STUDY OF PHYSICAL PARAMETERS CHANGE, BY STATIC REGIME MODELING, IN A HETEROGENEOUS INSULATING MATERIAL XLPE, CONTAINING THREE CAVITIES, OF A MEDIUM VOLTAGE CABLE

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Abstract: *The Partial discharges (PD) in micro cavities within the insulation of HV power cables drastically affect their performances, and their reliability. In the present work, we suggest a study on the influence of defects (cavities) and their positions by the static regime modeling, on the potential distribution and the physical constraints namely the electric field, the temperature and the electromechanical pressure, in a heterogeneous insulating material (containing three cavities) of a single core cable for medium voltage. This study joins in the general framework in reliability of the synthetic insulation and aims at applying the finite difference method. The results obtained, were successfully compared to those published in the literature, are considered very satisfactory.*

Keyworks: *XLPE cable, Cavities, Electric filed, temperature, electromechanical pressure.*

1. Introduction

An important observation, on synthetic dielectric materials used in insulating systems and the conductors, shows that their degradation is closely linked to the presence of defects (micro cavities) under any volume form in the XLPE (cross polyethylene chemically) in particular, the air cavities, water drops and the impurities (figure 1) [1-2].

In the case of cables, the cavities are formed by the differential expansion and contraction of the cable material under cyclic loading conditions, or because of the thermal gradient during the isolation of the cable core. The micro cavities being effectively pockets of low pressure electrically weak and will ionize at quite low electric stresses. The ionization and occurrence of partial discharges within the cavities would cause erosion and local deterioration of the insulation eventually leading to a complete degradation of the cable [1-4].

The present work joins in the general framework on the electric reliability of the synthetic insulation used in the domain of conveying electric power.

Considering that very often, various mechanisms appear at the same time and mutually influence each other; our contribution will concern only the phenomena related to the physical constraints in the static regime susceptible to appear in the heterogeneous XLPE.

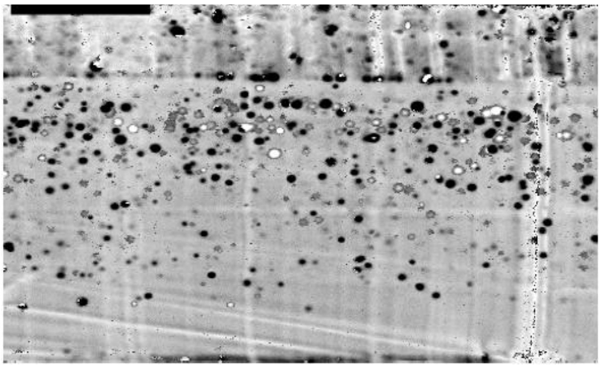

Fig. 1. Sample of polyethylene cable insulation [5]

The scientific approach we will develop here; will consist on analyzing the influence of defects within XLPE insulated of medium voltage cable (30 kV).

In this paper, the effect of XLPE cables stress conditions on the impact of spherical cavities was studied. The variation of the physical parameters (potential and electric field, temperature, and electromechanical pressure) around and inside the cavities was examined. This study is important because in the high voltage insulation systems, the material could be subject to critical stress conditions especially under fault circumstances.

Indeed, the elaboration of a mathematical model allowing to make a simulation study in static regime of an insulating material containing three inclusions for predicting their influences on the ageing of insulation.

2. Simulation model geometry

A two-dimensional (2D) model geometry of an insulated cable with a three spherical cavities, represents an axi-symmetric of a simple geometry, [1, 6-8], what allows us to choose the finite difference method (MDF) has been developed. The model consisting of three cavities with the same Dc diameter, located at r1, r2 and r3, are the positions from the cable center, in a dielectric material (XLPE), is shown in figure 3.

New techniques for calculation are established, to minimize the memory space of the computer and thus reduce the calculation time. Consequently, the study is limited to a zone where the physical constraints are perturbed by the influence of the cavities presence (called area or region of influence).

We are interested on the outside of this zone where we must not have the disturbance of the magnitudes to be calculated.

The contribution to the cavity potential for the all system is represented by:

$$V = -E_a r\left[1 + \frac{\varepsilon_c - \varepsilon_i}{2\varepsilon_i + \varepsilon_c}\left(\frac{r_c}{r}\right)^3\right]\cos^2\theta \qquad (1)$$

We can clearly see that, the potential disruption is caused by the second term in the equation above. To calculate the region of influence, we must use the radial and tangential components of electric field, in polar coordinates, for this expression.

After mathematical development, the intensity of the electric field is given by the following result:

$$E = E_a\left[\left(1 - 2\frac{\varepsilon_c - \varepsilon_i}{2\varepsilon_i + \varepsilon_c}\left(\frac{r_c}{r}\right)^3\right)^2\cos^2\theta + \left(1 + 2\frac{\varepsilon_c - \varepsilon_i}{2\varepsilon_i + \varepsilon_c}\left(\frac{r_c}{r}\right)^3\right)^2\sin^2\theta\right]^{\frac{1}{2}}$$

$$\approx E_a\left(1 + \frac{\Delta E}{E_a}\right) \qquad (2)$$

While neglecting terms of order 6, before the other words, and to admitting a tolerance of 10^{-3} for estimating the factor $(\Delta E/E_a)$:

We obtain:

$$\frac{r}{r_c} \approx \left|10\left[2\left(\frac{\varepsilon_c - \varepsilon_i}{2\varepsilon_i + \varepsilon_c}\right)(1 - 3\cos^2\theta)\right]^{\frac{1}{3}}\right| \qquad (3)$$

This ratio reached its maximum value for : θ = k.π or k = 1, 2, 3,…….

Finally, the radius of the influence region is given by the following formula [1]:

$$r_z = r_c\left|10\left(4\left(\frac{\varepsilon_c - \varepsilon_i}{2\varepsilon_i + \varepsilon_c}\right)^{\frac{1}{3}}\right)\right| \qquad (4)$$

Where r_z, r_c, ε_c, ε_I and E_a; are respectively, the radius of the area of influence, the radius of cavity, permittivity of cavity, permittivity of the dielectric XLPE (equal 2,3) and the uniform electric field in homogeneous system.

This formula shows that the region of influence is proportional to the radius of the cavity and is a function of the nature of the latter. For example, for a water cavity (permittivity 80) this zone is wider than that of air cavity (permittivity 1) as shown in the following figure.

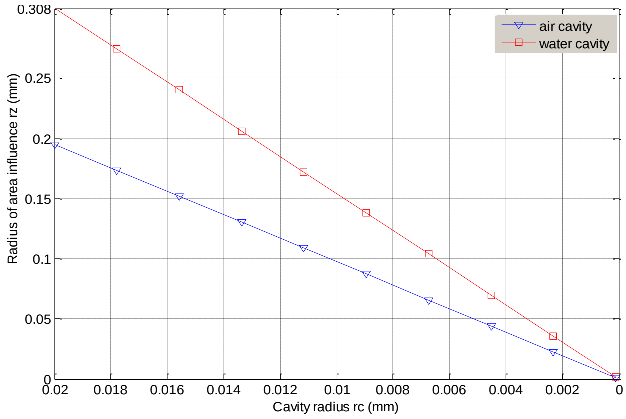

Fig. 2. Variation of r_z in function of r_c and ε_c.

We can notice that, the difference between the size of the region of influence and the defect (water or air cavity), which are almost in the same order. In this respect, we are going to make the mesh along of a rectangular (region of influence) limiting the three cavities, as illustrated in the following figure.

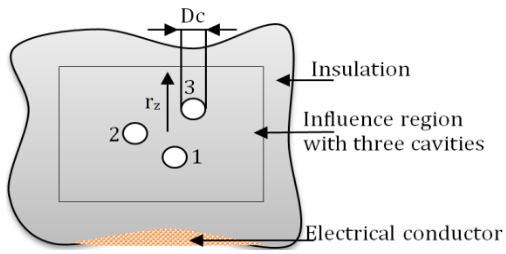

Fig. 3. Zoom of insulation horizontal section of a cable with three cavities.

3. Physical parameters computing

The defects take several forms; the most severe is that which contains asperities where the electrons concentration is highest. We utilize the spherical shape, because it is very easily modeled and show less effect as compared to other forms.

The obtained results lead us to predict the influence of the other forms.

It is assumed that all PD occur at the center of the cavities where the applied electric field is strongest, hence the electric potential distribution in the cavities and with the axi-symmetric. The potential distribution is found by equation (1) [4]:

$$\Delta V + \frac{\rho}{\varepsilon} = 0 \qquad (5)$$

ρ is the volume charge density, V is the electric potential, ε is the permittivity of the dielectric material.

The Poisson's equation turns into the Laplace one if the free charge density ρ in the insulator is neglected:

$$\Delta V = 0 \qquad (6)$$

The electric field is deduced by the gradient of the potential; indeed, the module of the electric field in each node of the meshing is given by the following formula [1]:

$$E(i,j) = \sqrt{E_r^2(i,j) + E_\theta^2(i,j)} \qquad (7)$$

Where: E_r, E_θ are respectively the radial and tangential components of the electric field.

According to Stark and Garton, the polymer insulators could be deformed under the influence of the compression strengths due to an electromechanical constraint. They showed that, if we submit a dielectric to a potential difference, the resultant constraint of the pressure makes the thickness of this dielectric decrease. The pressure variations within a cable subjected to an electric field is given by [9-10]:

$$P = \frac{1}{2}\varepsilon_0\varepsilon_r E^2 \qquad (8)$$

Where P, ε_0, ε_r and E; are respectively, the pressure, the vacuum permittivity, the relative permittivity of the dielectric, and the electric field.

According to K.W.Wagner [4, 7], the thermal rupture can take place after the formation of a canal along which the conductivity of the dielectric becomes much more important than in the rest of the dielectric volume.

$$(\sigma + w\varepsilon_0\,\varepsilon_r'')E^2 = C_v\frac{\partial T}{\partial t} - div.(\lambda\nabla T) \qquad (9)$$

If a static electric field is applied in an insulating material, the heat produced by Joule's effect is ($\sigma\boldsymbol{E}^2$). In alternating current is necessary to add the term which takes into account the dielectric losses ($\omega\varepsilon_0\ \varepsilon''\ \boldsymbol{E}^2$). We consider that the temperature in a point of the walls or premises is independent of time *(dT/dt = 0)*.
Such as:

Cv : Specific heat; λ : thermal conductivity; T : temperature ; σ : electrical conductivity, r and t are the radius and time respectively.

4. Results and discussion

The obtained results will be presented in thereafter. The study concerned an insulating material with a three cavities of 1 µm diameter located at different distances by going from the center conductor. The physical parameters (electric potential, electric field, pressure, and temperature), and the effect of the cavities natures (air and water) has been investigated.

The figures 4 and 8 show the influence of air and water cavities on the distribution and the deformation of equipotential lines.

The figures 5, 6, 7, 9, 10 and 11 depict respectively the radial distribution, passing through the centers of the cavities, of the physical constraints; electric field, pressure, and temperature.

We can notice that the deformation of the electric field and pressure are caused by the polarization charges accumulation in and around the cavities (air and water). Besides, the electric field inside inclusions exceeds the disruptive field of air (3 KV) [11-14], what explains the possibility of partial discharges appearance.

On the other hand, we notice clearly the difference between both types of defects, where the electric field (figures 5 and 9) inside the water cavity is lower compared to air cavities because of the difference between the permittivities. The pressure decrease (figures 6 and 10) is due to the mutual interaction between the accumulated charges in and around the cavities.

The obtained results are in good accordance with the findings of a research group working on PD activity modeling published in [14, 15].

In reference to figures (7 and 11) the temperature remains almost stable regardless of the cavities natures, whatever is perhaps interpreted by the lower excitement of the dielectric losses.

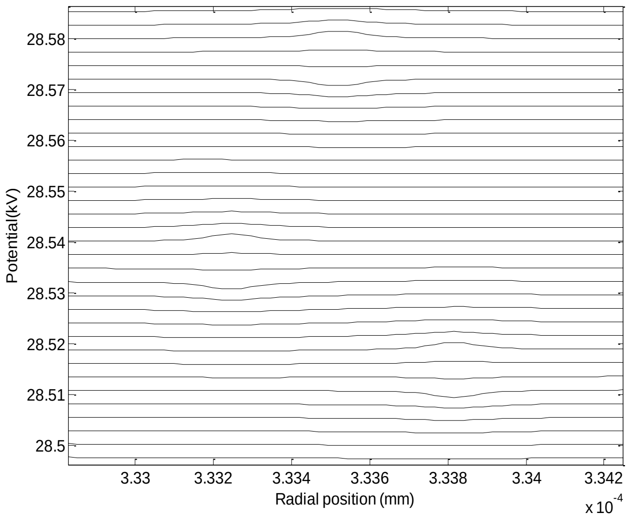

Fig. 4. Zoom of the equipotential lines distribution

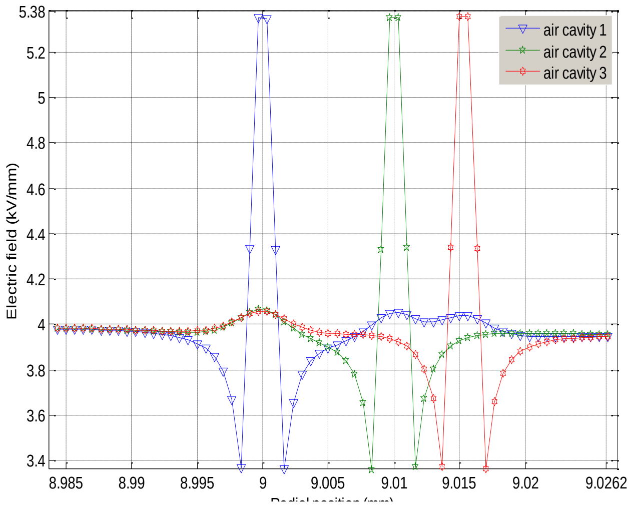

Fig. 5. Radial disturbance of the electric field.

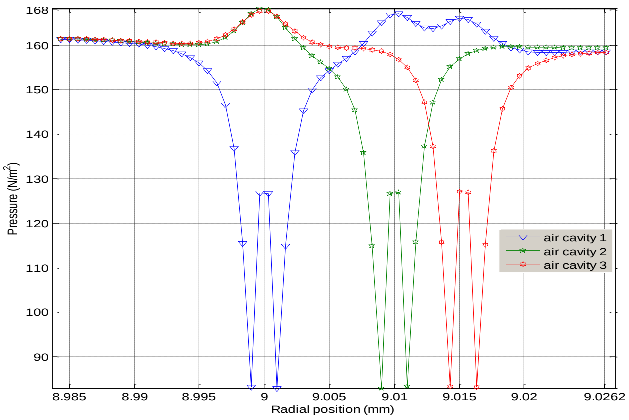

Fig. 6. Radial Disturbance of the pressure.

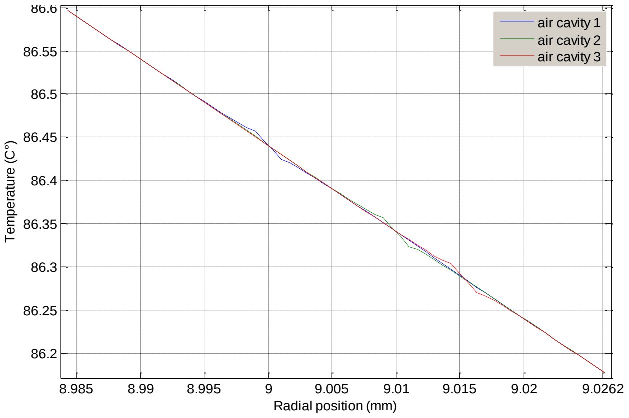

Fig. 7. Radial temperature variation

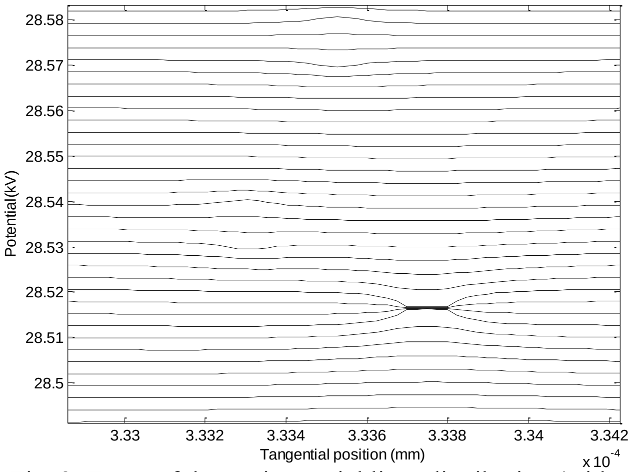

Fig. 8. Zoom of the equipotential lines distribution (with two air cavities and water drop).

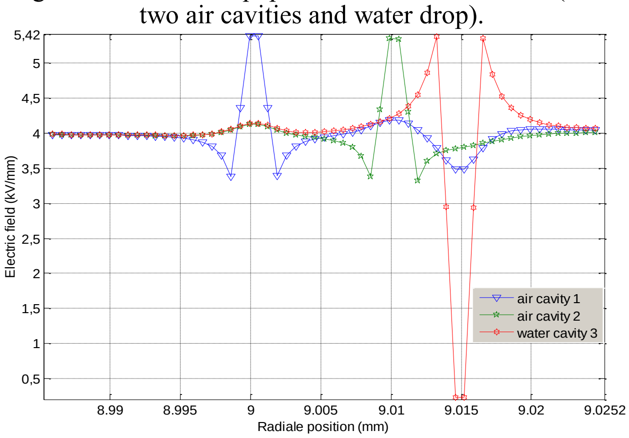

Fig. 9. Disturbance radial of the electric field.

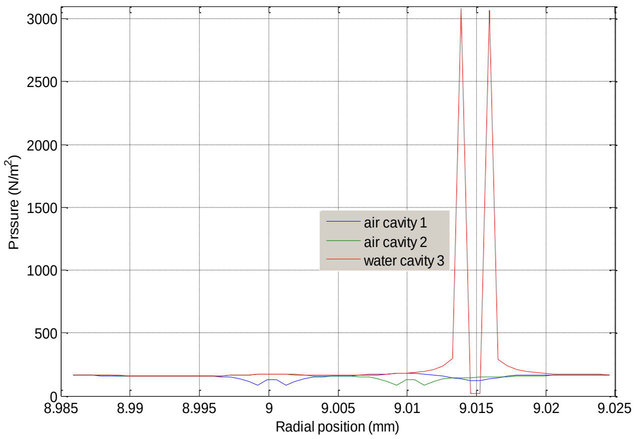

Fig. 11. Radial electromechanical pressure variation

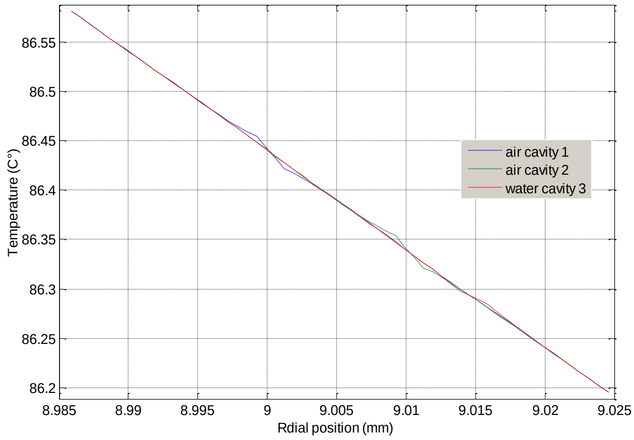

Fig. 12. Radial variation of theperature.

In a general way, the presence of the defects within an insulation material have a negative impact on the quality, and the life-time of insulation, because they modify of the local properties and that can cause a premature aging [16-19].

4. Conclusion

The main objective of the present paper is to make a simulation study, in static regime modeling, of the behavior in XLPE insulated medium voltage cable containing manufacturing defects (cavities), that are the seats of the partial discharges leading to the fatigue, therefore the aging, and so limit the service life-time of an electric cable.

A two-dimensional geometry analysis model with axi-symmetric has been developed by the finite difference method to predict in static regime the activity of the physical parameters (electric potential, electric field, temperature and electromechanical pressure) in and around the spherical cavities within XLPE insulation.

According to the results obtained from this study, we can say, if air or water cavities are included inside the insulating material used in high voltage, we shall possibly have partial discharges. For that purpose, the concentration on the defects has a potentially harmful execution which can lead to a fast aging of the insulation.

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