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THE IMPACT OF LAYOUT AND CONCENTRATION OF DEFECTS ON THE ELECTROMECHANICAL CONSTRAINTS IN THE MV CABLES INSULATION

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Abstract

The problem of the dense presence of voids in the solid insulation of cables remains a concern for researchers in terms of diagnosis and maintenance. The focus of this paper is to investigate the influence of both the layout and density of microcavities on the electrical and electromechanical constraints in the XLPE insulation of MV cables using numerical simulation. The simulation is based on the resolution of Laplace's equation by the finite element method (FEM) using MATLAB. The electrostatic pressure and the elongation of the microcavities are estimated. This elongation leads to the formation of microchannels and then develops due to partial discharges to arborescence and in the end, the cable becomes out of service. This process takes a long time, so we use simulations to deepen the understanding of this phenomenon in a very short time. The electromechanical constraints are determined for different layouts and densities of microcavities.

Keywords: diagnosing, microcavities, density, electromechanical, XLPE, MV, FEM, partial discharges

1. INTRODUCTION

The distribution of electrical energy in highly urbanized agglomerations and even in rural areas is currently done by insulated cables. The availability and reliability of these networks depend on the service life of the cables, which is essentially dictated by the behaviour of the insulating layer against the service constraints. A good underground cable entails outstanding electro-mechanical features and good resistance against chemical corrosion, heat aging, and environmental stress.

Over the years, cross-linked polyethylene (XLPE) has been a widely used insulation material for both HVAC and HVDC cables. According to widespread belief, extruded cables have many significant advantages [1]–[3]:

1. Maximum service temperature is higher (>90°C).
2. Extruded cables are recyclable and reduce the environmental problem caused by oil leaks.
3. In general, cables are mechanically robust, and installation is simpler.

It is for these reasons that extruded cables continue to develop rapidly.

Despite the efforts made by researchers to improve XLPE, the extensive presence of microcavities is still considered the inherent defect of this dielectric especially as it appears from the manufacturing phase. For example [4] Yoshimura et al. reported that the density of microvoids included in two samples of XLPE cable insulation is 103-105 cavities/mm^3 with different sizes (1 to 20 µm).

The danger of the presence of these voids and other defects is to make the insulation layer heterogeneous, which distorts the electric field distribution, on the other hand, the possibility of elongation of these voids if the value of the electric field reaches the threshold of partial discharges (PD) that relate to the permittivity of the material inside the gap (air, moisture, gas, etc.).

Several research papers have examined the effect of voids location relative to cable core, shape, and size on electrical constraints, others focused on thermal and electromechanical constraints [5], [6]. Others studied the above in the presence of space charges with different densities [7]. In [8] and [9] Gouda et al. investigated the computational electrostatic fields necessary to evaluate the electrostatic compression of eccentric insulation power cables and analysed the effect of filling the voids with different materials which have different permittivities by experimental method.

In this article, we continue in many details about what we started with in the paper [10], where the effect of the location and number of voids was studied using the COMSOL Multiphysics software. Where we focused on calculating the elongation rate and deformation of a cavity with neighbouring cavities at different positions. The study of the various constraints in terms of the density of voids will be further clarified.

We rely on solving Laplace's equation by FEM method using the PDE tool of MATLAB environment and obtain the voltage distribution that we use to calculate the electric field strength in both the defects and the XLPE insulation layer. The elongation of the microcavity is estimated by calculating the electrostatic pressure on their sides in a different layout and different densities.

2. FEM MODEL OF THE CABLE UNDER MATLAB

The finite element method is used to solve multi-physical problems with extreme precision. Steps to put the FEM on the PDE Toolbox of MATLAB are presented in the chart in Fig. 1, which is characterized by its simplicity and speed of giving the electrical voltage distribution by solving the Laplace equation (1):

$$\nabla^2 V = 0 \qquad (1)$$

The potential distribution in XLPE cable under MATLAB with geometry, specification of dielectric and boundary conditions (Dirichlet conditions boundary at the interface between core and XLPE layer and Neumann boundary between the XLPE and surrounding air) is present in Fig. 2.

The electric field strength is estimated by the negative gradient scalar potential imported from the solving Laplace equation, equation (2) explains the important relation between E and V:

$$E = -\nabla V \qquad (2)$$

Notice that, the values of potential gained from the PDE Toolbox of MATLAB and electric field are classified with aid of an algorithm into an array $(n \times m)$ elements.

The electrostatic pressure on the walls of cylindrical microcavity in coaxial form is calculated by the equation (3), this constraint is produced from the electrical field constraint, which leads to a deformation of the cavity so an elongation of the defects, and this later is estimated by the expression (4):

$$P = \frac{1}{2}\varepsilon_0 \varepsilon_r E^2 \qquad (3)$$

$$\frac{d_0}{d} = e^{\frac{P}{Y}} \qquad (4)$$

With:

$\varepsilon_0, \varepsilon_r$ are the vacuum and XLPE relative permittivity respectively.

d_0, d are the initial and final thickness (after deformation) of the defects respectively.

Y is Young's modulus of elasticity.

The challenge of this study is how to determine the effects of microcavities density and the position between them. Because the use of experimental analysis in these cases is not easy and the fact that PD activity occurs on the microscopic level of the XLPE insulation layer we opt for the simulation method.

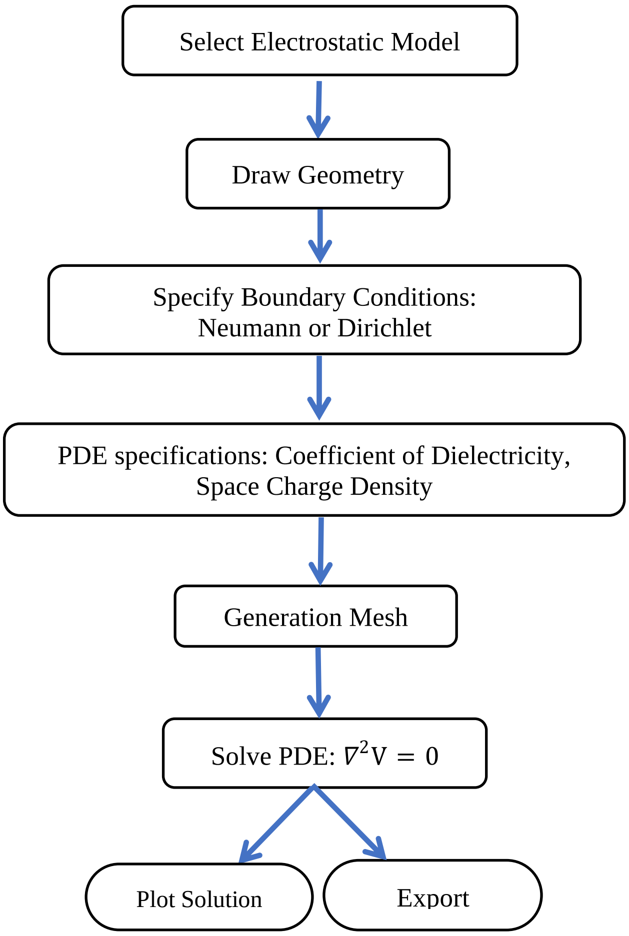

Fig. 1. Flowchart of the steps to put the FEM model of the cable on the PDE Toolbox of MATLAB

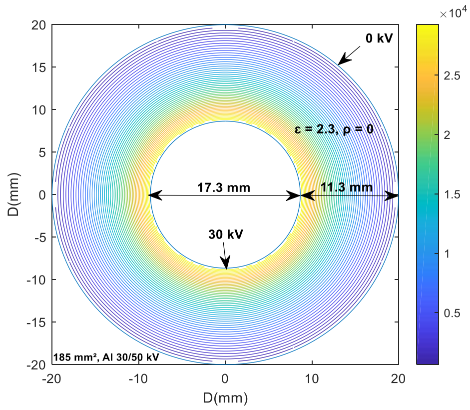

Fig. 2. Potential distribution in XLPE cable with geometry, specification of dielectric and boundary conditions

3. RESULTS AND INTERPRETATION

The results illustrated in Figures 3 to 7 shows three values: the electric field strength, the elongation (deformation) of the microcavity, and the value of the electrostatic pressure of the same microcavity in the case of two different defect concentrations.

In both concentrations (two and three voids), the defects have the same permittivity (air ε=1), size, shape, and the same applied voltage but differ in their positions relative to each other.

Fig.3. presented the effect of the position angle between two microvoids. The results cleared that in each case (0°,30°, 45°, 60° and 90°) the PD can apparition because the electric field is higher than the critical electric stress E=3 kV/mm for air. In each simulation the angle between two defects is changed, this inclination increases the value of the electric constraint of the first cavity. These remarks are confirmed by Fig.4, where the highest deformation of the cavity walls is noted at the angle of 45°. This phenomenon is named: mutual influence between defects. These results are accorded by [10].

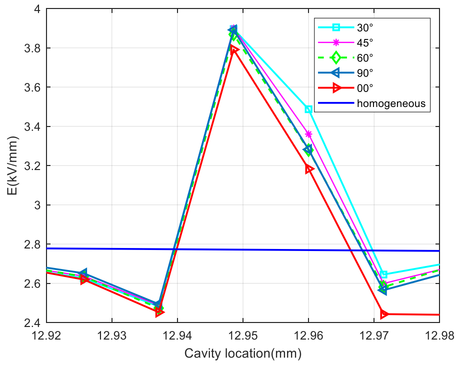

Fig. 3. Electric constraint in the 1st defect by different positions of the second microcavity

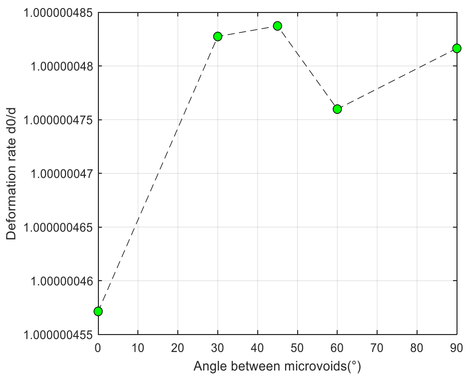

Fig. 4. Deformation rate of microcavity walls versus the angle between defects

In the same case of two voids, the elongation results from the repetitive activity of electrostatic constraints (see Fig. 5) on the walls of microcavity i.e., this activity leads to a change the chemical structure of the dielectric so weakening XLPE strength.

We note that in the case of the presence of three cavities, the value of the elongation rate continues to enhance, compared to the case of one or two cavities Fig.7. This proves that the increase in the density of the defects is a source of raising the stress in the insulator layer, and increasing the possibility of the appearance of partial discharges with greater activity, thus, forming microscopic channels that lead to the phenomenon of electrical treeing, i.e. the breakdown of the insulator and making it out of service. On the other hand, we note that the position (angle) of the cavities with respect to each other affects the constraints of each of them as shown in Fig. 6.

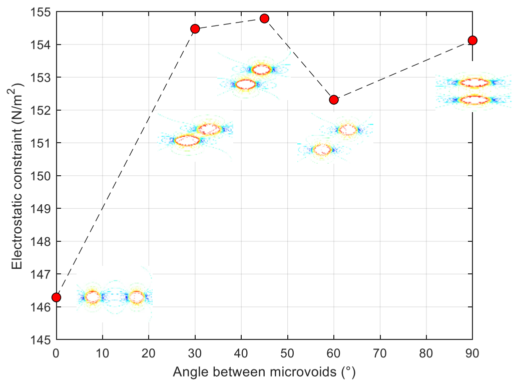

Fig. 5. Electrostatic constraint in the 1st defect versus the angle between microcavities

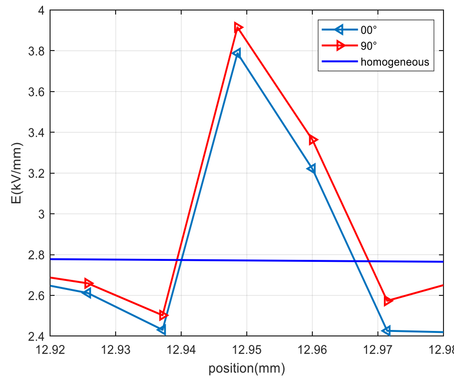

Fig. 6. Electric constraint in the 1st defect: the case of three cavities by different positions

It is worth pointing out in our article [1] that the heterogeneity factor has a decisive role in the formation and propagation of electrical trees and among the main reasons for the heterogeneity is the

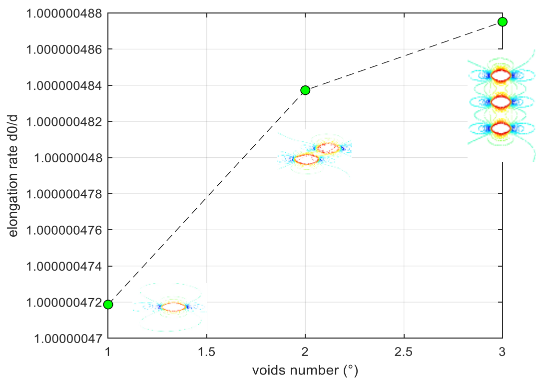

Fig. 7. Elongation rate of the 1st microcavity against to their density

density of microcavities. Therefore, the challenge lies in finding ways to reduce the presence of these defects and thus increase the homogeneity of the insulators.

4. CONCLUSION

The density of the microcavities at the level of the insulation layer has a significant impact on cable reliability. The study leads to the following results:

- The density of the microcavities is directly proportional to the value of the electrical and electromechanical stresses.
- The position of the voids relative to each other has a clear effect on the elongation due to the mutual influence.
- The microcavities remain favourable environment for the occurrence of the partial discharges thus electrical trees.
- Estimating voids density and constraints would help to predict possible failures and thus the reliability of the cable.

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