INTRODUCTION

The electrical tree propagation is simulated in the present paper. The material is considered to be polyethylene which is located between two plane electrodes. The electrical tree emanates from a random point of the upper electrode and propagates towards the opposite electrode.

THEORETICAL BACKGROUND

The electrical trees are one of the main reasons that lead the solid dielectrics to break down. The electrical tree behaviour has been studied at the inception and propagation stage. The evolution of this system has been simulated [1-7] for various cases. The point-plane electrode arrangement was used in these simulations. Moreover various values for space charge densities, air voids, insulating and conducting spherical particles are the parameters that were modified till now. In the present paper the case of plane-plane electrode arrangement is used, with and without the presence of space charges. Cellular Automata is the simulation method used in this paper [8-9]. According to Cellular Automata the whole system is divided into a number of cells, so every cell is correlated with a couple of coordinates in the x-y plane. Solving Laplace equation ($\sigma^2V=0$) for the dielectric, one potential value is corresponded to each cell. Of course, Poisson equation ($\sigma^2V=-\rho/\epsilon$) is solved in case of a uniform space charge density. The electrical field is calculated inside the solid dielectric and the rule for the tree propagation is the same for all the cells belonging to the solid insulating material.

SIMULATION RESULTS

The plane-plane electrode arrangement is divided into

Fig. 1 The arrangement shown the two plane electrodes and the discontinuity in the middle of the upper electrode. The insulating material is divided into 100x100 cells

Fig. 2 Magnification of the discontinuity region. The arrows show the five cells that may break down if $E>E_c$. 
100x100 cells (Fig. 1). Matlab and Partial Differential Equation Toolbox were used for this simulation. Setting the boundary conditions in Laplace equation, the program calculates the solution of the equation and corresponds one potential value to each cell of the insulating material. Moreover, a random variation of the dielectric constant is considered between the values 2.2-2.4, inserting the notion that the electrical tree will propagate to dielectrically “weaker” paths.

The electric field for very small distances is approximated with the aid of equation:

\[ E \rightarrow \varepsilon \frac{\Delta V}{\Delta l} \]  

(1)

where \( \varepsilon \) : dielectric constant of a cell produced by a random way,
\( \Delta V \) : potential difference between the two neighbouring cells,
\( \Delta l \) : distance between the centers of the cells

The discontinuity in the middle of the upper electrode is the point from where the electrical tree can emanate because the electric field at such regions is strongly enhanced. The criterion for the electrical tree propagation is as follows: If the electric field is greater than a critical value, then the tree moves towards the direction of the field (Fig 2).

So, for example, if the value of the electric field, calculated with the aid of eq. 1 is greater than a predefined critical value \( E_c \) then the electrical tree propagates towards these cells. Let us say that the critical value of the electrical field is an indicative value. In the simulations, the critical value of electrical field is taken as 50 kV/mm and a voltage of \(+250\) kV is applied at the upper electrode. In Fig. 3 the magnified region around the discontinuity is shown again with two out of five cells that have broken down. Laplace equation is solved again for the new structure and the program checks the electrical field towards the cells that exist in the neighbourhood of the tree cells (grey color). The dimensions of the sample is 10mm x 10mm so every cell has dimensions 0.1mm x 0.1 mm.

In Fig 4 is shown the initial step in tree propagation. The electrical field is strong enough around the discontinuity, so the dendrite can emanate and propagate with a lot of branches. In Fig. 5 there is a middle step in tree propagation where the electrical tree has now created a complicated formation of cells.

If a steady uniform space charge density is considered throughout the insulating material, then the Poisson equation instead of Laplace’s is solved. For \( \rho = +100 \, \text{Cb/m}^3 \) a uniform distribution of positive homocharges is present inside the sample, affecting the potential distribution. The applied voltage is \(+250\) kV and the dimensions of the sample is equal to 10mm x 10mm again. In Fig. 6 the electrical tree propagation for the positive value of space charge density is
shown. The field modification due to the presence of homocharges creates fewer branches in the propagation stage. The electrical tree stops after a short activity around the discontinuity region. The behaviour of homocharges in our simulation agrees with the experimental results of [11]. Generally speaking, the simulation results of our paper and especially these of Figs. 4 and 5 agree well with the experimental results of [12].

CONCLUSION

This paper presents the simulation of electrical tree propagation in solid insulation. The simulation results both without and with the presence of space charges agree with previously published experimental results. The novelty of the present paper is that it introduces the (even slight) variation of the dielectric constant of the insulation and points out its important influence on electrical tree propagation.

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