

# PREDICTION OF THE PHYSICAL PARAMETERS CHANGE INSIDE A SPHERICAL CAVITY LOCATED IN A MATERIAL XLPE OF A MEDIUM VOLTAGE CABLE BY NON-STATIONARY MODELLING

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**Abstract:** The studies on the reliability of the synthetic insulation of a cable for conveying electric power, lean on the behavior and the ageing of dielectric insulators during their service. Several methods have been proposed to study the non-stationary evolution of the physical parameters (temperature, electric field, the pressure and the energy storage) in a heterogeneous insulating material (containing a cavity) of an electric power conveying cable (medium voltage). Our study fits into in this series of works and aims at applying the finite difference method, as a tool of simulation. The purpose was to understand the phenomena taking place within the insulation and to predict the temporal change to the physical parameters, by taking into account the dimensions of the cavity. Results being considered very satisfactory have been obtained.

**Key words:** Cable of electric power, polymer, cavity, Thermal conduction, electric field.

## 1. Introduction

The influence of the thermal constraint on the long-term holding of the organic materials was the object of numerous investigators, in particular in the case of the thermoplastic materials [1-2].

The works done by H. St-Onge et al, on the chemically cross linked polyethylene (XLPE) used in the insulation of the cables for conveying electric power, showed that the thermal constraint accelerates the ageing and that its influence depends mainly on the morphology of the material [3].

In recent works, it was shown that the dielectric properties of XLPE as the dielectric rigidity, the dielectric losses factor and the electrical conductivity, depends on the morphology, on the oxidation, the contaminations and the presence of impurities and/or on cavities within the material (figure 1) [1-2], [4-6]. In reality, the crystalline networks present certain imperfections in their structures, due to missing atoms or more frequently the presence of the impurities or air cavities (structural defects).

These defects correspond to the weak points of construction, and they accelerate aging, and hence the break of insulators [1], [6], [7]. Considering the insufficiency or, even, the non-existence of expressions which can lead to the instantaneous calculation of the temperature gradient and the

electric field in a heterogeneous dielectric (XLPE), we are lead to use the most adequate method to adapt in this kind of problems that is the finite differences method.

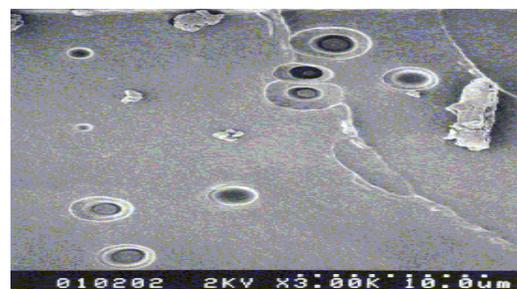


Fig. 1. Sample of polyethylene cable insulation [6].

A mathematical formalism is introduced to predict the dynamic evolution of the physical parameters in an air cavity contained in an insulating material.

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 temperature and to the electric field susceptible to appear in the heterogeneous XLPE. 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 in the modeling and show less effects as compared to other forms. The obtained results lead us to predict the influence of the other forms.

According to studies published by [2-3], [7-8] the degradation of the material is particularly stressed by the presence of impurities of various natures, in particular the vacuoles of gas in the dielectric. These cavities are generally the places of partial discharges, and local heating which can generate, after a relatively long time, the erosion of the material and finally, the break of the dielectric [9], [12].

## 2. Mathematical formulation

According to K.W.Wagner [3], 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.

$$(\sigma + w\varepsilon_0 \varepsilon_r'')E^2 = C_v \frac{\partial T}{\partial t} - \text{div.}(\lambda \nabla T) \quad (1)$$

If a static electric field is applied in an insulating material, the heat produced by Joule's effect is  $(\sigma E^2)$ . In alternating current it is necessary to add the term which takes into account the dielectric losses  $(\omega\varepsilon_0 \varepsilon_r'' E^2)$ .

Such as:

$C$ : Specific heat;  $\lambda$ : thermal conductivity;  $T$ : temperature;  $\sigma$ : electrical conductivity,  $r$  et  $t$  are the radius and time respectively.

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 [17-18]:

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

Where  $P$ ,  $\varepsilon_0$ ,  $\varepsilon_r$  et  $E$ ; are respectively, the pressure, the vacuum permittivity, the relative permittivity of the dielectric, and the electric field.

When a cavity is present in a dielectric, subjected to an electric field, it can behave like a capacitor, for that purpose, this gaseous vacuum stores an electrical energy which is expressed according to the volume of the cavity, as reported by the following expression  $w(J)$ :

$$w = \iiint \frac{1}{2} \vec{E} \cdot \vec{D} \, d\tau \quad (3)$$

D: Electrical induction.

### 3. Technical calculation

The analytical solutions determining the exact distribution of the temperature are available, only for a limited number of ideal cases.

The graphic solutions were used to obtain a preview of heat transfer complex problems, where the analytical solutions are non-existent, but they have not much precision and are mainly used in two dimensions problems.

Consequently, it is necessary to determine the non-stationary variation of the temperature in an irregular geometry, by using the operating conditions of a cable for transport of electrical energy.

The problem to be solved presents certain symmetry, of a simple geometry, what allows us to use the finite difference method [1], [12-15].

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 electrical and thermal magnitudes are perturbed by the influence of the cavities presence (called area or region of influence). We focus on the outside of this zone where we must not have disturbance of the magnitudes to be calculated [1], [12-13]. After mathematical development, the ratio of the region of influence is given by the following formula:

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

Where  $r_z$ ,  $r_c$ ,  $\varepsilon_c$  et  $\varepsilon_i$ ; are respectively, the radius of the area of influence, the radius of the cavity, permittivity of the cavity and permittivity of the dielectric (XLPE). This ratio 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 cavity of water (permittivity 80) this zone is wider than that of air cavity (permittivity 1) as shows the following figure:

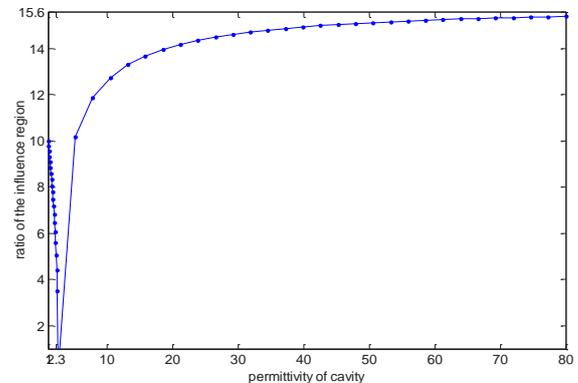


Fig. 2. Ratio variation of the influence area according to the permittivity of cavity (the permittivity of XLPE equal to 2,3).

The following figure represents a horizontal section of a cable containing a cavity by indicating the boundaries of the zone of influence.

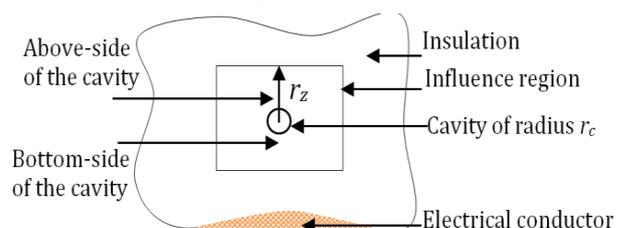


Fig. 3. Zoom of a horizontal section the insulation of a cable containing a cavity.

The obtained results will be presented in the following paragraph. The study concerned an insulating material having a cavity of 1  $\mu\text{m}$  diameter located at a distance of 10 mm (by going from the center conductor).

#### 4. Results and discussion

The temporal evolution, of the thermal gradient in and around the cavity, as well as, the electric field, the pressure and the energy storage due to the thermal change is presented in the figures 4, 5, 6, 7, 8, 9 and 10.

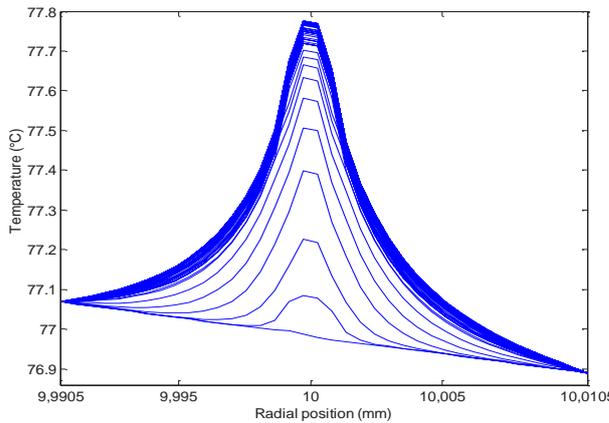


Fig.4. Variation of thermal gradient according to the position

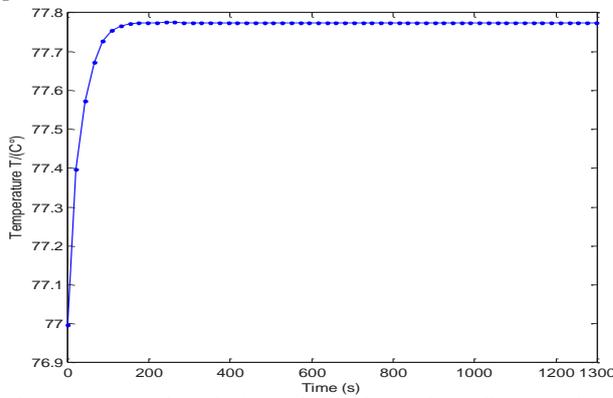


Fig.5. Temporal variation of the thermal gradient in the centre of cavity

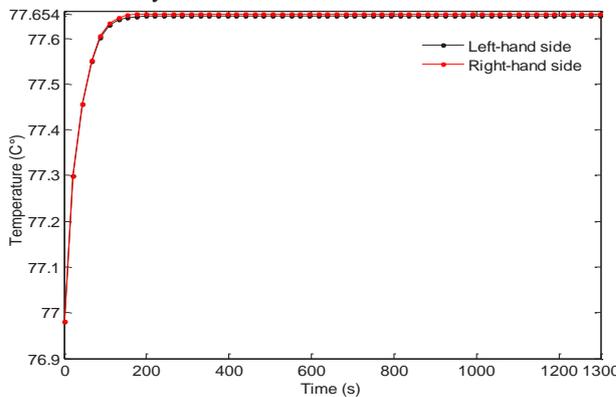


Fig.6. Variation of the temperature to the left-side and right-side of the cavity

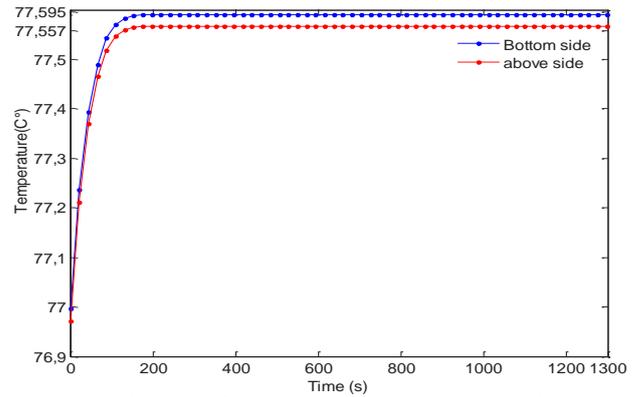


Fig.7. Variation of the temperature bottom-side and above-side of the cavity

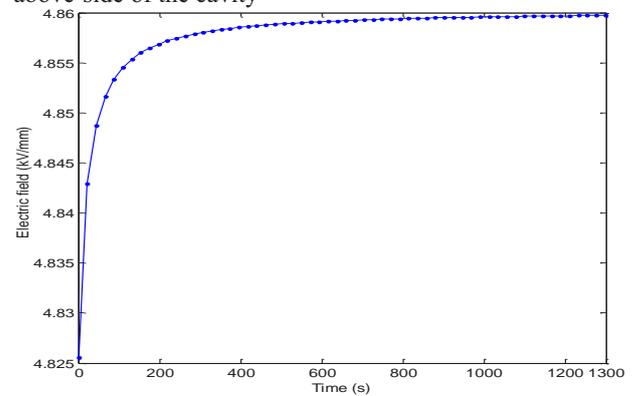


Fig.8. Variation of electric field according to the time in a cavity of 1  $\mu\text{m}$  radius

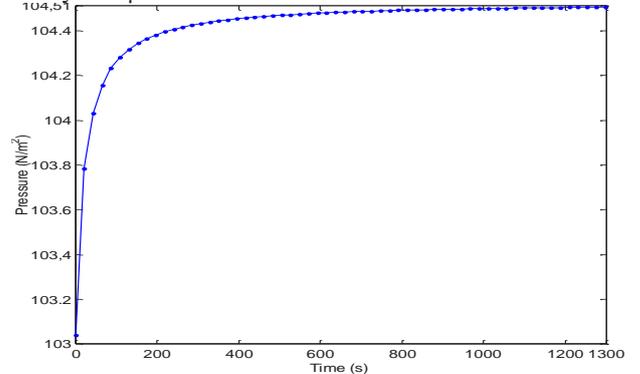


Fig. 9. Variation of pressure according to the time in a cavity of 1  $\mu\text{m}$  radius

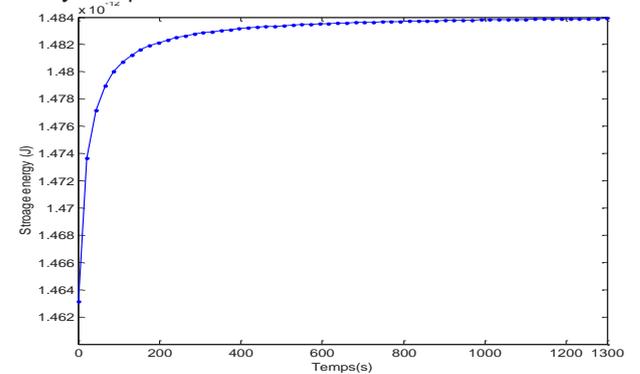


Fig.10. Temporal evolution of energy storage in a cavity of 1  $\mu\text{m}$  radius

Firstly, the temperature in the whole cavity is almost uniform and equal to the initial temperature. The temporal evolution of the temperature along the influence region represented in the figure 4, shows that, the heat around the cavity is quickly dissipated in the surrounding material more than at the center of the cavity, where the temperature reaches its maximum. Although, the applied external field is practically uniform, it is important to notice that the electric field inside the cavity exceeds the critical value of the disruptive electric field of air, causing the partial discharges. The cavity is submitted to a polarization causing, thus, the appearance of a local field contributing to the increase of the electric field inside the cavity.

After a certain time, a very fast increase of the temperature will take place around and inside the cavity. This effect is caused by the dielectric losses and the partial discharges (DP) which are established after a time in the order of nanoseconds [8], [19-20]. According to the figure 5, we can notice that between 0 and 70 (s) the temperature quickly increases in a linear manner. This effect could be interpreted by the growth of DP due to the increase of the electric field inside the cavity. In the interval 70-200 (s), the temperature variation follows the shape of an elbow, where the thermal phenomenon varies slowly. From 200 (s) the temperature is uniform, which can be interpreted by the thermal equilibrium in the cavity.

In what follows, we are going to see the influence of the cavity size on the temporal variation of temperature, of electric field, the pressure and the energy storage. For this purpose, we are going to fix the position of the cavity by varying its radius of 1  $\mu\text{m}$  to 10  $\mu\text{m}$ . The results obtained are presented in figures 11, 12, 13 and 14. They show, that the thermal gradient, the electric field, the pressure and the energy storage, are increasing with time and with volume.

In other words, the degree of the influence of a defect depends strongly on its size.

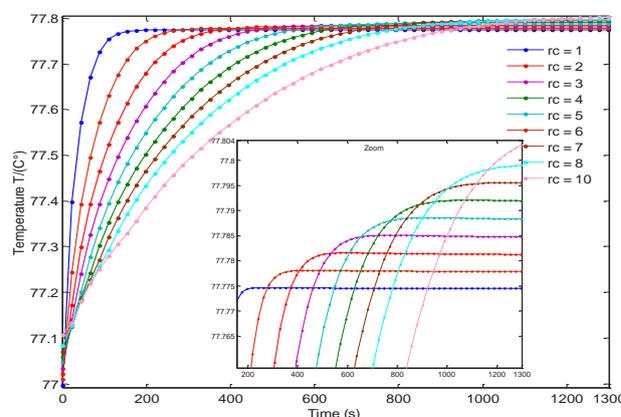


Fig.11 Variation with time of the thermal gradient in a cavity of variable radius (for 1  $\mu\text{m}$  to 10  $\mu\text{m}$ )

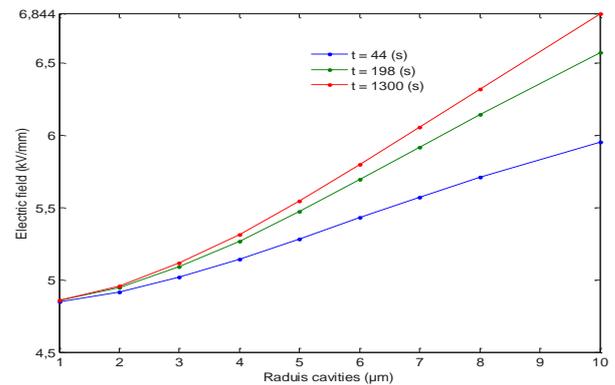


Fig.12. Variation according to the time of the electric field in a cavity (for radius of 1  $\mu\text{m}$  to 10  $\mu\text{m}$ )

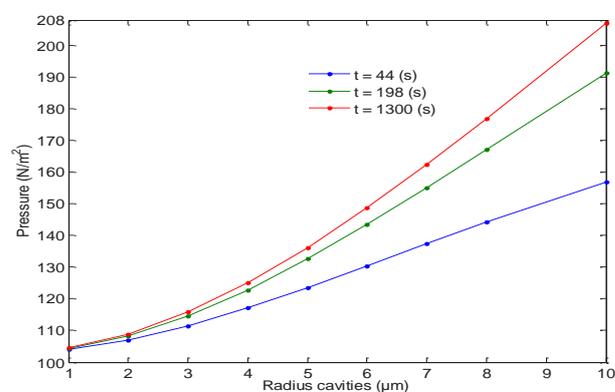


Fig.13. Variation according to the time of the pressure in a cavity (for radius of 1  $\mu\text{m}$  to 10  $\mu\text{m}$ )

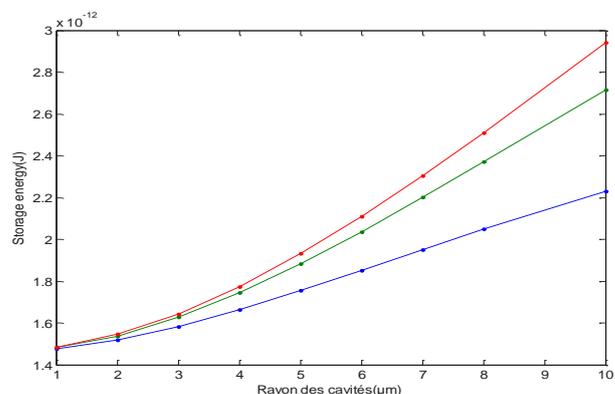


Fig.14 Temporal evolution of energy storage in a cavity (for radius of 1  $\mu\text{m}$  to 10  $\mu\text{m}$ )

In a general way, the presence of the defects within an insulation material influences the electric and thermal behavior of the dielectric, what degrades its characteristics and so limits its life time.

## 5. Conclusion

The main objective of the present work is to make a simulation study for the behavior of insulation XLPE of a unipolar cable for medium voltages containing a cavity of air.

A two dimensional geometry model of analysis with axial symmetry has been developed by the finite difference method in order to predict the non-stationary activity of the temperature, the electric field, the pressure and the energy storage in and around a spherical cavity within XLPE.

The results obtained from this study showed that the temperature increase of the heterogeneous dielectric causes that of the electric field and the pressure within a cavity of air and that they are strongly bound to the size of this one.

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