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A NEW METHOD FOR SIMULATION OF ELECTRICAL TREE GROWTH IN SOLID INSULATING USING CELLULAR AUTOMATA

Rahim Ildarabi[1] Javad Saddeh Habib[2] Rajabi Mashhadi[2] Saeed Torabi[3]

[1]Islamic Azad University unit Gorand, Iran [2]University of Ferdowsi, Iran
[3]YazdRegional Electric Company,Iran

ABSTRACT: One of the essential problems in solid dielectric structure is its failure while operating at normal voltage stress which is due to electrical treeing. It is well-known that this electrical tree grows progressively and damaging locally too. To analyze the electrical treeing in the laboratory being not cost effective, computer simulations are used. In this paper electrical tree has been simulated with Cellular Automata algorithm based on new rules. These rules have been resulted of physics sense of the problem and analyzing of the electrical equations. These new rules also have helped to reduce computation time and doing simulation in a simple way.
Keywords: Electrical Tree, Breakdown Solid Dielectric, Cellular Automata, Dielectric Constant.

I. INTRODUCTION

Surveying breakdown in the dielectric is one of essential problems in studying properties of the dielectrics. Breakdown of the solid dialectics is one of important index for determining the limitations of insulation in cables, capacitors, electrical machines, and so on [1]. Procedure of creating and growth of electric tree that at last is caused breakdown in solid dielectric can be studied in form practical in the laboratory. It is expensive creating and consumes a lot of time. It is also require to complex equipments for distinguishing of correcting results of experiments. Because of simulation methods are usually used for studying creating and growth electrical tree [2-10]. Simulation methods have been based on distinguishing causes of creating and expansive of breakdown. Maine reason of breakdown in solid dielectrics is to take under high intensity field electric that solid dielectric can't sustain it and thus electrical tree is created and with increasing growth this electrical tree, breakdown occur in dielectric [2]. Breakdown in dielectrics is dependent to several parameters, such as distribution of dielectric coefficient, thickness of dielectric, intensity and distribute of electric field. Therefore breakdown in dielectric can investigate of different aspects. Space charges can change form of the crystal of the solid dielectric, that it is caused breakdown in dialectics [4]. Some of theories do analysis breakdown in dielectric with avalanche growth [4]. Some others studying breakdown in dielectric respect to affect of electrical potential. Electromagnetism theory is also used for studying breakdown in solid dielectric [5]. It is possible to be used partial discharge [6]. But most of these manners can't solve all of problems of breakdown in dielectrics. Klein use of hole traps and the ionizing electrons, and their respective distributions models for studying breakdown in dielectric [7]. His method is able to respect to affects such as distribution of dielectric coefficient, thickness of dielectric, intensity and distribute of electric field. Cellular automate (CA) is already used for simulation electrical tree. Parallel processing decreases analyzing time [8, 9 and 10]. Cellular automate is used in understanding of how growth electrical tree. It is able to participate effective parameters in analyzing electrical tree. CA distinguishes state of any point based on state of its adjacent points. The rules that are used for CA base on electromagnetism theories and solving those is complex that it is caused increase time analyzing electrical tree.

In this paper has been proposed new rules for CA that with omitting additional accounts, analysis electrical tree in very simple state. This manner also reduces time simulation of tree dielectric

II. ELECTRICAL TREEING

Usually two kinds of defects are found to be present in the body of the cable insulation; viz. conducting and dielectric. The presence of these defects in the insulation, even under normal operating voltage stress, gives rise to non-uniform stress distribution causing divergent electric field, thus enhancing the field around the defect. Localized disruptive partial pre-breakdown would occur in this area. The geometrical pattern of these pre-breakdown channels resembles the branches of a tree. Hence, the name treeing is given to this deleterious process and since such an occurrence is purely due to electrical stress, the phenomenon is termed as Electrical Treeing [2].

III. CELLULAR AUTOMATA

Cellular automata (CA) are models of physical systems where space and time are discrete and interactions are only local. CA, first introduced by von Neumann, has been extensively used as models for complex systems. CA has also been applied to several physical and technological problems, where local interactions are involved. In spite of their structural simplicity, CA exhibit complex dynamical behavior and can describe many physical systems and processes [11]. A CA consists of a regular uniform n-dimensional lattice (or array). At each site of the lattice (cell) a physical quantity takes values. This physical quantity is the global state of the CA, and the value of this quantity at each cell is the local state of this cell. Each cell is restricted to local neighborhood interaction only, and as a result it is incapable of immediate global communication. The state at each cell is updated simultaneously at discrete time steps, based on the states in its neighborhood at the preceding time step. The algorithm used to compute the next cell state is referred to as the CA *local rule*. Usually the same local rule is applied to all cells of the CA. The dimension of space CA can be infinite. But it is considered in practice one, two or maximum three dimensions. Two dimensions lattice CA can be considered in two different forms that are shown in figure 1.

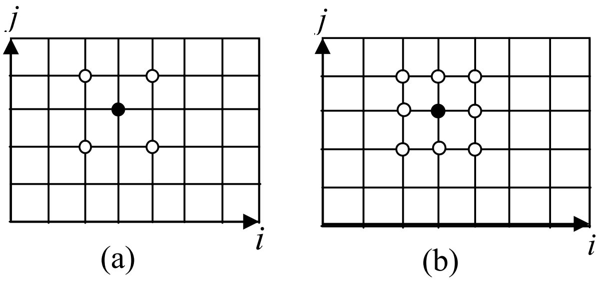


Figure 1: Two different forms two dimension lattice CA

● c_{ij} (Itself cell) ○ Neighborhoods of the c_{ij}

If $c_t(i,j)$ shows state of cell in t time and (i,j) place, then for figure 3-b can write for $c_t(i,j)$:

$$c_{t+1}(i,j) = F[c_t(i-1,j-1), c_t(i-1,j), c_t(i-1,j+1), c_t(i,j-1), c_t(i,j), c_t(i,j+1), c_t(i+1,j-1), c_t(i+1,j), c_t(i+1,j+1)] \quad (1)$$

Function **F** is determined by rule of CA. not that time is done distinct and $t+1$ is shown one step ahead of t.

IV. SIMULATION OF ELECTRICAL TREE GROWTH USING CA

The electrical tree become growth the path where the insulating material is locally weakest, i.e. the electrical tree will progress taking into account the local dielectric strength. The problem of electrical tree growth will be surveyed in two dimensions. Figure 2 shows the point/plane electrode arrangement. The solid dielectric to be placed between the point/plane electrodes is divided into a matrix of identical square cells, with side length a, and it is represented by a CA, each cell of the dielectric considered as a CA cell. Amount of a determines accurate of simulation. Such that if a is small, then accurate of simulation will increase But time of simulation will also increase.

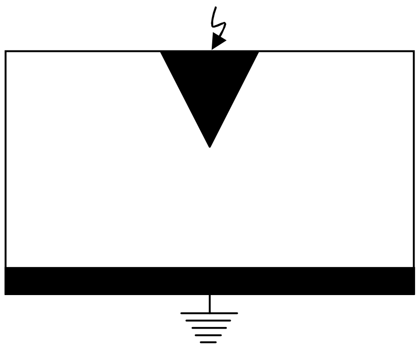


Figure2: across section of solid dielectric

The algorithm has been used to simulate solid dielectric breakdown with a point/plane electrode arrangement. The voltage applied was taken to be equal to 20 kV and the distance between the tip of the point electrode and the plane electrode was taken to be equal to 5 mm. The (non-homogeneous) dielectric constant varied randomly and continuously between 2.10 and 2.25.

If cell (i,j) is jointed to tree eclectic, then $c_t(i,j)=1$ and if (i,j) isn't belong to electrical tree, then $c_t(i,j)=0$. Below notes are considered in investigation electrical tree:

1- Electrical tree is created when closest cell to tip of point electrode is broken down. This condition exists when field electric intensity $E(i,j)$ is larger than maximum field electric intensity E_{Max} that dielectric can tolerate. Field electric intensity has direct relation with dielectric constant and voltage of cell.

$$E_t(i,j) = \varepsilon(i,j)\frac{V_t(i,j)}{a(i,j)} \quad (2)$$

2- Voltage all of cells of electrical tree is equal with point electrode. Thus voltage of neighborhoods cell of electrical tree is more than infinitely other cells. Therefore it is possible breakdown only for neighborhoods cells of electrical tree and also it is possible growth electrical tree from end cells of branches.

3- If end cells of electrical tree against plate electrode are assumed a point electric charge (that it is function of voltage of electrical tree), then one can consider that all of adjacent cells of this cell have same voltage [12]. Thus field electric intensity of adjacent cells of end of electrical tree can consider only according to dielectric constant. Therefore to investigation how to create and growth of electrical tree in solid dielectrics is presented below algorithm:

I: Survey that: if $\varepsilon_{a,b}\, V_{P-1} \geq E_{\max}$? $i = a$, $j = b$ are coordinates of closest cell to tip of point electrode, and V_{P-1} is voltage of these cells than it isn't equal with electrical tree voltage but it is identical for all of these cells. If answer is negative, then electrical tree don't happen and simulation is finished. But if answer is positive then go to **II**. Because of voltage in any cell of electrical tree is identical, thus it can replace condition $\varepsilon_{a,b} \geq \left(\frac{E_{\max}}{V_{P-1}}\right) = \varepsilon_{\max}$ with above condition ($\varepsilon_{ab}\, V_{P-1} \geq E_{\max}$).

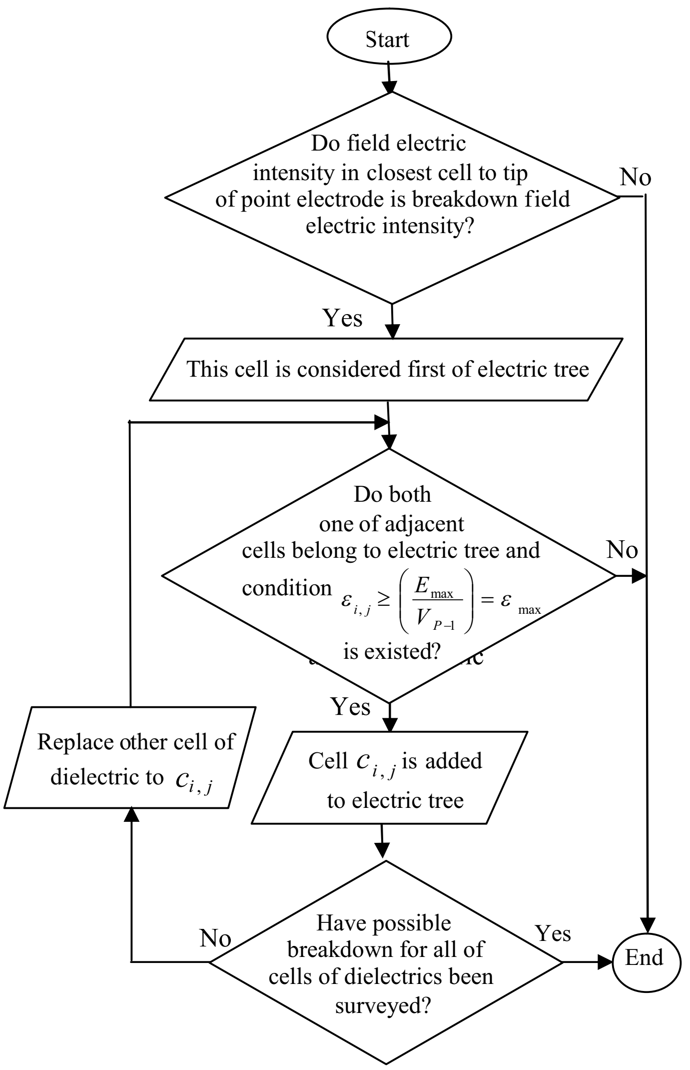


Figure3: analyzing electric tree Algorithm for solid dielectric

II: Generally when $c(i, j)$ (under studying cell) can be jointed to electrical tree that both at least one of adjacent cells belongs to electrical tree and condition $\varepsilon_{i,j} \geq \left(\frac{E_{\max}}{V_{P-1}}\right) = \varepsilon_{\max}$ is existed.

III: must is checked **II** for all of cells.

Figure 3 is shown electrical tree analyzing in solid dielectrics.

V. SIMULATION RESULTS

In this section results of simulation are presented. These simulations show different states that may happen in survey of electrical tree in solid dielectric. Simulation results follow in below figures. Vertical and horizontal axis in these figures show number of cells that have been used in simulation.

Figure 4 show state that flied electric intensity in nearest point to tip electrode plate is less than of electric intensity breakdown dielectric; namely: $\varepsilon_{a,b}\, V_{P-1} \geq E_{\max}$, In other words $\varepsilon_{a,b} \geq \varepsilon_{\max}$ *that* $\left(\varepsilon_{\max} \approx \frac{E_{\max}}{V_{P-1}}\right)$. Therefore it is observed that no have happened any breakdown in solid dielectric.

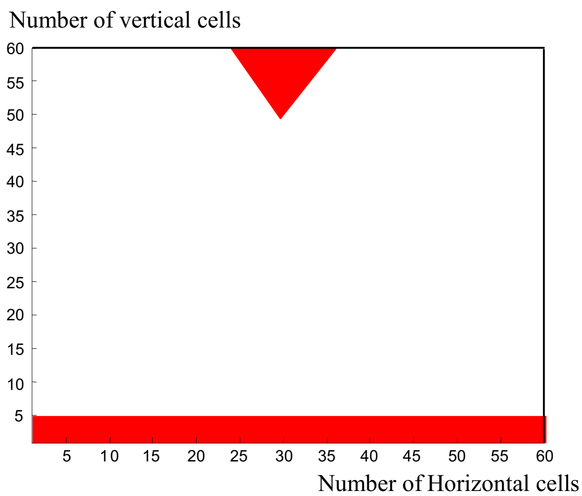


Figure 4: No happens any breakdown in solid dielectric $(\varepsilon_{\max} = 2.26)$

In case breakdown happen in closest cell to tip point electrode, then it can continue into dielectric and either finish into dialectic or continue till plate electrode. Figure 5-10 show breakdown solid dielectric and creating electrical tree in it, for deferent $\varepsilon_{\max}$. In spite of the fact that $\varepsilon_{\max}$ is affect to create and growth electrical tree, but it is dependent to consider random dielectric constant. So that in figures 6,7 in spite of same $\varepsilon_{\max}$, but configure and amount of electrical tree growth is different.

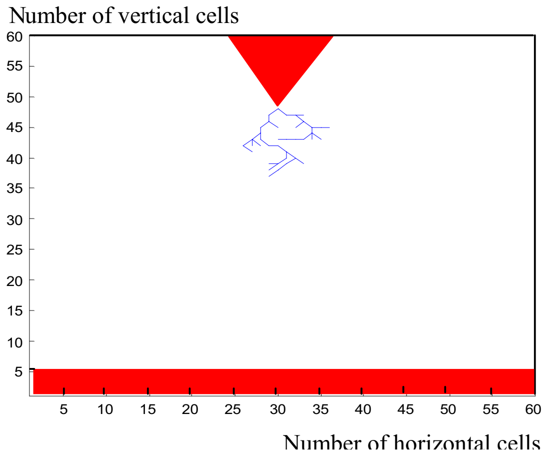


Figure5: electric tree be created and growth into dielectric and is finished within it $(\varepsilon_{\max} = 2.190)$

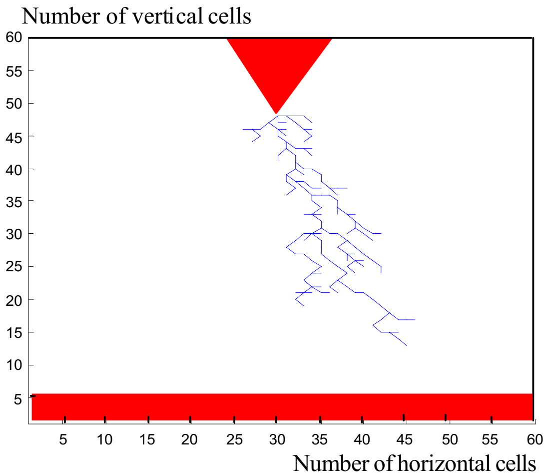


Figure 6: electric tree be created and growth into dielectric and is finished within it $(\varepsilon_{\max} = 2.184)$

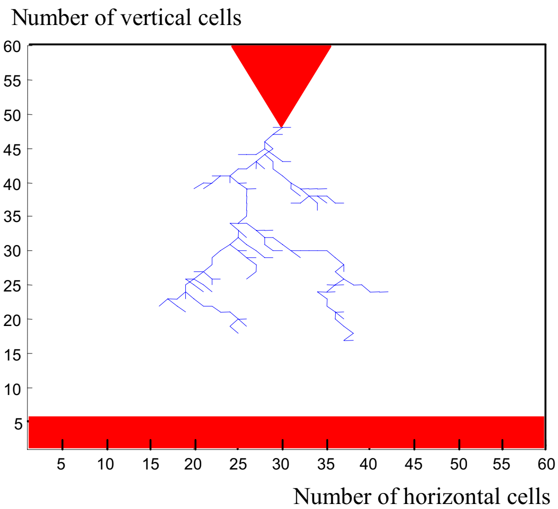


Figure 7: electric tree be created and growth into dielectric and is finished within it $(\varepsilon_{\max} = 2.184)$

Figure 8 is shown the state that voltage between two electrodes is infinitely more then breakdown voltage. Thus electrical tree has been finished to plate electrode.

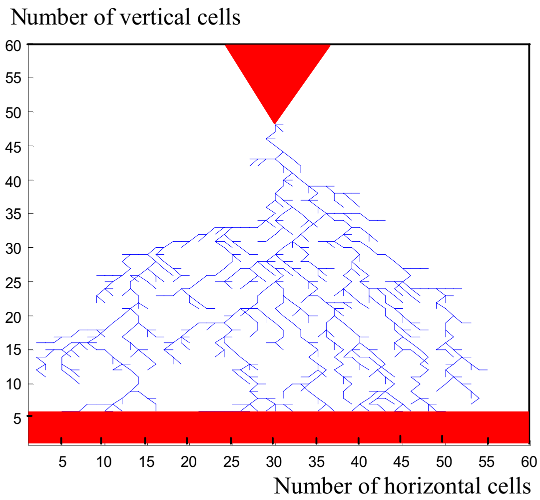


Figure 8: electric tree be created and growth into dielectric and continue until plate electrode $(\varepsilon_{\max} = 2.170)$

Number of cells is considered $60 \times 60 = 3600$ in above figures. If number of cells increases, then accuracy simulation will also increase. Instead of time simulation will also increase. Figures 9, 10 show simulation electrical tree for $200 \times 200 = 40000$ cells.

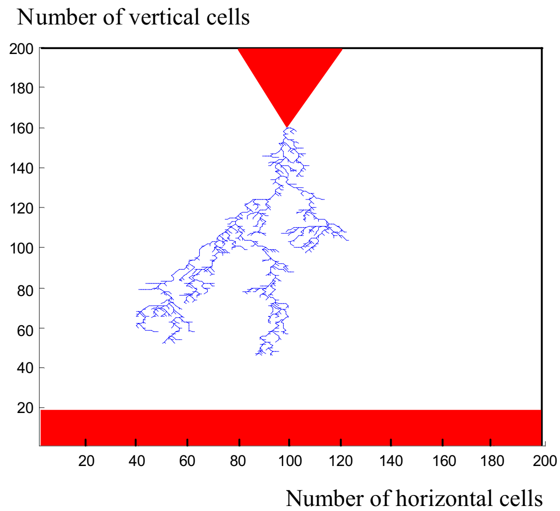
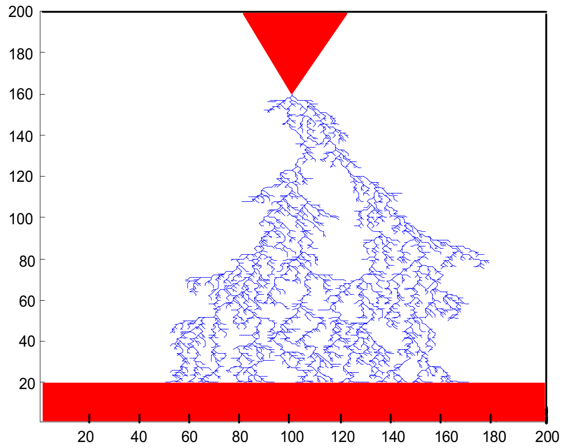


Figure 9: electric tree be created and growth into dielectric and is finished within it $(\varepsilon_{\max} = 2.184)$

Number of vertical cells



Number of horizontal cells

Figure 10: electric tree be created and growth into dielectric and continue until plate electrode $(\varepsilon_{\max} = 2.172)$

VI. CONCLUSION

Generating electrical tree in laboratory consumes most time and it is expensive and also require to accuracy instruments. Electrical tree can be analyzed by simulation method such as CA. In this paper is presented electrical tree simulation by Cellular Automata (CA) and using simple rules. Thus simulation is done both simpler and faster then of other rules that are presented till now. This method is presented in form of an algorithm. Results of simulation show that if number of cells increases, than accurate of simulation will increase, but instead time of simulation also increases.

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