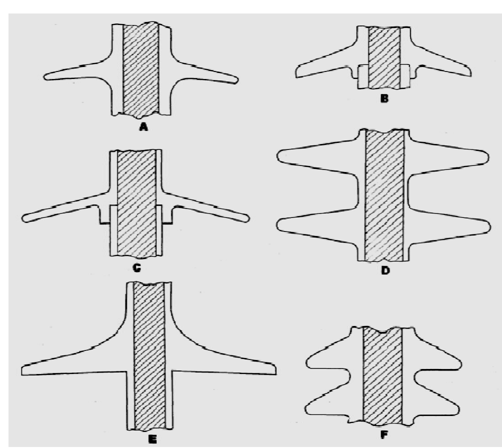

Fig. 4. Other modes of polymer insulator that have been selected for optimization of their corona ring as 3-8th case studies.

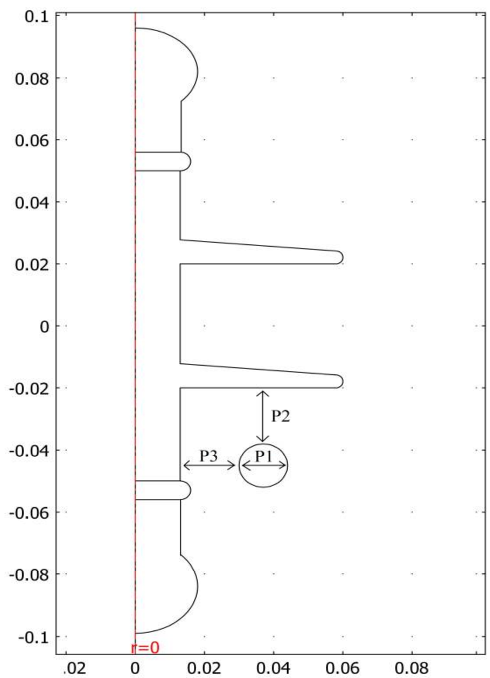

Fig. 5. Optimization parameters for 1th case study.

After these case studies are presented, the size and distance of corona rings should be optimized. P1, P2, P3 are the optimization parameters (Fig. 5). This procedure is applied to all of the case studies. The optimization results for them are presented at following section.

5. OPTMIZATION RESULTS

The application of appropriately designed corona rings can be used to reduce the maximum E-field magnitudes and move the position of the maximum E-field away from the end-fitting (as the end-fitting seal is considered critical). The dimensions and location of the corona ring have a significant influence on the E-field. In this section the results due to optimization procedure for presented insulators will be presented (Figs. 6-12). Models are simulated by FEM in 2D axial symmetry module.

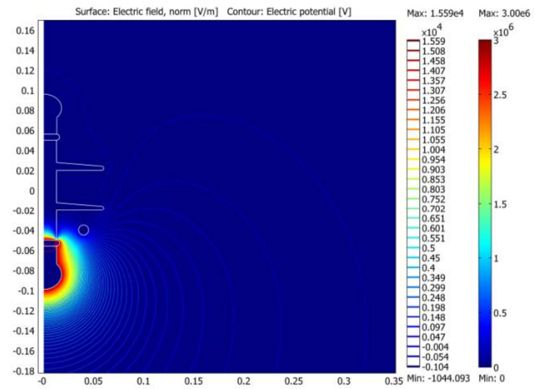

Fig. 6. Electrical field distribution and electrical potential contour for the 1th case of polymer insulator with the presence of corona ring which optimized.

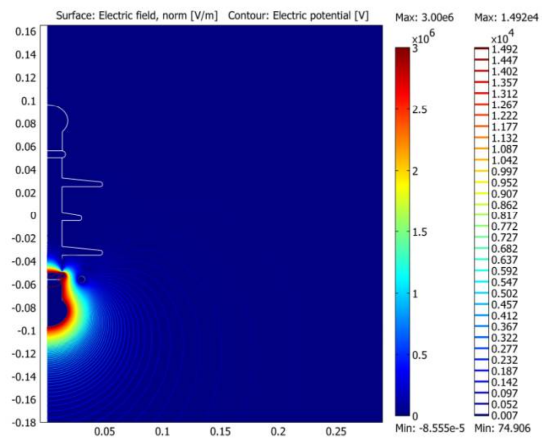

Fig. 7. Electrical field distribution and electrical potential contour for 2th case of polymer insulator with the presence of corona ring which optimized.

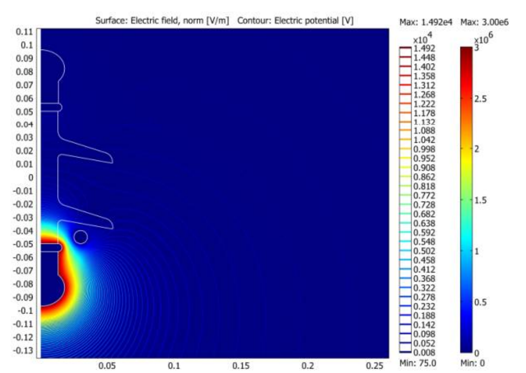

Fig. 8. Electrical field distribution and electrical potential contour for the 3th case of polymer insulator with the presence of corona ring which optimized.

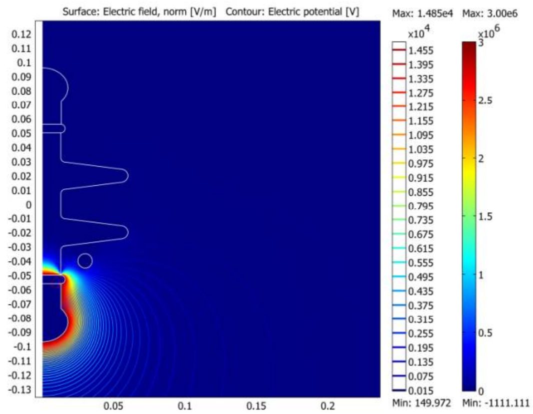

Fig. 9. Electrical field distribution and electrical potential contour for the 4th case of polymer insulator with the presence of corona ring which optimized.

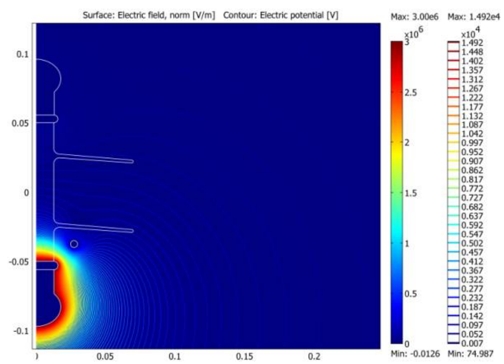

Fig. 10. Electrical field distribution and electrical potential contour for the 5th case of polymer insulator with the presence of corona ring which optimized.

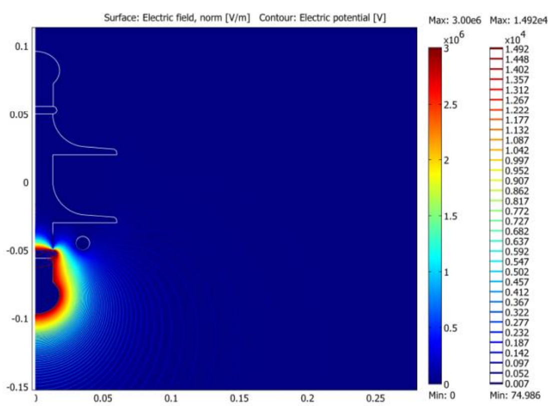

Fig. 11. Electrical field distribution and electrical potential contour for the 6th case of polymer insulator with the presence of corona ring which optimized.

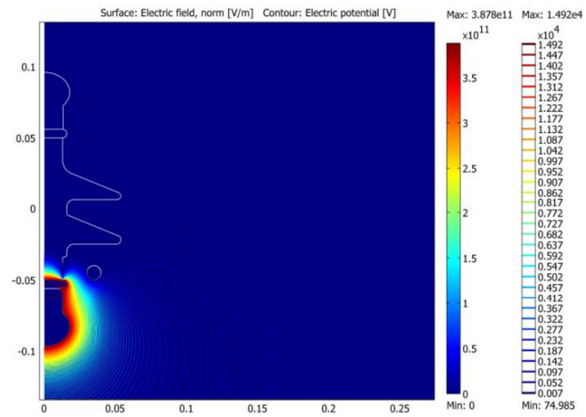

Fig. 12. Electrical field distribution and electrical potential contour for the 7th case of polymer insulator with the presence of corona ring which optimized.

The optimized values of P1, P2, P3 parameters and reduction percent of maximum electrical stress for each model are presented in Table 1.

Table 1. Optimized values of P1, P2, P3 parameters and reduction percent of maximum electrical stress

Cases	P_1 [m]	P_2 [m]	P_3 [m]	reduction percent of electrical stress
Case 1	0.01	0.015	0.022	24
Case 2	0.012	0.015	0.011	22
Case 3	0.01	0.005	0.01	16
Case 4	0.01	0.007	0.012	20
Case 5	0.005	0.009	0.012	19
Case 6	0.01	0.01	0.017	27
Case 7	0.01	0.014	0.017	18

6. CONCLUSIONS

The E-field distribution on composite insulators is nonlinear with the regions close to the energized end normally is subjected to the highest magnitudes. For most applications, the dominant direction of the E-field is along the axis of the insulator. The E-field distribution influences the presence and magnitude of discharge activity within and on the surface of the dielectric material, as well as discharge activity from the metal end fittings. Internal and external discharge activity need to be considered when considering maximum allowable fields.

Field magnitudes on the rubber surfaces of composite insulator sheath sections may vary considerably depending on the design, configuration and application. The electrical stresses can be reduced using corona rings. However, instances have occurred where corona ring designs have been inadequate. Therefore, the optimization design for utilization of corona ring is very important that discussed in this paper and employed for different models of polymer insulators. With using this method, the maximum field stress reduced greatly.

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