MODELLING OF BREAKDOWN AND PREBREAKDOWN PHENOMENA IN LIQUID DIELECTRICS

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Abstract: A computer model was developed for the simulation of electrical breakdown and prebreakdown phenomena in liquid dielectrics, for short gap distances up to 20mm length. For the results given in this paper a sphere to sphere electrode system was considered and a dc positive voltage was applied. The spheres have diameter of 25mm. The simulation is taking place in a two dimensional rectangular area. The electrodes and the space between them is simulated using a two dimensional lattice of points. The computer model used for the simulation is a combination of two stochastic models. The first one based on Biller's criterion is used for the simulation of propagation of the filamentary structure into the electrode gap. A second stochastic criterion named the Field Fluctuation Criterion (FFC) is used in order to take into account the gradual degradation of the dielectric and the presence of gas bubbles, moisture and solid impurities. A large number of results were acquired with the help of the computer model, concerning mainly the breakdown voltage in relation to the gap distance for pure liquid dielectric and for dielectric with gas bubbles and solid impurities.

1 INTRODUCTION

Electrical breakdown in liquid dielectrics is a complicated physical phenomenon and the mechanisms that lead to the breakdown of liquids are not yet fully understood. It seems that two main breakdown mechanisms exceeds in liquids, namely, bubble and ionization one. In the bubble model the main source of charge carriers creating the plasma discharge channel are the processes inside of gas bubbles, while in the second model, the plasma in the initial stages of channel development is created as a result of field ionization in the liquid [1-5]. Moreover the discharge process depends on a number of other factors including the curvature radius of the electrode initiating the discharge, discharge polarity, viscosity of the liquid, interelectrode gap length and hydrostatic pressure.

Our purpose is the development of computer model for the simulation of prebreakdown phenomena in liquid dielectrics, that it can take into account the two fundamental mechanisms of electrical breakdown. In order to keep the complexity of our model in low levels, at least in this initial stage of development, we consider the ionization mechanism to be the main one for the breakdown of liquid dielectrics while the bubble mechanism was taking into account as a decrease of the electric field necessary for the initiation of field ionization. This can be justified by taking into account that the dielectric strength of gas is much less than that of liquid and the occurrence of breakdown in a gas bubble may lead to liquid breakdown.

Based on the above assumptions we used two different stochastic criteria for the simulation of prebreakdown phenomena in liquids. The first one named Biller's criterion is used for the simulation of propagation of the filamentary structure into the electrode gap [6]. The second one named the Filed Fluctuation Criterion was used in order to take into account the gradual degradation of dielectric due to the presence of gas bubbles, moisture and solid impurities [7-8].

2 DESCRIPTION OF THE MODEL

The simulation is taking place in a two dimensional lattice of points. The dimension of the lattice changes in accordance to the distance between anode and cathode and took values from 100x100 to 400x400. The distance between two neighbouring points of the lattice also varied and took values between 0.015cm and 0.075cm following the increase of the gap space. Ideally this distance should be kept constant but in this case the lattice dimension will be enormously big and the simulations will be very slow.

Due to the length scale it was impossible to simulate the electrodes exactly. Taking into account that only a small area of the electrodes was simulated and the electric field between them was practically uniform due to the small distance between the spheres, the electrodes during the simulations were represented as two planes.

The electric field in the electrode gap was calculated at every time step by solving the Laplace equation:

$$\frac{\partial^2 \varphi}{\partial x} + \frac{\partial^2 \varphi}{\partial y} = 0 \quad (1)$$

with boundary conditions on the electrodes and the filamentary structure. The filamentary structure propagates in a stepwise manner from the anode to the cathode. At every time step a new bond is added to the structure according to the Biller's criterion and the procedure is repeated until it reaches to the cathode. In this case it is considered that we have electrical breakdown.

2.1 Filamentary structure propagation

For the simulation of the propagation of the filamentary structure between anode and cathode Biller's criterion was used. In Biller's model the creation of a new bond is considered to be a Poisson process. The bond is a part of the structure that connects two neighbouring points. With a new iteration of the computer program the necessary time for the creation of a new bond for every possible propagation direction of the filamentary structure is calculated by using the formula:

$$t_i = -\frac{\ln(\xi)}{r(E_i)} \quad (2)$$

Here ξ is a random number uniformly distributed in the interval from 0 to 1, and $r(E_i)$ is called "growth rate function":

$$r(E_i) \propto \left(\frac{E_i}{E_0}\right)^n \quad (3)$$

Here E_i is the mean electric field between two points of the lattice, n is a parameter of the model which influences the branching of the created pattern and in our simulation was equal 2. E_0 is the mean electric field between the anode and the cathode:

$$E_0 = \frac{U}{d} \quad (4)$$

Here U is the applied voltage and d is the gap length. In each growth step only the bond with the minimum growth time is added to the conductive structure, because it is assumed that its growth suppresses the evolution of the others. The growth of a new bond changes the distribution of the electric field and thus a new iteration begun with a new calculation of the electric field. The growth time of the new bond is also the time step of the iteration. The conductive structure may propagate to only those directions where the mean electric field exceeds a threshold value E_{th}. Thus, if the electric field drops below this critical value the propagation of the filamentary structure is intercepted and the breakdown is not occurred.

As the filamentary structure propagates toward cathode, points of the lattice are added to it. The potential of these points is simply calculated by the following equation:

$$V_n = V_{n-1} - E_S \cdot d \quad (5)$$

Where V_n is the potential of the new added point, V_{n-1} is the potential of the point from where the new bond arises and E_s is the voltage drop along the conductive channels of the structure.

2.2 Degradation of dielectric liquid

As it was already mentioned in our simplified model the existence of gas bubbles inside liquid are taking into account as a decrease of the electric field necessary for the initiation of field ionization. For this we used the Field Fluctuation Criterion. According to this criterion the threshold value of electric field E_{th} is not constant but varies according to the formula:

$$E_{th} = E_* - \delta \quad (6)$$

Where E_* is the necessary electric field for the initiation of ionization in an ideal case, without the presence of any impurities. The variable δ specifies the random fluctuations of the field caused by many reasons, in our case the presence of gas bubbles, moisture and solid residues inside liquid. Variable δ is random with an exponential probability density function and it is calculated from the equation:

$$\delta = -g\ln(\xi) \quad (7)$$

where ξ is a random number uniformly distributed in the interval from 0 to 1 and g is the characteristic width (scale) of the distribution of the random variable. Larger concentrations of gas bubbles, moisture etc is taking into account with greater values of the parameter g.

3 SIMULATIONS - RESULTS

A variety of simulations were realized by using our model in order to investigate if the results are consistent with some basic experimental observations. During the simulations we used arbitrary values for the parameters of the model with an exemption on the gap length. Thus a comparison with experimental results can be made only qualitatively. We focus mainly on the derivation of breakdown voltage versus gap length and the change of breakdown voltage with the parameter g.

The model also created patterns that are very common in the case of breakdown in liquid dielectrics. A characteristic pattern is illustrated in Figure 1.

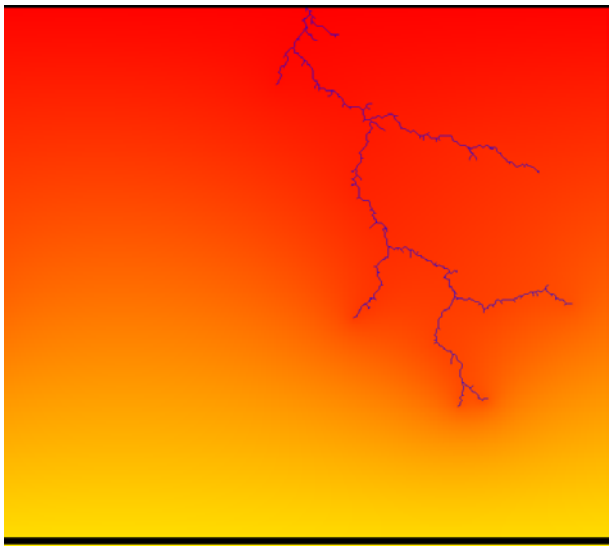

Figure 1: A pattern of the filamentary structure created by the model.

In Figures 2, 3 and 4 breakdown voltage versus gap length for different values of g is illustrated. In all cases breakdown voltage increases with the increase of the gap length as it was expected.

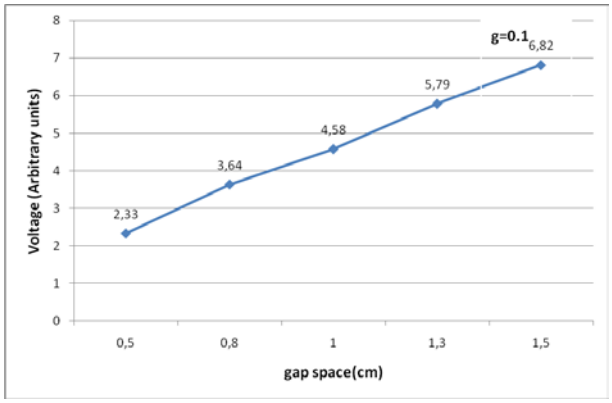

Figure 2: Breakdown voltage versus gap space for g=0.1

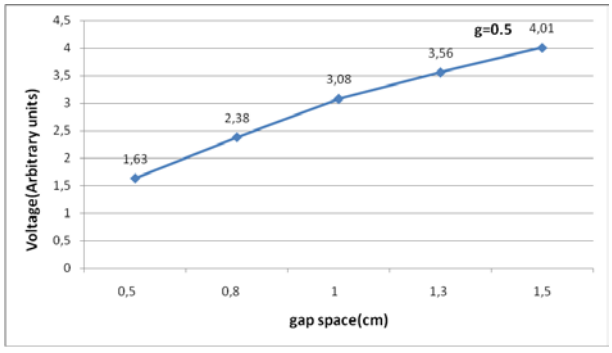

Figure 3: Breakdown voltage versus gap space for g=0.5

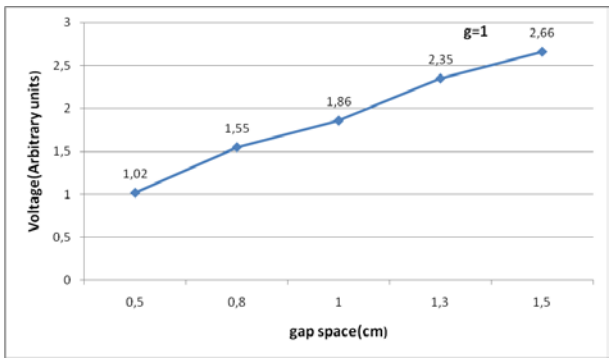

Figure 4: Breakdown voltage versus gap space for g=1

One may notice that breakdown voltage decreases as the parameter g increase. This is in accordance with the experimental results that show a decrease of breakdown strength of the liquid with the increased concentration of moisture and gas bubbles. This decrease which was observed in our simulations is illustrated better in Figures 5 and 6. We should notice that above a certain value of g (usually 0.8) breakdown voltage does not change noticeably.

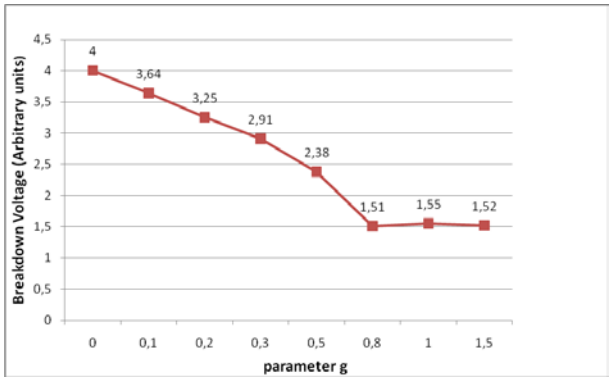

Figure 5: Breakdown voltage versus parameter g for 0.8cm gap space

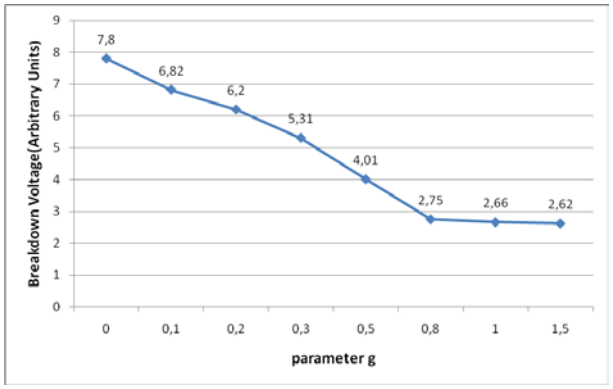

Figure 6: Breakdown voltage versus parameter g for 1.5cm gap space

Although the majority of the simulations were realized for the case of uniform electric field, it is interesting to see the change at the values of breakdown voltage in the case of non uniform fields, by replacing the plane electrode at the anode with a needle. The results are shown in

Figure 7. The breakdown voltage in the case of non uniform gaps is reduced in comparison with uniform one.

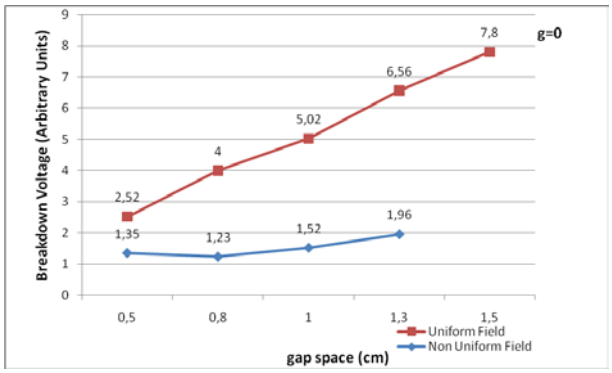

Figure 7: Breakdown voltage versus gap space for uniform and non uniform field.

4 CONCLUSION

In this paper a stochastic model was used for the simulation of the electrical breakdown in liquid dielectrics. The purpose of the simulations was to test whether the model is capable to give results in agreement with the experimental observations. The comparison we made was only qualitatively because we used arbitrary units.

From the results of the simulation we can see that there is an agreement between experiments and simulations. Breakdown voltage is linearly depended on gap length as it is observed in many experimental observations. On the other hand with the increase of the parameter g the breakdown voltage is reduced. This is also observed in experiments were the increase of the moisture and gas bubbles inside liquid lead to the decrease of breakdown strength. The parameter g may be considered as a factor that represents the aging of the dielectric.

In order to purchase quantitative results many things should be made. At first a calculation of the threshold electric field E_{th} is necessary. This threshold value is different for each liquid dielectric and it depends on its chemical structure. Another parameter that should be determined is the voltage drop E_s along the channels of the filamentary structure. These two parameters greatly affect the breakdown voltage.

Once the above mentioned parameters are determined it is possible to find a relation between the parameter g and the degradation of the dielectrics. However it is very difficult to establish theoretically a correlation between g and the presence of gas bubbles, moisture and solid impurities.

5 REFERENCES

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