Analysis of Initiation and Growth of Plasma Channels Within Non-Mixed Dielectric Liquids

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Abstract

Pre-breakdown phenomenon was investigated within the two, non-mixed dielectric liquids; transformation oil and cresol. Finite element technique was used to follow the initiation and growth of plasma channels (streamer discharge) within pin-plane configuration. That was done for different spacing between the pin-electrode and the liquid-liquid interface. Streamer growth model assumed that, the streamer initiation occurs at the region of the highest value of electric field. Our study shows that the streamer initiates at the tip of the pin and growths toward the other electrode. The study shows, too, that the streamer path controlled by the difference of permittivity of the two liquids and spacing distance of the liquid-liquid interface from the tip of the pin electrode. This type of studies is very important to give a good approximation for the high voltage equipments designing.

Keywords

Streamer discharge Plasma channels, Dielectric liquids.

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تحليل نشوء ونمو القنوات البلازمية داخل السوائل العازلة التي لاتختلط

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الخلاصة

تم بحث ظاهرة الانهيار الكهربائي الابتدائي في سائلين عازلين لايختلطان هما زيت المحولات والكر يسول. استُخدمت تقنية العناصر المحددة لتتبع نشوء ونمو القنوات البلازمية (تفريغ التدفق) في ترتيب إبرة- مستوي ، وقد أُنجز ذلك لمسافات مختلفة بين رأس الإبرة والسطح الفاصل بين السائلين. يفترض نموذج نمو التدفق إن النمو يحدث في المنطقة ذات القيمة الأعلى للمجال الكهربائي.

بينت دراستنا إن التدفق ينشأ عند رأس الإبرة ثم ينمو باتجاه القطب الآخر، كما بينت الدراسة أيضا إن مسار التدفق محكوم بالفرق بين السماحية الكهربائية لكل من السائل وكذلك المسافة التي تفصل رأس الإبرة عن السطح الفاصل بين السائلين. هذا النوع من الدراسات مهم كثيراً لإعطاء تصور تقريبي وجيد لتصاميم منظومات الجهد العالي.

Introduction

The increased use of electronic devices in our modern society implies a higher demand on the quality of the electric power supply. In many practical situations, it is found that the quality of the electric power is determined by the performance of the insulating elements used in the power generation and transmission utilities. The traditional materials used for outdoor insulation have until recently been glass and porcelain, polymeric materials, and gases. A lot of damage is caused by the electrical breakdown over the insulators which can affect their insulating properties.

In recent years, therefore, there has been a trend to replace these insulators with dielectric liquids [1]. Most liquids have characteristics more similar to solids than gases, such as high permittivity, high densities, and weak molecular order. Also, the ability to conform to complex geometries ,as for gases, while maintaining the "flowing quality" of a gas. Research on conduction in liquid dielectrics, especially transformer oil, began many years ago because of its importance for applications as an insulator. Others [2-7] have conducted studies of the effects of age, contamination, and gas content on the overall quality of the oil, affecting the conduction and breakdown mechanisms. The of researches in the area of liquid dielectrics increased dramatically in the last 50 years with increased interest in compact pulsed power and switching systems. The desire for compact pulsed power systems drives research to develop a model that is capable of describing the basic processes of liquid breakdown, similar to the promotion of the model for gaseous breakdown almost a century ago.

Several models of liquid breakdown have been proposed over the years, commonalities between many of them include the presence of an electron avalanche and bubble formation. These avalanches are observed experimentally as current pulses or partial discharges (PD) and precede the formation of a gas bubble or low density region as verified using optical diagnostics. Most of the energy of the partial discharge is used in the vaporization of the liquid forming a small bubble [8]. The main aspect of the bubble model is that a vapor or low density region forms in front of the needle and leads to a breakdown that develops in the gas phase. This is the base of this work. Here, the streamer growth model [9] was modified and simulated to show the behavior of the plasma channels (streamer discharge) within non-mixed dielectric liquids.

The Modeling

Many facts about the per-breakdown mechanisms for liquids insulating are still waiting for adequate theoretical explanation. This work is an attempt to assemble some facts about liquid pre-breakdown and build an improved model for streamer propagation. The model uses Garton and Krasuck [10] approach of bubble discharge.

The model assumed that, a weak ionized spherical gas bubble is suggested to forming the body of the liquid. The first streamer (plasma) channels start from the tip of the pin and extend to the region with the highest electric field. These channels are not perfect conductors (i.e. they has resistance). The streamer channels continue to grow, anywhere in the dielectric liquid, until the value of electric field at the tip of streamer becomes greater than that at the tip of the pin for starting of the streamer. For more details, the author give a full description of the model[11].

The Analysis

The streamer growth model was simulated to obtain information not readily accessible to physical experiment; such as the voltage and electric field within the pin-plane configuration. Then, the site of the initiation of the steamer was indicated and follows it is growth. That was done using finite element technique to solve

Laplace's equation within the configuration.

Many practical problems in science and engineering are either extremely difficult or impossible to solve by conventional analytical methods, the finite element method is a numerical procedure for solving this type of problems. This is because the method basically relies on solving a large set of algebraic equations and entails considerable manipulation as the case with the finite difference procedure.

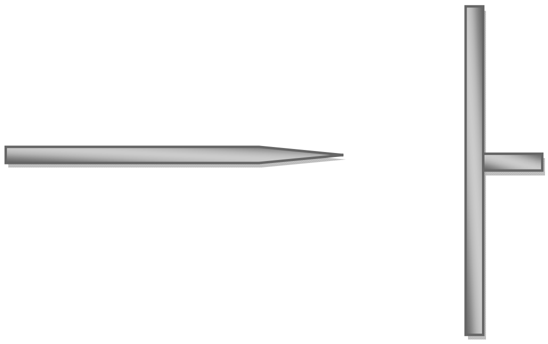
The fundamental concept of the finite element method is that any region is made up of element; therefore, the general behavior of a system can be determined by considering the behavior of its component (subsystem). The finite element analysis of any problem involves basically four steps [12]:

1. Discretizing the solution region into finite number of subregions or elements.
2. Deriving governing equations for typical elements.
3. Assembling of all elements in the solution region.
4. Solving the system of equations that obtained.

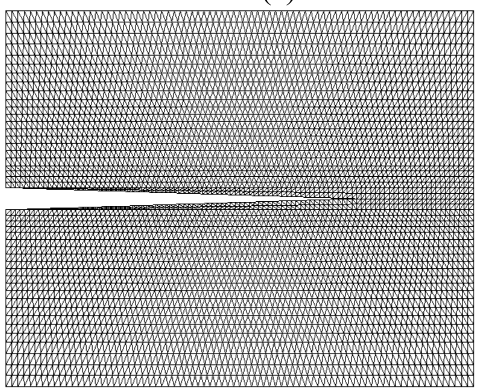
The simulation was implemented using a FORTRAN program. We wrote the program to follow the streamer (plasma channels) path within the configuration. The program modifies the boundary conditions for each step (iteration) of the streamer growth.

As has been shown previously, the finite element method required a grid to discrete the region for the solution. A linear triangular element were used for the problem in this case, to discrete the region between the electrodes. The region of interest for pin-plane Configuration is that which surrounds the pin tip. This is because a high electric field is expected in this region. Therefore, the elements in the grid were not made with the same size. This is important in saving the time in running the program. The elements close to the pin tip were made very small and those faraway are larger. Using a large number of elements yields more accurate results but takes more time for the finite element calculation.

The grid, which we designed, includes many mesh regions to be flexible to study many liquids in same time. The radius of the pin is 0.5 mm, and the length of the pin is (15)mm ,the distance between the pin to the plane is 5 mm, in this grid the number of elements is (6722) and the number of nodes is (3509), as in figure (1).



(a)



(b)

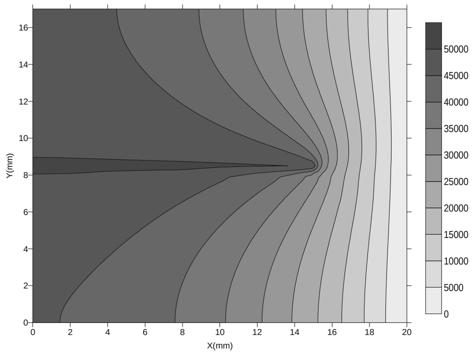
Figure (1): The Pin- plane configuration, (a) cross section for the configuration, (b) the grid within the configuration.

Results and Discussion

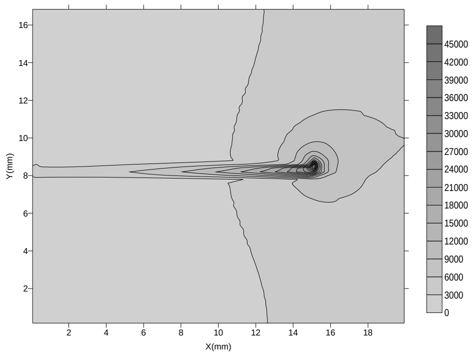
In this section we present the results of the simulation to show the behavior of the streamer growth within non-mixed dielectric liquids such as transformer oil and cresol. The output of our simulation was presented as con plots to show the voltage and electric field distribution within the configuration filled with the two liquids also the path of the streamer was followed and presented for different distance between the pin and liquid-liquid interface.

1- Voltage and Electric Field Distributions

The placement of the two non-mixed liquid interface depends on the application. The interface is used either to encourage or discourage the breakdown to happen. Therefore it is important to find this weak region and decide what type of liquids, and spacing is needed for the interface. Under the conditions of, 50kV on the pin, 0 kV on the plane, and 1.0 atm pressure, the configuration filled by a transformer Oil and Cresol liquid with relative permittivities of 2.3 and 10.6 respectivly. The solution, over the region between the electrodes, shows the voltage and the electric field (magnitudes and directional) distributions as in figure (2). Figure (2) is a contour plots show the voltage and electric field value distributions and the direction of electric field respectively. Figure (2a) shows the effect of the two liquids interface, which is parallel to the pin electrode, on the distribution of the voltage within the configuration. This effect appears clearly at the tip of the pin where the placement of the second dielectric liquid which has highest mass density. It appears as decreasing in the values of the voltage within the region of the second liquid here in the region between (0 and 8 mm) on the y- axis. So that the values of electric field decreased too as shown in figure (2b). Also here, the effect of the two dielectric liquids appears as increasing of the angle of the electric field direction with x-axis. That was shown in the directional distribution of the electric field in figure (2c).



(a)



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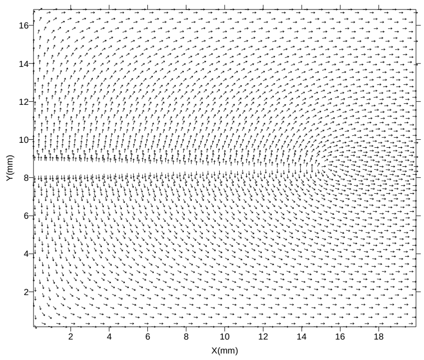

(c)

Figure (2): The potential and electric field distributions within the pin-plane configuration (a) potential distribution, (b) electric field distribution, and (c) directional distribution of the electric field.

2- The Streamer Growth

The effect of interface of the two liquids on the streamer growth was tested within the configuration under the same previous conditions. Figure (3) shows the complete configuration with streamer growth along the interface, and figure (4) shows the development of the streamer growth within the enlargement of the region between the electrodes. Here, it appears clearly, the deflection of the the streamer growth toward and along the liquid-liquid interface. That is because of the high permittivity of the second liquid which becomes the site of the highest values of the electric field .

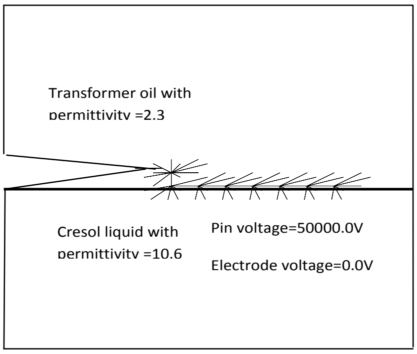

Figure (3): the complete configuration with the streamer growth along the liquid-liquid interface.

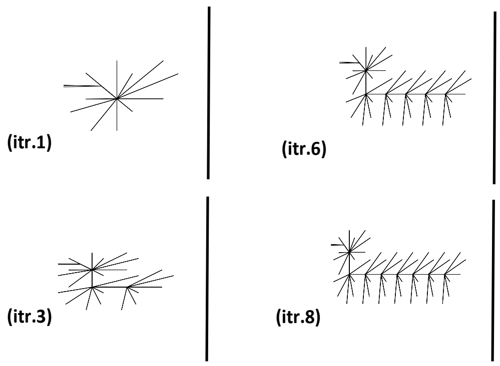

Figure (4): The development of the streamer growth for iterations 1,3,6,8 in transformer oil with Cresol liquid.

Figures (5), (6), are an enlargement of the region between the pin and the plane electrodes. The first one shows contour plots for the voltage distribution according to the streamer growth. It appears clearly the deflection and moving the region with the highest values of the potential. In the same way, the second shows the movement of the region of the highest values of the electric field for the same iterations. For this case, the weak region, that of the high value of electric field can be identified to be as the interface between the two liquids interface.

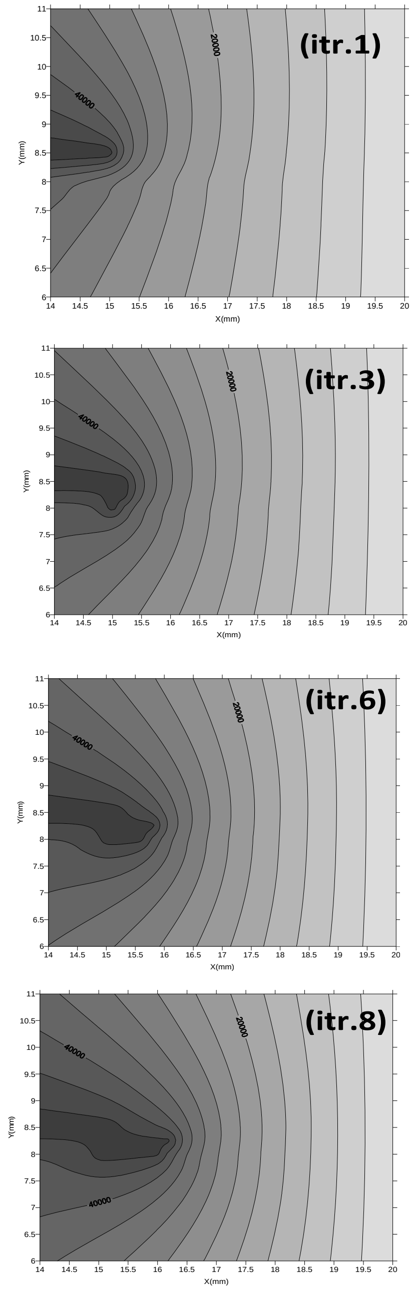

Figure (5): The effect of streamer growth on the potential distribution for iterations 1, 3, 6, 8, in transformer oil with cresol in pin-plane configuration

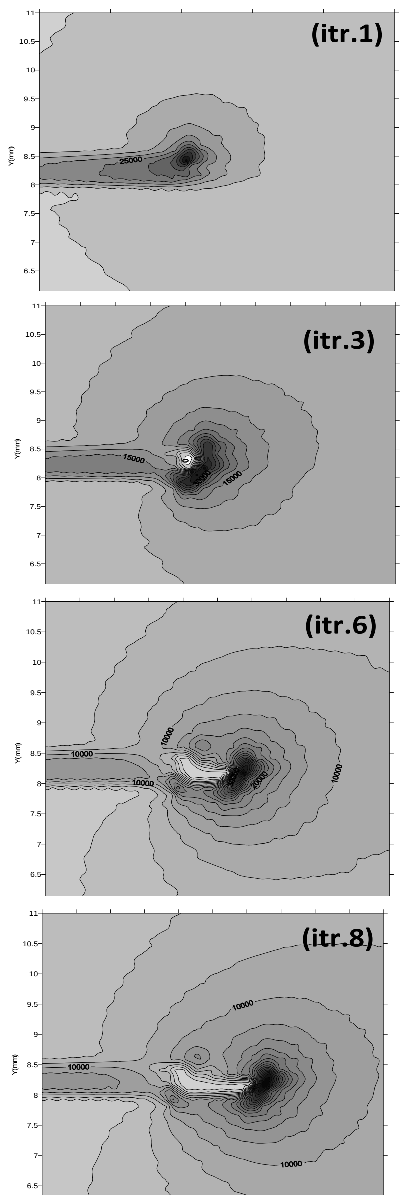

Figure (6): The effect of streamer growth on the electric field distribution for iterations 1, 3, 6, 8, in transformer oil with cresol in pin-plane configuration.

3-Spacing Effect

The spacing distance between the liquid-liquid interface and the tip of the pin (needle) is very important in some applications. It is possible to add a second liquid to changing the path of the Streamer. It is either to encourage or discourage the breakdown to happen depending on the mismatch permittivity between the two liquids on the two sides of the interface. That was studied for different distance spacing as in figure (7).

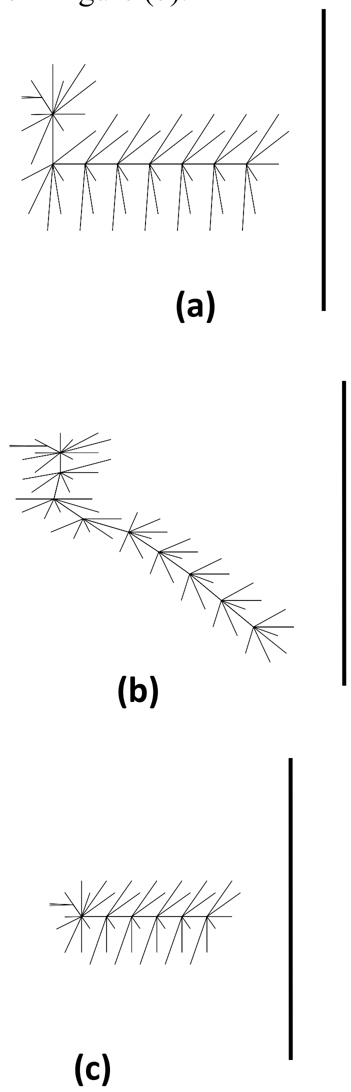

Figure (7): The streamer growth for distances, a-0.5mm, b-1mm, and c-1.5mm, in transformer oil with Cresol liquid.

Figure (7a) shows the streamer growth when the spacing is 0.5mm. It appears clearly, there is a deflection in the path of the streamer growth. The streamer growths toward the plane electrode with some deflection toward the liquids interface. Figure (7b) shows the streamer growth when the distance is 1mm. It appears clearly, there is large deflection in the path of the streamer growth, toward the plane electrode through the second liquid (Cresol). This is because the weak region effect for the two liquids interface and the permittivity of the second liquid. Figure

(7c), shows the development of the streamer growth within the enlargement of the region between the electrodes when the distance between the liquid-liquid interface and the tip of the pin (needle) is 1.5mm. It appears clearly here, there is no deflection of the path of the streamer growth at this distance. That means, the electric field at a directional distance becomes more great than that at the interface.

Conclusions

From an overall observation to the results of this work, one can estimate that, the higher electric field value is at the shape edge which explain the initiation of the streamer. The presence of liquid-liquid interface troubled the potential and the electric field distributions. In most cases, the presence of liquid-liquid interface creates a weak region that becomes suitable path for the streamer growth. So that the liquid-liquid interface with its distance from the tip of the pin control the path of streamer growth.

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