

The Velocity and Initiation Time for the Streamer Discharge with in Dielectric Liquids

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Abstract

Dielectric liquids are widely used in high voltage equipments such as transformers. This study reports the computational results for some parameters that affect the initiation time and velocity of the streamer discharge within some dielectric liquids between pin-plane electrodes. Finite element technique was used to indicate the electric field distribution within a dielectric liquids. Results show clearly that, the applied voltage and the liquid permittivity affect (increasing or decreasing) the values of the initiation time and the velocity of the streamer.

Keywords: Streamer velocity, streamer simulation, streamer discharge, dielectric liquids.

Introduction

During the last decade, the development of electrostatic industry has been accompanied by a growing interest in understanding the phenomena that lead to the breakdown of equipments [1]. Dielectric liquids have played an important role as dielectric materials such as in oil-filled transformer for a long time. Also, an electrical insulation technology is of great importance for high voltage-large capacity electric power devices with an increase of electric power demand [2,3].

The growth of fast streamer trees in liquid-dielectric insulation provides the precursor "leader" conduction path through which damaging flashover between electrodes can take place. The high-speed, variable nature of this phenomenon have made its detailed mechanism elusive. Nonetheless, a global description of the process may be useful for its characterization [4].

There is considerable interest in the study of electrical breakdown in liquids for a variety of reasons. From a dielectrics breakdown standpoint, liquids seem to have some advantages over gas systems, as their electric breakdown strengths are higher. In comparison with solids, their ability to circulate leads to better thermal management and homogeneity. Liquid dielectrics are also better suited for applications involving complex geometries [5].

Numerous works report on the nature, the shape and the propagation velocity of the streamer discharge in dielectric liquids in pin-plane electrode geometries in which there is a

highly divergence electric field. The propagation velocity is markedly affected by the polarity of the applied voltage, the nature of liquids and the presence of small concentrations of selected additives. In this work, the velocity and the initiation time of the streamer within different liquids and applied voltages were numerically studied.

Evaluation of Streamer Velocity

A. Beroual and R. Tobazeon, remark that the positive streamer velocity is much higher than the negative one and the positive streamers are more filamentary than the negative streamers [6]. A model considers the streamer as an extension of the point (the tip of the pin in pin-plane geometry) was proposed by Chadband [7]. In this case, the tip velocity is expected to increase with the streamer growth.

To get an expression for the streamer velocity, a simple method is to use an energy criterion. For instant, Watson [8] used the energy criterion in a non-planar geometry to determine the velocity of the streamer propagation for pre-breakdown disturbance. For the case of unique filament model, it was got on equating kinetic energy to electrostatic energy. Then the streamer velocity is [6]

$$v = \left(\frac{\varepsilon}{\rho}\right)^{1/2} E \dots\dots\dots (1)$$

where ε and ρ are the permittivity and mass per unit volume of the liquid. E is the electric field strength at the tip of the streamer and it was given [6] as

$$E = E_a \left(\frac{L}{r_s} + \frac{1}{1 - \left(\frac{L_s}{L}\right)} \right) \dots\dots\dots (2)$$

where $E_a = U/L$, with U is the applied voltage and L is the electrode gap, L_s is the streamer length, and r_s is the sphere (bubble) radius.

Numerical Solution

The streamer velocity can be determined by equation (1). The electric field at the tip of the streamer must be determined. That was done numerically; the electrode gap was divided into sub small regions (finite element) and simple2d program [9] was used to solve Laplace’s equation. This program was written with Fortran language. It requires the value of the applied voltage on the nodes at the electrodes, as boundary conditions, included within the finite element mesh which is the input data and it gives the potential distribution between the electrodes. Then, a two dimensional electric field distribution was found over the gap. This is a main requirement to determine the initiation and length of the streamer along the electrode gap. So that, one can use equation (2) to determine the electric field at the streamer tip and equation (1) to evaluate the streamer velocity.

Results and Discussion

To calculate the streamer length, it is approximated that it is equal to the linear distance from the tip of the needle to the center of the element with the highest electric field in the first step of the streamer growth process. That can be indicated from the electric field distribution over the solution region between the two electrodes as shown in Fig.(1).

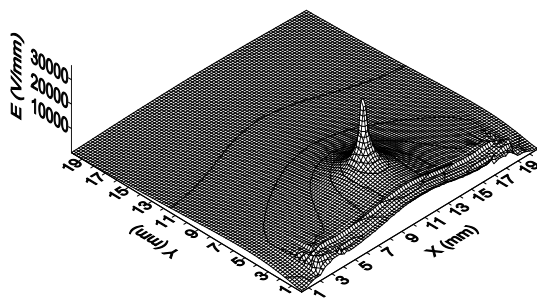


Fig.(1) The electric field distribution over the region between the electrodes.

From Fig.(1), it was easy to determine the position of the highest electric field value which it is the site of the streamer initiation. Then the streamer length was calculated. For next steps of the streamer growth, the streamer length was calculated as the distance between the centers of two sequence elements of highest values of electric field for each step. Fig.(2) shows the development of the position of the highest electric field values with the streamer growth development.

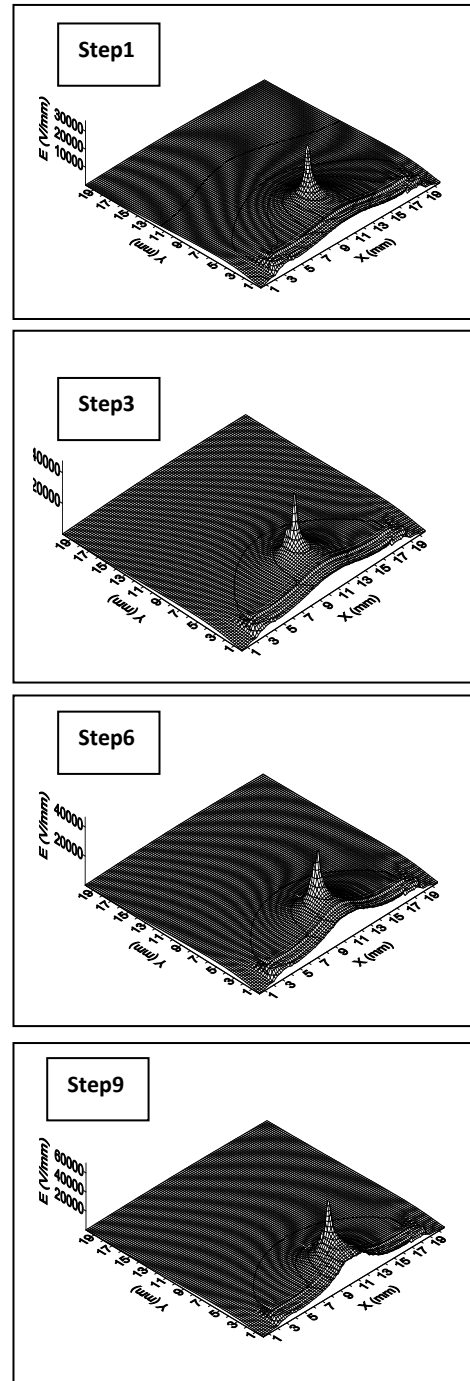


Fig.(2) The development of the position of the highest electric field values with the streamer growth development.

Fig.(3) shows the development of the streamer length with the steps of the streamer growth. It shows clearly the increasing of the streamer length linearly with the streamer growth steps. It is the pre-breakdown events that finally causes the breakdown.

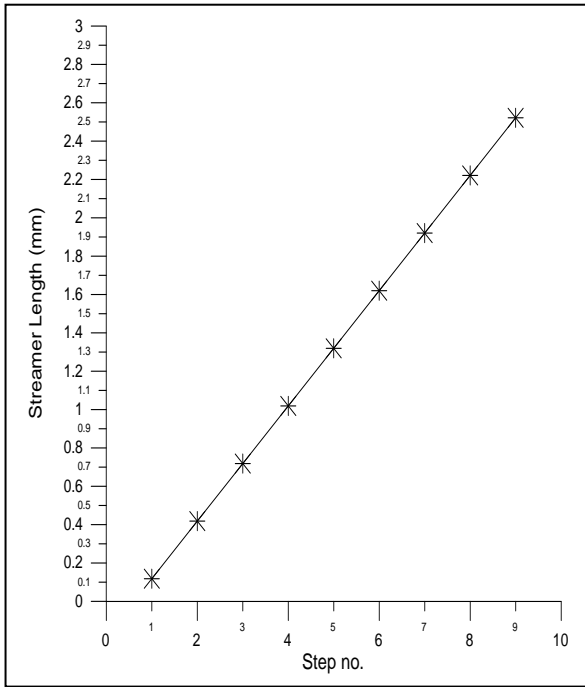


Fig.(3) The streamer length as a function of the streamer growth steps.

After the determination of the streamer length, and the electric field at the tip of the streamer, it becomes possible to calculate the streamer growth velocity according to equation (1). The streamer velocity was calculated within the transformer oil as a dielectric liquid which filled the gap between the two electrodes of a pin-plane geometry. The development of the streamer velocity according to the development of the streamer length, for different applied voltages (20, 30, 40, and 50 kV), was presented in Fig.(4).

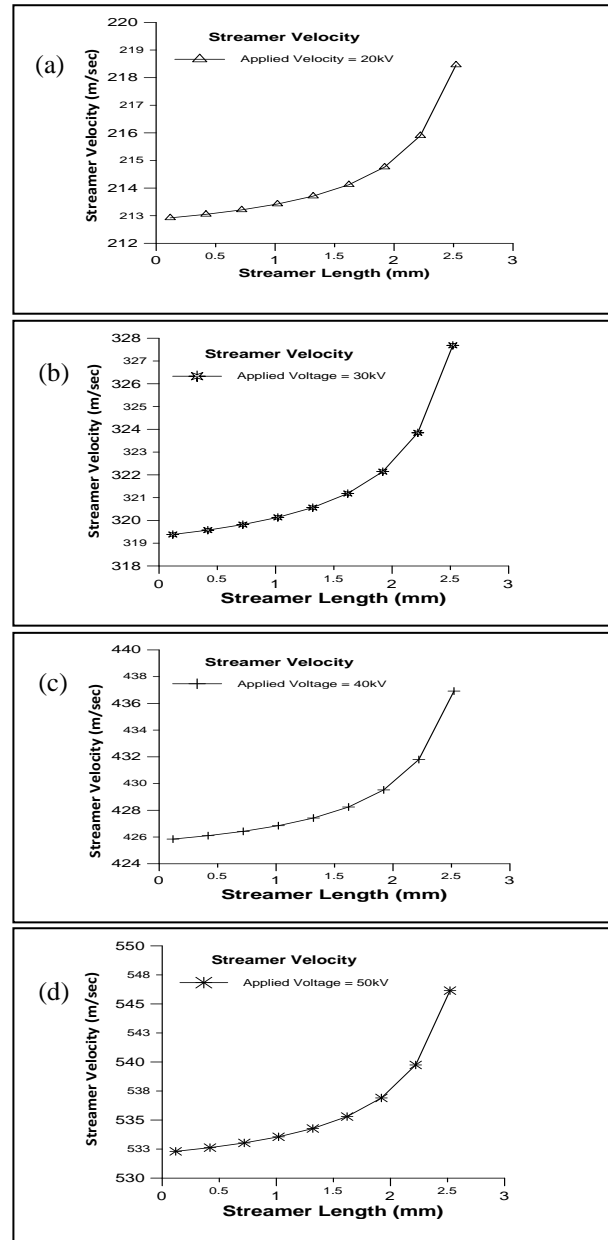


Fig.(4) The streamer velocity according to the development of the streamer length within transformer oil for applied voltages a) 20 kV, b) 30 kV, c) 40 kV, and d) 50 kV.

Fig.(4) shows the same behavior for all cases that, the streamer velocity increased with the increasing of the streamer length and it increased with the increasing of the applied voltage. This is because the electric field increases when the streamer develops and the gap decreases across the region between the two electrodes.

Also, the streamer velocity was calculated within different dielectric liquids, n-hexane, transformer oil, cresol, and water. 50 kV was applied on the electrodes, 3mm gap, as shown in Fig.(5).

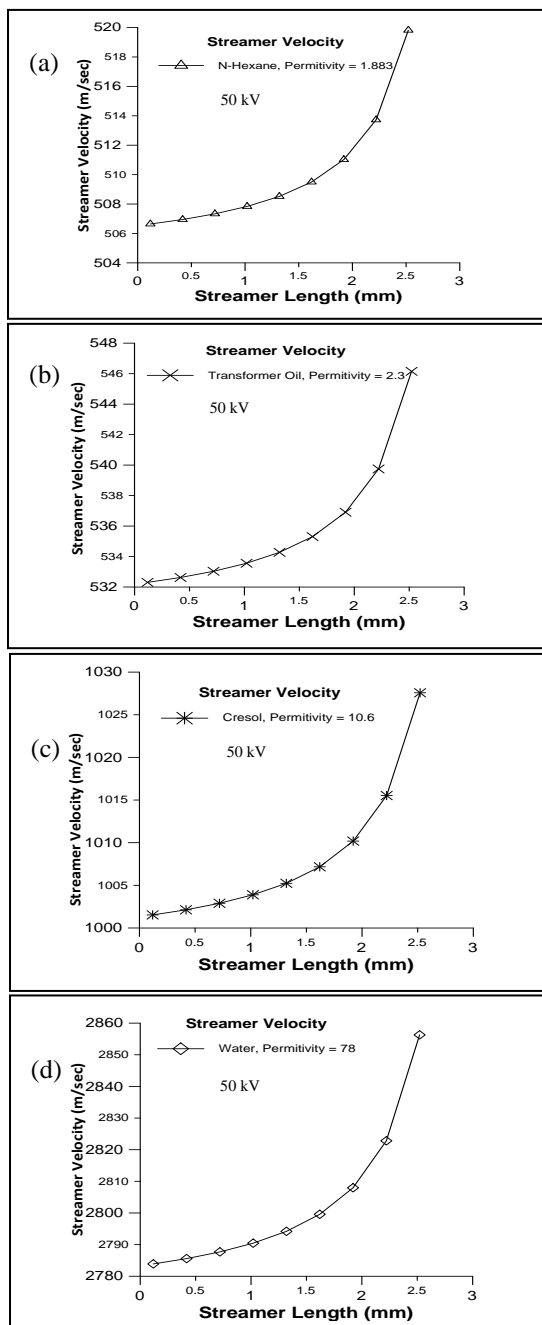


Fig.(5) The streamer velocity according to the development of the streamer length within dielectric liquids a) n-hexane, b) transformer oil, c) cresol, and d) water.

It can be noticed that, same behavior for the streamer velocity within all the used liquids; it increased with the development of streamer length and, the value of the velocity increased clearly with the increasing of the liquids permittivities (i.e. for all streamer length range, the streamer velocity is higher for the higher permittivity liquid). That is because the electric field increased with the increasing of the permittivity.

We define the time that required to initiate the streamer in the first step as an initiation time. It was calculated in different liquids when the applied voltages are 20kV, 30kV, 40kV, and 50kV, and shown in Fig.(6).

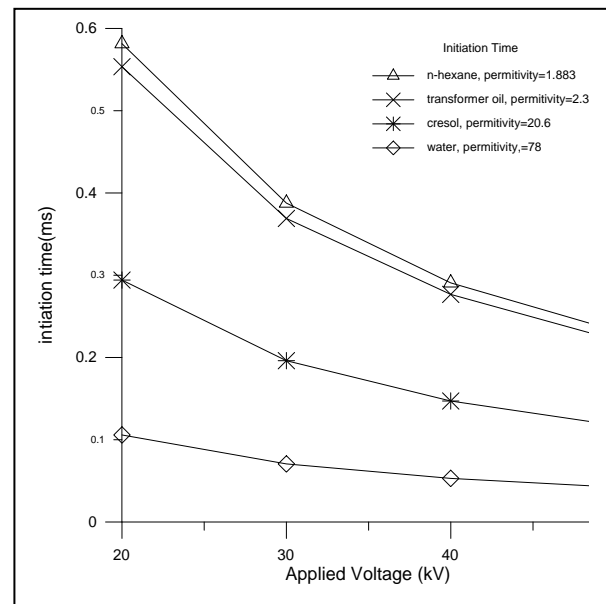


Fig.(6) The initiation time as a function of the applied voltage within transformer oil.

Fig.(6) shows that, the initiation time of the streamer, for first initiation, decreases with the increasing of the applied voltage and the liquid permittivity. That is the earlier indication or the pre-events for the streamer growing and then the breakdown.

Conclusions

The important conclusion is that, the streamer initiation and growth are faster when the applied voltage and/or the permittivity of the liquid is high, especially at the last third (1/3) of the streamer length.

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الخلاصة

تستخدم السوائل العازلة بشكل واسع في معدات الجهد العالي ومنها المحولات. وتناقش هذه الدراسة النتائج الحاسوبية لتأثير بعض العوامل في زمن نشوء وسرعة تفريغ التدفق في بعض السوائل العازلة بين قطبي الإبرة- المستوي. واستخدمت تقنية العناصر المحددة لبيان توزيع المجال الكهربائي داخل السوائل العازلة. وقد بينت النتائج إن الفولتية المسلطة والسماحية الكهربائية للسوائل يؤثران (زيادة أو نقصان) في قيمتي زمن النشوء وسرعة التدفق.