Electric Field Distribution within Underground Power Cables in Presence of Micro Cracks

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Abstract- In high voltage power cable, partial discharge (PD) phenomenon may occur within defects that can exist in its insulation system. Repetition of PD activity inside the defect may cause insulation breakdown when the defect grows until it bridges the electrodes between the insulation. Micro-cracks can be formed during cable installation or during passing heavy mechanical load above the underground power cable. This crack defect is one of the most common PD sources when cable insulation is stressed under high electric field. In this paper, electric field distribution within 132kV cross linked polyethylene cable was calculated and discussed using Finite Element Method. The effect of micro-crack size and location on the electric field distribution was presented.

Index Term- *Power* cable, electric field, Finite element method, partial discharge, micro crack.

I. Introduction

Electricity is an essential requirement for modern society. There are two ways to transport electricity from generating plants to load areas, overhead transmission lines and underground power cables. Cables have been used for high density urban areas and for other locations where overhead lines are inappropriate. Cables have advantages in environmental and safety aspects compared with the overhead transmission lines. So, most distribution networks of medium and low voltages are constructed with power cables rather than overhead transmission lines [1]. Cable lines are also less sensitive to climate and environmental conditions and therefore their reliability with respect to overhead lines is higher [2].

Electric insulation is main part of power cables and its quality affects expected life time. There is great interest in understanding the ageing and degradation of electrical insulation to improve its lifetime and efficiency [3]. Several types of insulators are used in high voltage electrical power system to protect the power equipment. For the purpose of safety and better efficiency, it is necessary to keep the insulators in a healthy condition during its operation. As the insulators are always in impure form due to presence of air bubbles/other impurities inside the insulators, the local electrical breakdown so called partial discharge (PD) takes place due to the high voltage stresses [4]. Due to this, PD occurs and property of insulators deteriorates enormously. Therefore, detection of PD is the one of the important task for electrical engineers to keep the high voltage power equipment in healthy condition [5, 6]. Other factors such as electric discharges. Impurities, roughness and space charges can also effect on cable insulator life time [7, 8, and 9].

Local electric field will rise due to humidity and water, and therefore it leads to increase the electric field. This electric field can cause insulation breakdown and causes the partial discharge. Partial discharges (PDs) are one of the major causes of electrical equipment or system Failure and degrading of the insulation. Various defects, such as cracks, contaminants and electrical trees [10] can cause partial discharge (PD) activity in the cable insulation. The gas (air) present in such small cracks in the insulation has dielectric strength significantly less than the surrounding insulation. Under these conditions, the discharges that take place in small cracks lead to erosion of the insulation (ageing) surfaces that are in contact with air in the crack. This leads to gradual decomposition of the insulation and eventual failure.

FEM has been used to study cavity effect in high voltage power cables as a basic method [11]. This leads to exact evaluation for the electric field distribution in the cable insulation [12, 13]. This paper calculates the electric field distribution inside the power cable with the presence of micro cracks. Finite Element Method is used to calculate the electric field due to its many advantageous. The influence of the micro crack size and location on the electric field intensity is calculated and discussed.

II. FINITE ELEMENT ANALYSIS

The computation of electric field is complex and it is usually difficult to find an exact solution. Several numerical techniques have been increasingly employed to solve such practical problems since the availability of high performance computers. The advantage of the application of numerical methods has many advantages compared to analytical methods such as computable accuracy, simplicity and low cost. Finite Element Method (FEM) is used in this work for its favorable accuracy, when applied to high voltage problems. FEM one of the efficient technique for solving field problems is used to determine the electric field distribution inside the power cable. FEM concerns itself with minimization of the energy within the whole field region of interest, whether the field is electric or magnetic, of Laplacian or Poisson type, by dividing the region into triangular elements for two dimensional problems or tetrahedrons for three dimensional problems. Under steady state the electrostatic field within anisotropic dielectric material, assuming a Cartesian coordinate system, and Laplacian field, the electrical energy W stored within the whole volume U of the region considered is:

$$W=\frac{1}{2}\int_u \in \left|grad(v)\right|^2 du \qquad (1)$$

$$W = \frac{1}{2}\iiint_u \left[\epsilon_X \left(\frac{\partial V_x}{\partial x}\right)^2 + \epsilon_y \left(\frac{\partial V_y}{\partial y}\right)^2 + \epsilon_Z \left(\frac{\partial V_z}{\partial z}\right)]dxdydz\right] \qquad (2)$$

For power cable arrangement, when we consider the field behavior at minute level the problem can be treated as two dimensional (2D). The total stored energy within this area-limited system is now given according to

$$\frac{W}{\varphi} = \frac{1}{2} * \epsilon \iint \left[\left(\frac{\partial V_x}{\partial x}\right)^2 + \left(\frac{\partial V_y}{\partial y}\right)^2\right] dxdy \qquad (3)$$

Where (W/φ) is an energy density per elementary area dA. Before applying any minimization criteria based upon the above equation, appropriate assumptions about the potential distribution V(x, y, z) must be made. It should be emphasized that this function is continuous and a finite number of derivatives may exist. As it will be impossible to find a continuous function for the whole area A, an adequate discretization must be made. So all the area under consideration is subdivided into triangular elements hence:

$$\frac{W}{\varphi} = \frac{1}{2} * \epsilon * \sum_{i=1}^{n} \left[\left(\frac{\partial V_x}{\partial x}\right)^2 + \left(\frac{\partial V_y}{\partial y}\right)^2\right] * A_i \qquad (4)$$

Where n is the total number of elements and A_i is the area of the triangle element. So the formulation regarding the minimization of the energy within the complete system may be written as:

$$\frac{\partial x}{\partial\{V(x,y)\}}=0 \qquad \text{where } X = \frac{W}{\varphi} \qquad (5)$$

The result is an approximation for the electrostatic potential for the nodes at which the unknown potentials are to be computed. Within each element the electric field strength is considered to be constant and the electric field strength is calculated as;

$$\vec{E} = \frac{-\vec{i}(\partial V(x,y))}{\partial x} - \frac{\vec{j}(\partial V(x,y))}{\partial y} \qquad (6)$$

III. ELECTRIC FIELD DISTRIBUTION WITHIN POWER CABLE

The electric field distribution within a cross sectional area of the 132kV cable with a presence of a cylindrical crack of 30µm radius located at a distance 1mm from the HV conductor surface using finite element method is shown in Figure 1. The cable is single core aluminum with copper wire screen. The radius of the high voltage conductor is 8mm and the radius of sheath is 37mm. The micro crack within the cable is simulated as cylindrical crack. The crack is assumed to be filled with air ε_r=1. The figure shows that, the electric field is enhanced inside the crack.

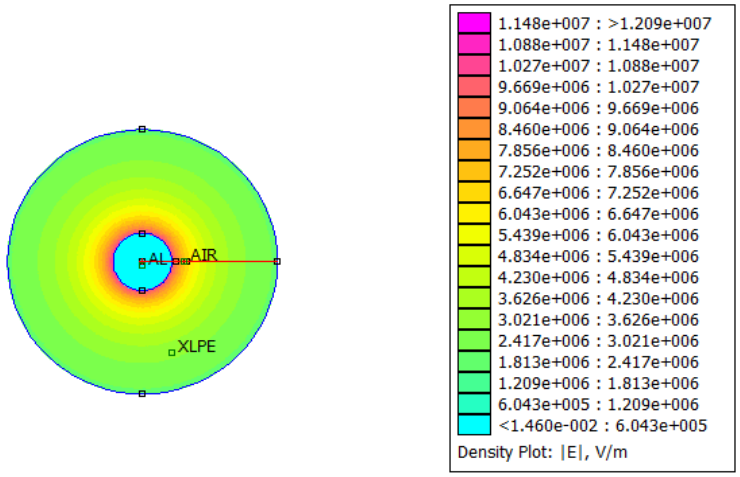
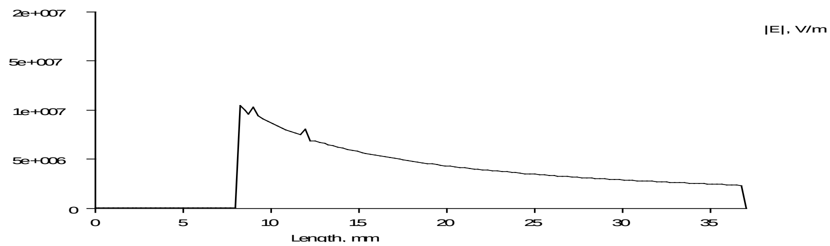
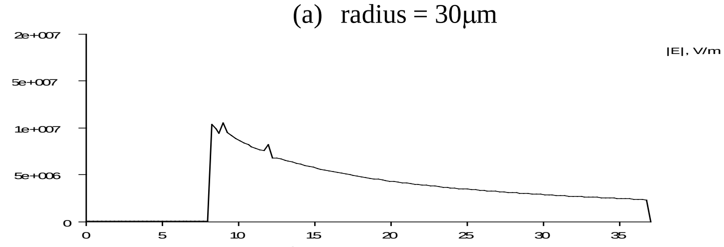


Figure 1. The electric field distribution inside a cross sectional area of a cable with the presence micro-crack.

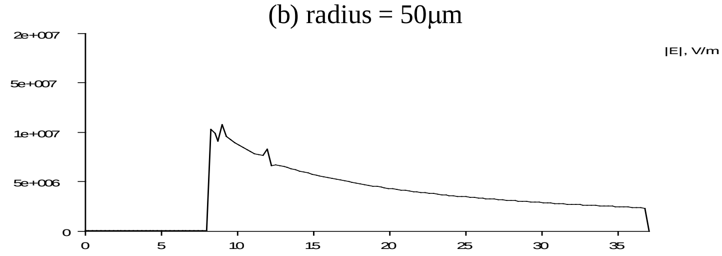
The effect of micro-crack radius on the electric field values inside the power cable when the micro-crack located at a distance 0f 1.0mm from the HV conductor surface, is shown in Fig.(2). The micro-crack length is taken as 3.0mm. The figure shows that the electric field is enhanced inside the micro-crack at both ends. As the radius increased, the electric field magnitude is slightly decreased. The electric field stress was decreased from about 11.3kV/mm to about 11.2kV/mm, as the crack radius increased from 30μm to 70μm.



(a) radius = 30μm



(b) radius = 50μm



(c) radius = 70μm

Figure 2. Lateral electrical field distribution with the presence of micro-crack.

Figure 3 shows the enhancement field factor inside the cylindrical crack versus the micro-crack radius. The enhancement field factor is approximately constant, where the variation is very small. The enhancement field factor is slightly decreased from 1.179 to 1.169 as the micro-crack radius increased from 10μm to 70μm.

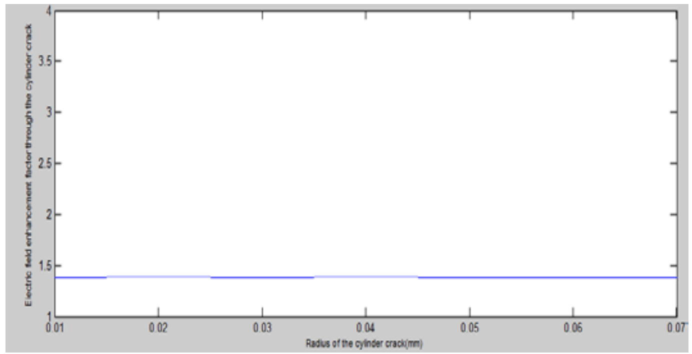
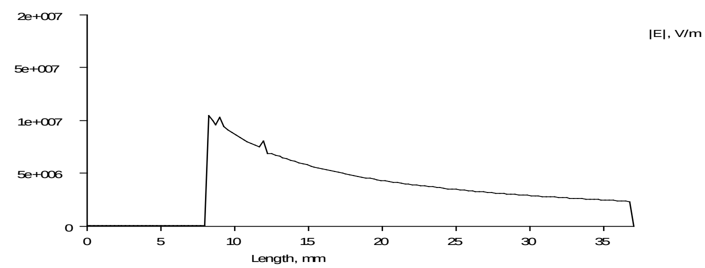
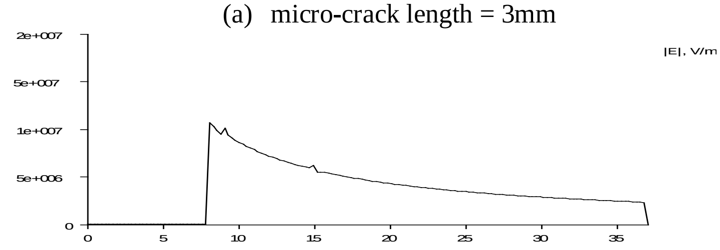


Figure 3. The enhancement field factor versus the micro-crack radius.

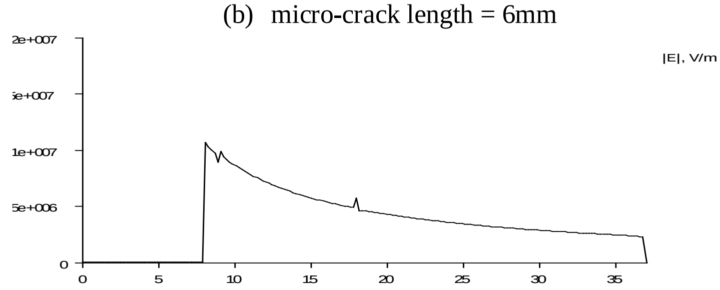
The effect of the micro-crack length on the electric field values is discussed with the presence of a micro-crack of 30μm radius located at a distance 1mm from the HV conductor surface. Fig.(4) shows the lateral field distribution at different micro-crack length. The electric field is increased inside the micro-crack especially at both ends. As the micro-crack length decreases, the electric field magnitude is increased. The electric field stress was increased from 9.861 kV/mm to 9.930kV/mm, as the micro-crack length decreased from 9mm to 3mm.



(a) micro-crack length = 3mm



(b) micro-crack length = 6mm



(c) micro-crack length = 9mm

Figure 4. Lateral field distribution with micro-crack of radius 30μm.

Figure 5 shows the enhancement field factor inside the micro-crack, of radius 30μm placed at 1 mm from the HV electrode, versus the crack length. The figure shows that, as the micro-crack length increases, the enhancement field factor is slightly decreased. The enhancement field factor decreases from 1.176 to 1.172 as the micro-crack length increased from 3mm to 9mm.

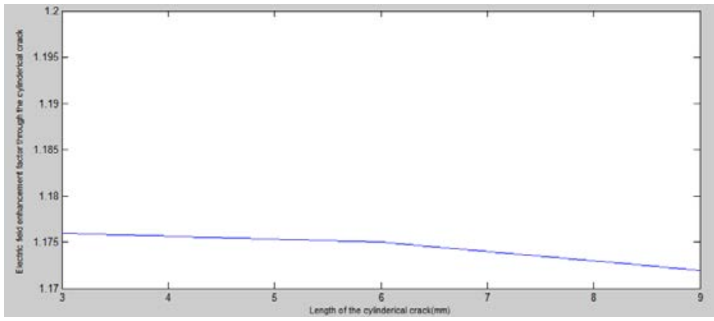
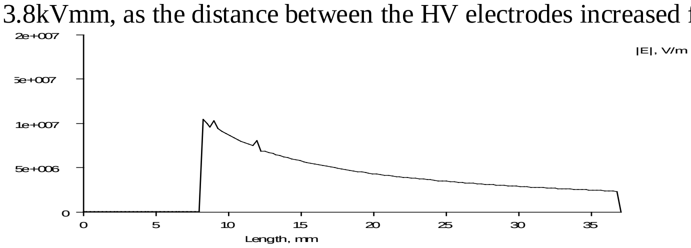
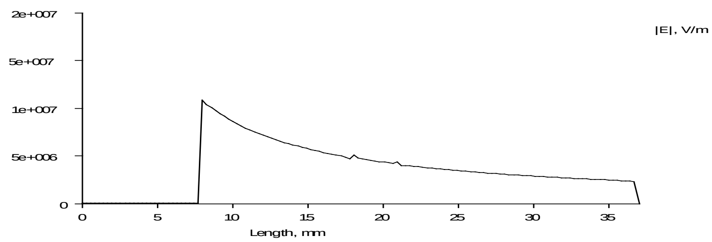


Figure 5. Enhancement field factor versus micro-crack length.

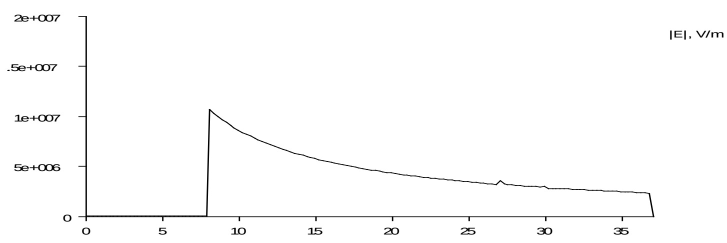
The influence of the cylindrical crack position on the electric field distribution for a cylindrical crack of radius 30μm and 3.0mm length is shown in Fig.(6). The figure shows that, the electric field is enhanced in the crack at the both ends. As the cylindrical crack becomes far from the HV conductor surface, the electric field magnitude was decreased. The electric field stress was decreased from about 11.3 kV/mm to about 3.8kVmm, as the distance between the HV electrodes increased from 1mm to 19mm.



(a) distances from the HV conductor surface = 1mm



(b) distances from the HV conductor surface = 10mm



(d) distances from the HV conductor surface = 19mm

Figure 6. Lateral electrical field distribution with micro-crack radius 30μm radius.

Fig.(7) shows the enhancement field factor inside the micro-crack, of radius 30μm and length 3.0mm, versus the distance between the micro-crack and the HV electrode. The figure shows that, as this distance increases, the enhancement field factor is slightly decreased. The enhancement field factor decreases from 1.176 to 1.172 as the distance between the crack and the HV electrode surface increased from 9mm to 19mm.

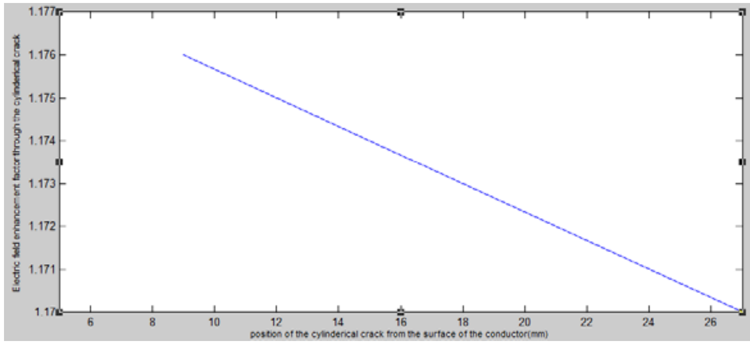


Figure 7. The enhancement field factor versus the distance between micro-crack and HV electrode.

IV. CONCLUSION

A model of 132 kV cable has been developed using finite element method (FEM) software to simulate the electric field distributions inside the cable. The simulation results shows that when there are defects exist in the cable, the electric field is distorted across the defect. The electric field is enhanced significantly at the defect region due to a lower dielectric constant than the surrounding insulating material. These defects can be the source of partial discharge phenomena, which can affect the performance of the cable termination. It was also found that the radius and location of the crack influence the electric field distribution and magnitude in the cable. Therefore, this information may assist in designing a model of cable to improve the electric field distribution.

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