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Simulation of Electrical breakdown in Polymer

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Abstract

Because of their excellent dielectric properties, polymer materials have been widely used for insulation system. However, polymers will deteriorate when subjected to high electric fields. In reality, there are so many factors that can change this process, such as characteristics of polymer and surrounding environment, etc. The pre-breakdown phenomenon is known as electrical treeing. It is difficult to examine electrical trees in experimental samples because of very short growth time and self-destruction after the dielectric failure. In this presentation, we will focus on predicting treeing behaviour and investigate how different elements could influence the polymer electrical performance.

Based on W-Z model, a simulation program to investigate the statistical property of electrical breakdown in polymer is presented, in which the morphology of polymers is simulated randomly and the trend of electrical tree growth is demonstrated. In addition, the characteristics about the electrical tree, such as growth time and electrical breakdown strength, can be studied and collected under AC field. Using the statistic data of electrical treeing growth, we can study the key factors that affect the dielectric properties of polymers.

Introduction

Polymer is one of the world's most used electrical insulators. They are used as electrical power cable insulation (shown in Fig.1), dielectric in capacitors and many more insulation systems. People have concerned about the electrical breakdown of polymers because it is very important for insulation applications. However, any practical experiments that intend to examine the breakdown strength of the polymer will become costly. To produce meaningful data, the experiments have to be conducted under strictly controlled conditions. Fortunately, with the joint force from modern computer technology, the studies of dielectric breakdown based on simulation have become possible.

Properties and Structure of Polymers

In most of cases, the synthetic high polymers are organic construction that consists of long sequence of molecules. Thousands of huge molecule chains build up different sizes and numbers of semi-crystalline (crystalline and amorphous) regions inside the polymer. The crystalline structure that contains crystalline area is called spherulite. These spherulites in the material can affect the electrical breakdown characteristics of the polymer insulators used in electrical power cables.

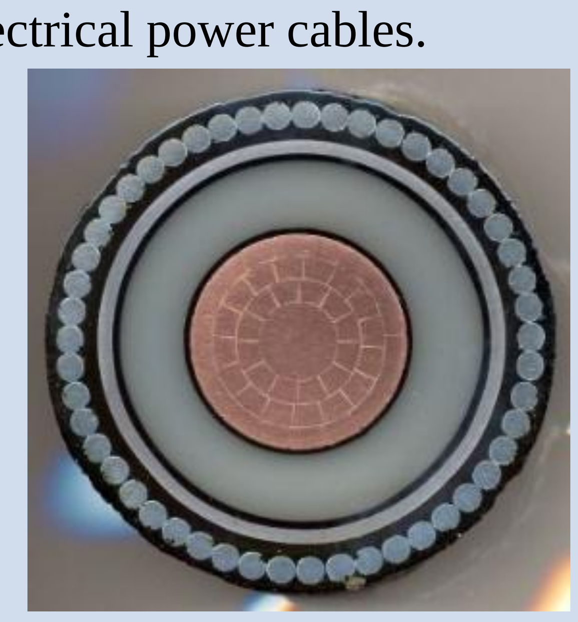

Fig. 1. Extruded polymeric material cable insulation **[1]**

Fig. 2. the real spherulite inside material. **[2]** (7% LPE blend crystallised at 124 ° C).

Dielectric breakdown

When breakdown happens, high velocity electrons will break the chemical bonds of the material and leave an air conductive passage. Material is damaged and lost its insulating property. In practice, breakdown often starts from inclusions (void or impurities) in the dielectric. Dielectric breakdown strength of a material is defined by the equation below when subjected to a ramp test:

$$E_b = \frac{Ramp\ rate * breakdown\ time}{Sample\ thickness}$$

Wiesmann and Zeller (W-Z) model

W-Z model was established by H.J.Wiesmann and H.R.Zeller. Based on NPW model, a model introducing fractal concept to dielectric breakdown, they made an improvement in adding two important parameters: Fc, a critical field for growth and Fs, a internal field in the structure. **[3] [4]**

In W-Z model, the probability of the development of tree growth is as follows:

$$p_i = \frac{(|\varphi_i{}' - \varphi_i| - \varphi_c)^\eta}{\sum(|\varphi_i{}' - \varphi_i| - \varphi_c)^\eta}$$

Where $\varphi_i{}'$ is the potential point which ready to be developed, φ_i is the electrical tree development potential point, φ_c is discharge threshold voltage, η is the probability of electrical tree growth.

Simulation program

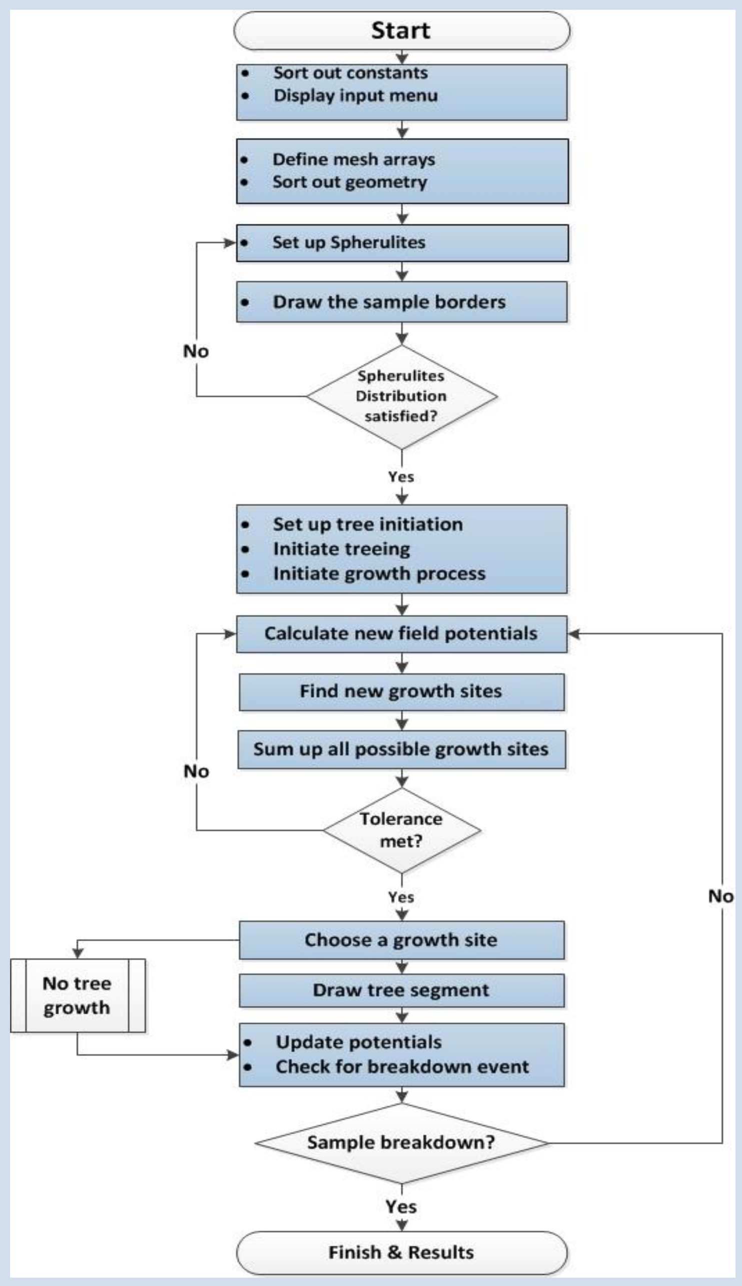

Fig. 3. Main process of program

This program is designed to simulate a certain polymer with desired properties under a controlled test environment. The algorithm will calculate several data with those settings for further research, including electric strength of polymer, breakdown time and so on. The main procedure of the program is displayed in Fig.3.

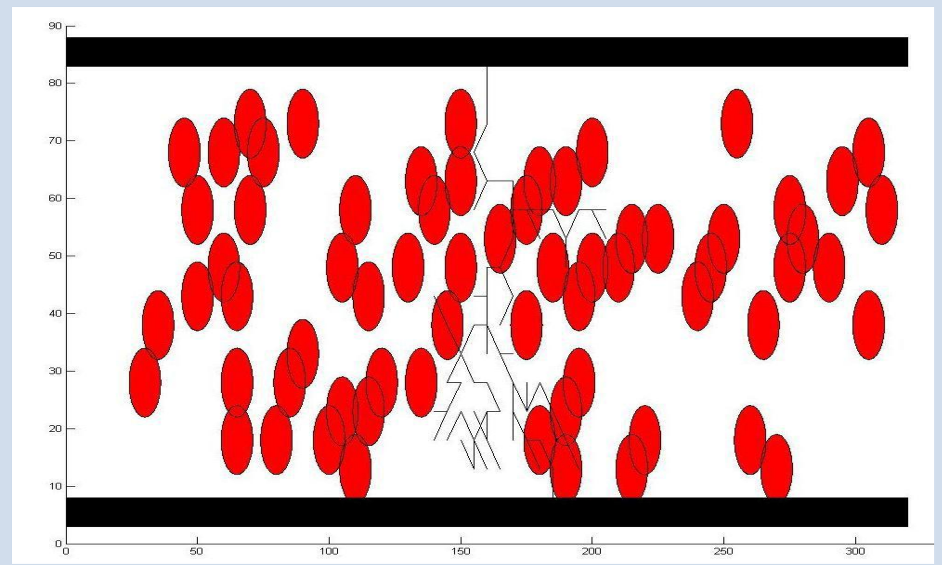

Fig. 4. The distribution of spherulites in polymer and the growth of electrical tree

Fig.4 shows simulation results of the distribution of spherulites and tree growth.

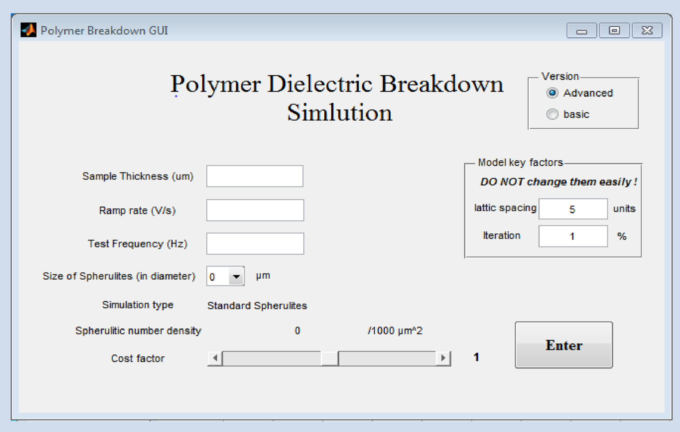

Fig. 5. GUI of the program

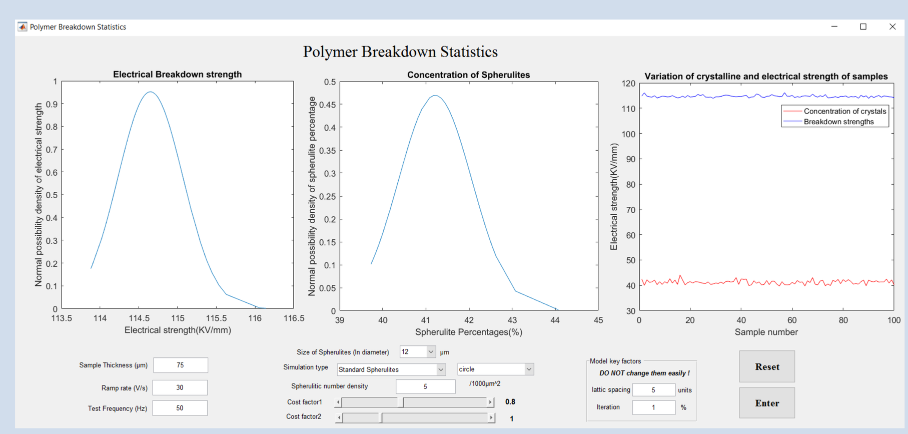

Fig. 6. Result figure of polymer breakdown statistic

Graphical user interface (GUI) has been developed for the convenience of the users (Fig.5). It is known that both the structure of the polymer and testing conditions will influence the breakdown strength. Therefore, test environment (involving sample thickness, ramp rate and test frequency) and polymer properties (involving different strength of crystalline and amorphous regions via cost factor, spherulite size, spherulite number density and simulation type) will both be taken into consideration.

Results and discussions

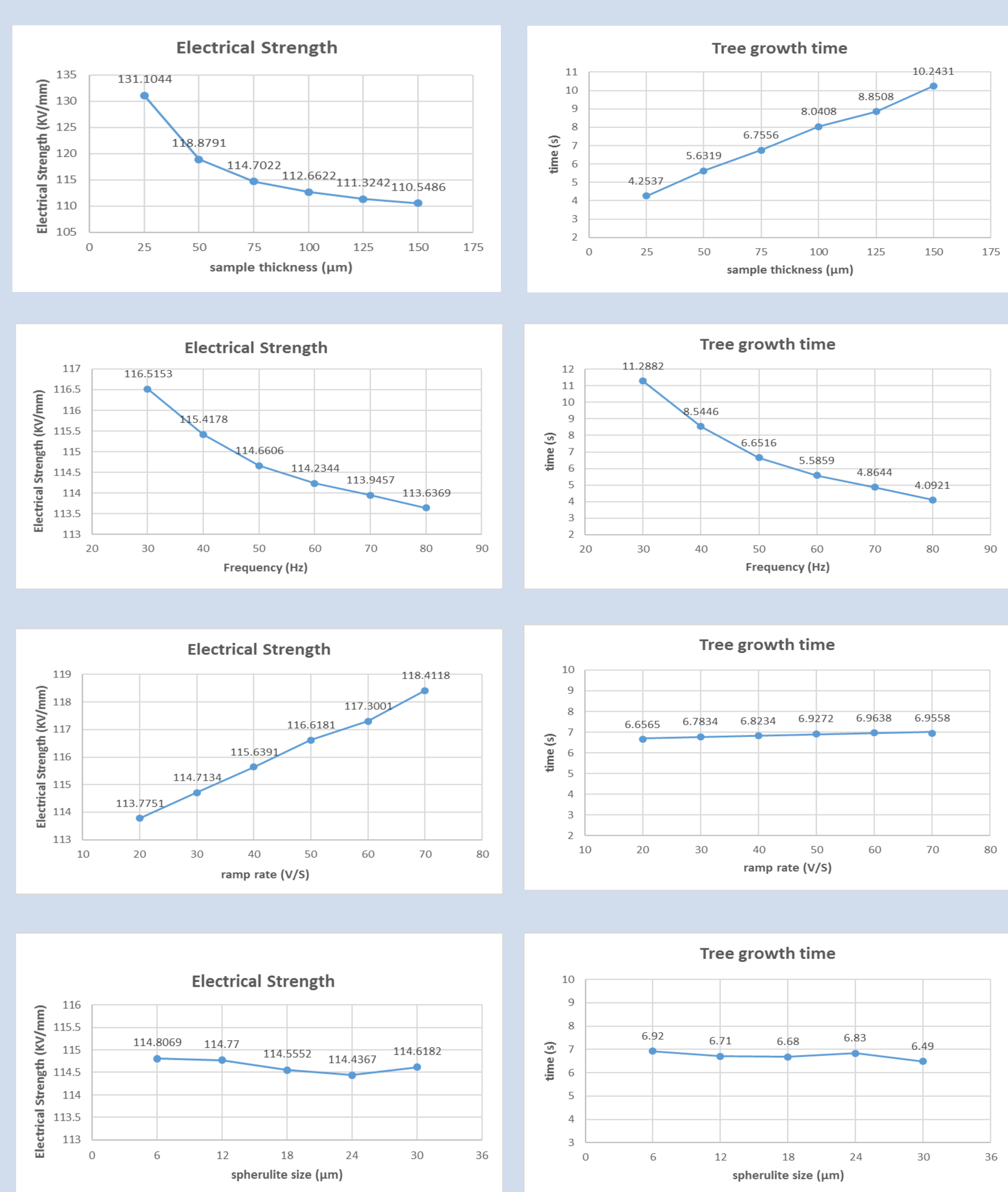

Fig. 7. The influences of sample thickness, frequency, ramp rate and spherulite size on electrical strength, tree growth time.

We can observe and study the impacts of each key parameter on the electrical breakdown of polymer with this program, which can simulate many kinds of polymer material in different conditions that might exist in reality. Compare with practical experiments data [2], the simulations results come from this program are very promising.

In summary, these results suggest that some of test environments could rapidly alter the measurements of polymer performance. But the change of spherulite size has little effect on the electrical characteristics of polymer.

Conclusion

Based on the algorithm using the W-Z model, this program can not only help the users to explore what the distribution of spherulites inside the polymer, but also study the impacts of various parameters on the electrical properties of polymer.

[1] G. Chen, M. Hao, Z. Xu, A. Vaughan, Cao, Junzheng, and H. Wang, "Review of High Voltage Direct Current Cables," *10 Csee J. Power Energy Syst.*, vol. 1, no. 2, pp. 9–21, 2015.
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[3] Wiesmann. H.J and Zeller. H.R, "A fractal model of dielectric breakdown and prebreakdown in solid dielectrics.," 13 May 1986.
[4] L. Niemeyer, L. Pietronero and H. J. Wiesmann, "Fractal Dimension of Dielectric Breakdown," 1983 23 Nov.

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