AIR-GAP DC VOLTAGE BREAKDOWN AND PARTIAL DISCHARGE MEASUREMENT EXPERIMENT PRE-LAB

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Abstract: The primary objective of this paper is to discuss the methodology and results for both pre-labs. The breakdown voltage for the rod using Calva method is calculated to be 32.5 kV for lab 1 pre-lab. The iteration method optimizes the breakdown with the assistance of FEMM and MATLAB, which is measured to be 52.3 kV which gives the value of K equal to 17.9315. The iteration method in FEMM is also applied to determine the inception voltages on the high voltage electrode creating partial discharge within the void. The inception voltages are simulated to be 8 kV, 9 kV and 9 kV for devices A, B and C respectively. When the is no void, the partial discharge occurs at 90 kV. The electric field strength is found to be uniform between the electrodes of device D.

Key words: Calva method, Electric field distribution, Electrical breakdown, Streamer

1. INTRODUCTION

The aim of this paper is to provide simulations done using FEMM and Microsoft Excel to determine the breakdown voltage for the rod and to determine the voltage breakdown of air within the void located at different points. Section 2 gives the questions and answers based on the safety measurements in the lab. Section 3 and 4 gives the methodology for lab 1 and lab 2 respectively with all necessary calculations.

2. SAFETY QUESTIONS AND ANSWERS

2.1 *Why is it necessary that all experiments undertaken in the lab are equipped with an earth stick?*

This is because any source of the High Voltage which shows no sign of ground is assumed to be live, therefore the ground stick is usually used to act as the ground. This ground stick will prevent the flow of current and leakage currents thus protecting the user.

2.2 *Why should all capacitor banks in the lab, that are not in use, have their terminals shorted?*

The voltage used in the lab is high, which creates high electric field strength distributed through to create the breakdowns. This electric field can reach the dielectric area of the capacitors as it propagates through space. This electric field will thus create charges [1], and since the capacitors are open-circuit at the point, that in no flow of charge, which implies that the charges will keep on growing which shows the capacitor charges at that moment. When the voltage of the capacitor exceeds its specified surge voltage, it will explode [2]. It is therefore important to short-circuit the capacitor to ensure it discharges quickly when the electric field imposes charging.

2.3 *Why are current limiting resistors necessary in certain high voltage experiments?*

This is to reduce the strength of the short-circuit current imposed on the High Voltage equipment thus protecting them from high current and arching.

2.4 *Is it advisable for a person to point at objects in the HV laboratory?*

The finger will imitate the radius of curvature, which allows the high electric field to be developed around the finger since the radius and electric field are inversely proportional. This results in the formation of voltage that can electrocute a human. It is therefore not advised to point at objects.

3. LAB 1 PRE-LAB

Figure 1 showcases the experimental setup, the red line is the gap distance, the bottom horizontal blue line is the ground plane and the upper shape is the rod. This Prelab aims to determine the gap length and the minimum streamer breakdown voltage.

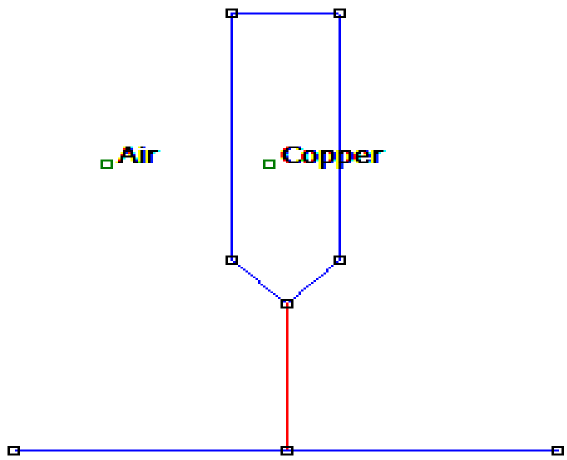

Figure 1: Electrical breakdown of a rod-plane air gap

3.1 *Determining The Gap-Length*

Equation 1 below is used to determine the gap length to be used for the experiment.

$$d = \frac{N}{40} \times 10 \qquad (1)$$

Where N characterizes the highest possible number created by the sorting the last digits of the student numbers of the group members. The last digits are found to 0 and 2 respectively for both students of which the highest possible number is found to be 20. Therefore substituting the value into equation 1 gives the gap length of 5 centimeters.

3.2 *Determining V_{start} for Iteration Using Calva Method*

It is required to determine the voltage that will give the breakdown and discharge within the calculated gap length. This will require iteration method, therefore the Calva method is used to give the voltage that will put the system into the nearest solutions. The Calva equation for calculating the breakdown voltage is represented by equation 2 below.

$$V_b = E_{so} \cdot d \cdot (K_1 + K_2) \cdot S \qquad (2)$$

Where E_{so} is the electric field required for streamer propagation and considered to be 500kV/m. K_2 characterizes the humidity correction factor, K_1 is the air density correction factor and S is the gap factor. The air density correction factor is therefore calculated using equation 3 below.

$$K_1 = \delta^m \qquad (3)$$

where m is 1.4 for positive polarity and 0.44 for negative polarity, for this experiment the positive polarity will be considered. δ is factor calculated using equation 4 below. Where P and P_o are actual and standard pressure respectively. T and T_o symbolizes the actual and standard temperature respectively.

$$\delta = \frac{P}{P_o} \cdot \left[\frac{273 + T_o}{273 + T}\right] \qquad (4)$$

The humidity correction factor is therefore calculated using equation 5 below which knowledge of equation 4 results.

$$K_2 = 1.3\delta^{-0.83} \times \left[\frac{h - 11}{100}\right] \qquad (5)$$

Where h is the absolute humidity. S characterizes the gap factor, which is equal to 1 for a conical geometry [3].

With all the equations mentioned above, it is now possible to calculate the breakdown voltage. Given that the set breaks up 260 kV with a gap of 0.4m, the summation of K_1 and K_2 can be obtained using equation 6 below by rearranging equation 2.

$$K_1 + K_2 = \frac{V_b}{E_{so} \cdot d \cdot S} \qquad (6)$$

The values of K_1 and K_2 are affected by the weather conditions as aforementioned. Therefore it assumed that the experiment will be carried out under the same condition the given data was obtained. The calculated summation is found to 1.3.

The breakdown voltage was therefore calculated to be 32.5 kV. This implies that the iteration method can now be applied to obtain the precise value for the breakdown voltage.

3.3 *Trial and Error Approach To Determine V_b*

The obtained value of the starting breakdown voltage was used on FEMM to observe electric field distribution all the gap. The data for the change in distance and its corresponding electric field strength was recorded and used in Excel to assess the data and draw the conclusion about the breakdown voltage. For every data obtained for a certain voltage, equation 7 below was applied to calculate the K_n for every segment.

$$K_n = 1.605 \times [E_n - 2.165 \cdot P]^2 - 0.2873 \cdot P \cdot X \qquad (7)$$

It was required to calculate K_n for the segments with E_n greater than 2.6 kV/mm. It is necessary to determine K which is the sum of all values of K_n with positive values. The streamer breakdown is reached when the value of K is equivalent to 18 and the corresponding voltage to give that value is the required minimum breakdown voltage. The data was sampled using the segment of 0.0334 mm, which gives 1500 data point. Due to the use of smaller segment value, the difference between electric fields of two points within a segment is small such that E_n is taken to be E corresponding to the start position of the segment

With the voltage initially set to the obtained 32.5 kV using Calva equation, then manipulating the extracted data from FEMM using equation 7 with the help of Microsoft Excel, the calculated value of K was found to be 1.539. This occurred as a result of calculating K_n values for the segments with E_n greater than 2.6 kV/mm while most segments have E_n which is less than the requirement. This behaviour can be observed in Figure 2 below.

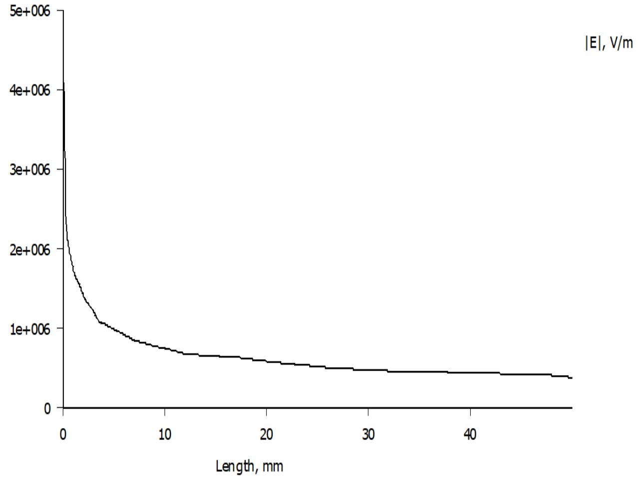

Figure 2: Electrical field strength distribution for 32.50 kV

The voltage on FEMM is increased while extracting data and still presenting it on Excel to check if the streamer breakdown is reached. The voltage of 52.3 kV is reached and the corresponding value of the K is calculated to be 17.9315. Figure 3 below showcases the field strength distribution along the gap resulting from the voltage within the conductor. These results show that the streamer breakdown is reached since the value of K is equivalent to 18, this implies the corresponding voltage is the required minimum breakdown voltage.

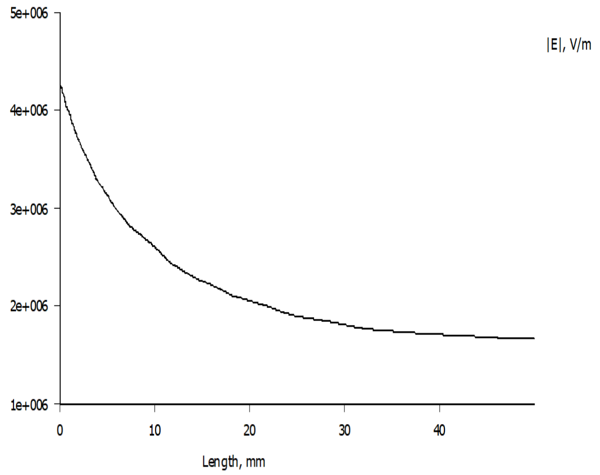

Figure 3: Electrical field strength distribution for 52.3 kV

4. LAB 2 PRELAB

This section presents the method and results for simulations carried out to determine the inception voltage necessary to cause partial discharge within the void for different devices.

4.1 ***Test Circuit Arrangements***

Figure 4 below showcases the experiment arrangement setup. A variable transformer will be used to supply voltage to the circuit. The resistor is connected to limit current imposed to the load, which is the test object that will be experimented.

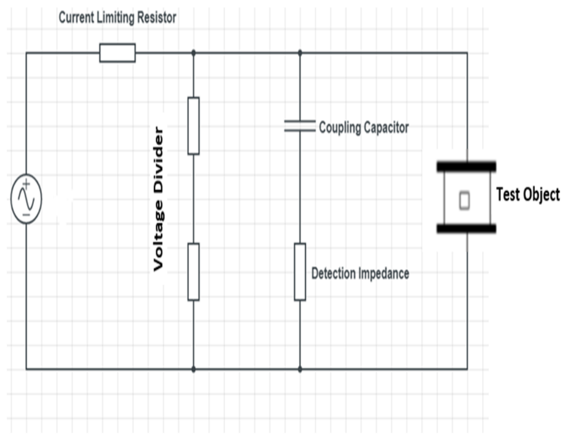

Figure 4: Test circuit arrangements

4.2 ***Devices Electrode Voltage Causing Partial Discharge***

4.2.1 ***Device A*** Figure 5 below showcases the FEMM diagram for device A. The electrode are symbolized by the rectangles labeled copper and the air bubble is characterized by the rectangle in the middle of the electrodes.

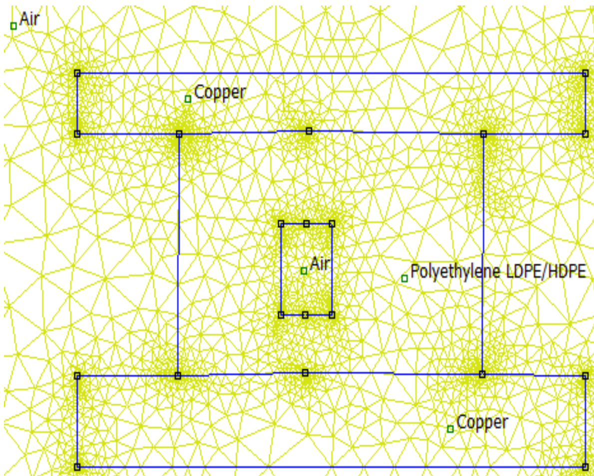

Figure 5: Device A to be investigated by HVRG

Figure 6 below shows the equipotential lines for device A.

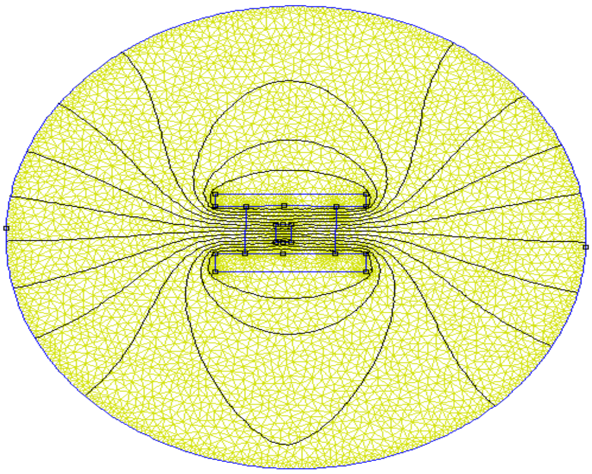

Figure 6: Equipotential lines for device A

The iterative method is therefore applied to determine the electrode voltage that will cause partial discharge within the air bubble. The electrode voltage that will cause the partial discharge in the air was obtained to be 8 kV. Figure 7 below showcases the graph of the electric field distribution within the electrode gap length using the obtained voltage. It is observed that the breakdown occurs in the out surface of the void.

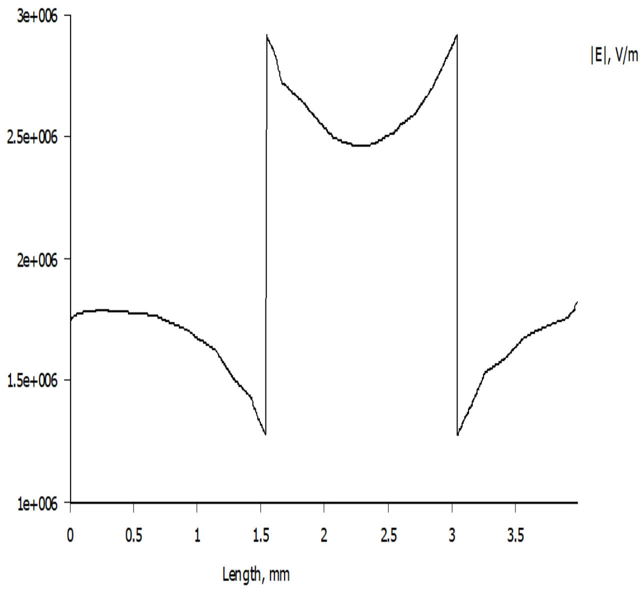

Figure 7: Electrical field strength distribution for device A

4.2.2 ***Device B*** Device B is setup as shown in Figure 8. The void is located at the inner surface of the upper electrode.

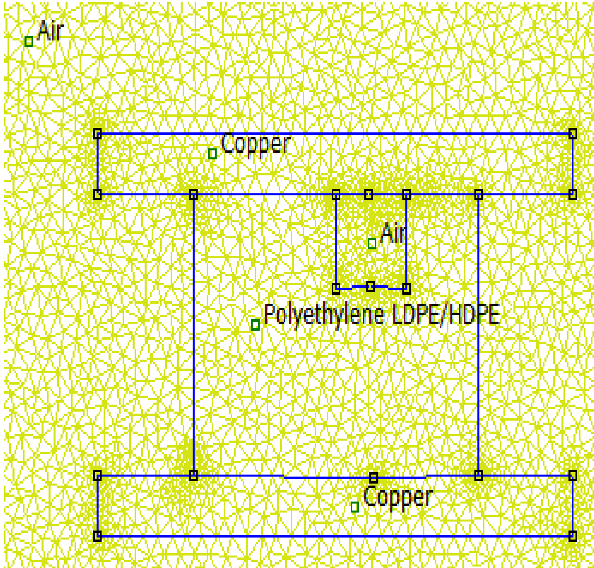

Figure 8: Device B to be investigated by HVRG

The iterative method was also applied to determine the voltage of the electrode that will give rise to the partial discharge within the void. The electrode voltage was calculated to be 9 kV. Figure 9 below showcases the electric field strength distribution along the electrode gap. The curve shows that the electric field strength is concentrated more on the bottom surface of the void whereby the strength is equivalent to 3 kV/mm which is the breakdown of air insulation.

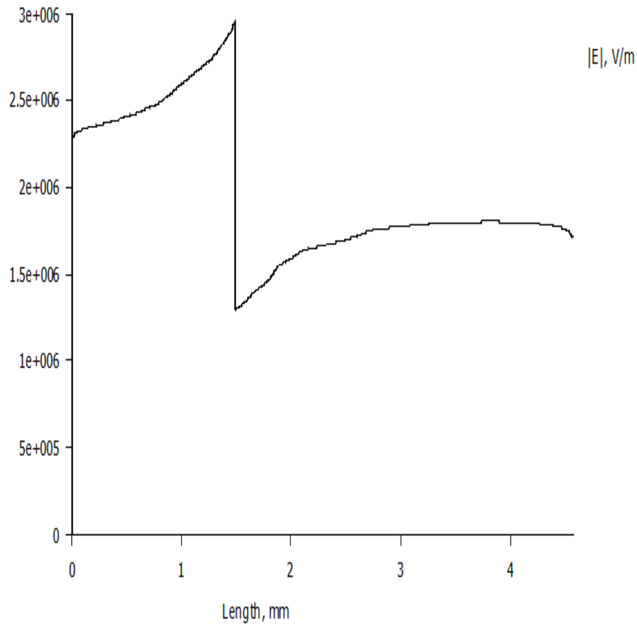

Figure 9: Electrical field strength distribution for device B

Figure 10 below showcases the equipotential diagram for device B. The it is observed the electric field is uniform within the electrode gap except nearer to the bottom surface of the void.

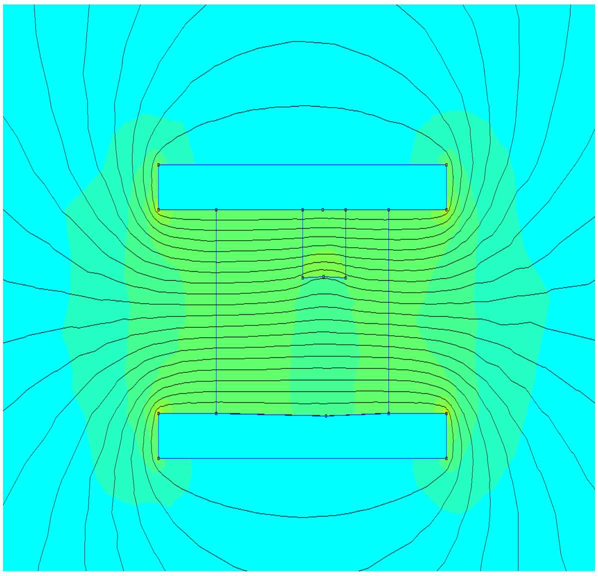

Figure 10: Equipotential lines for device B

4.2.3 ***Device C*** The setup for device C is shown in Figure 11 below. The bottom of the void is now located on the inner surface of the bottom electrode.

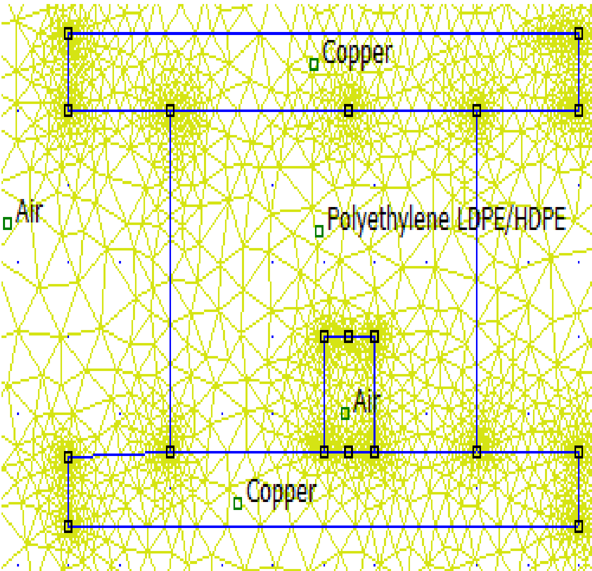

Figure 11: Device C to be investigated by HVRG

Continuing with the iteration method to obtain the electrode voltage that will give rise to the partial discharge within the void it was observed that the voltage of 9 kV in the upper electrode will create the breakdown. Figure 12 below shows the electric field distribution along the gap length of the electrodes. It is observed that the electric field strength is more concentrated on the upper surface of the void with the value equivalent to 3 kV/mm which is the breakdown of air insulation.

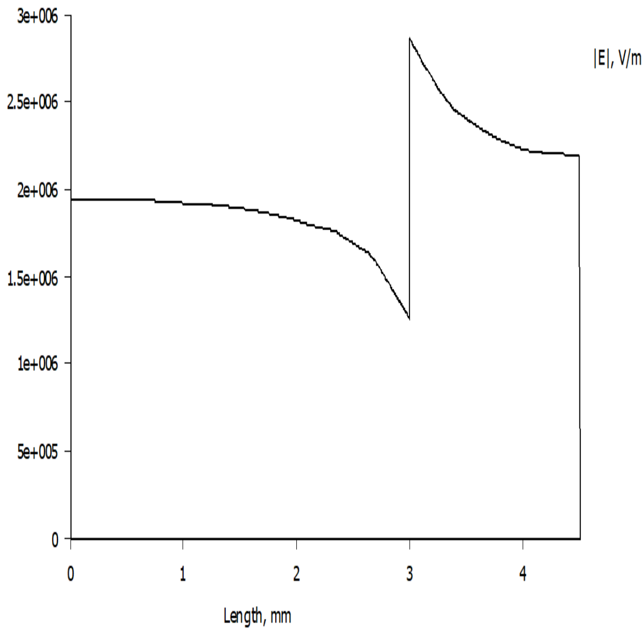

Figure 12: Electrical field strength distribution for device C

Figure 13 below showcases the equipotential lines for the device C. The fields are uniform within the insulation except for the top of the void. This also proves that the breakdown occurs at that point.

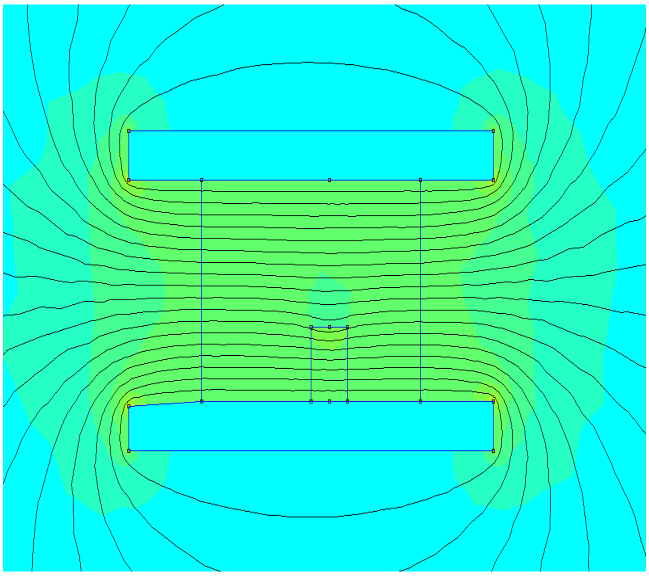

Figure 13: Equipotential lines for device C

4.2.4 ***Device D*** The setup for device D is shown in Figure 14 below. The void is no longer present within the Polyethylene insulator. The electrodes are now purely separated by the Polyethylene.

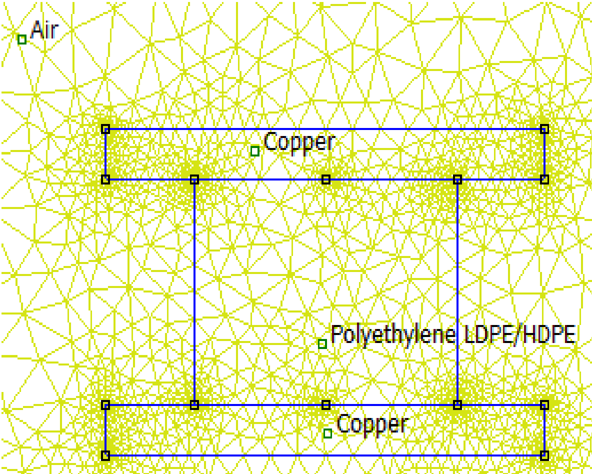

Figure 14: Device D to be investigated by HVRG

The voltage of the upper electrode was iterated to obtain the voltage that will bring electric field strength greater than equal to the breakdown of the Polyethylene. Since the electric field strength of Polyethylene range between 20-160 kV/mm, for this case, the minimum breakdown of 20 kV/mm was targeted. The upper electrode voltage to cause the insulation breakdown was found to be 90 kV. The electric strength within the insulator is always evenly distributed even when the breakdown is reached as shown by Figure 15 below.

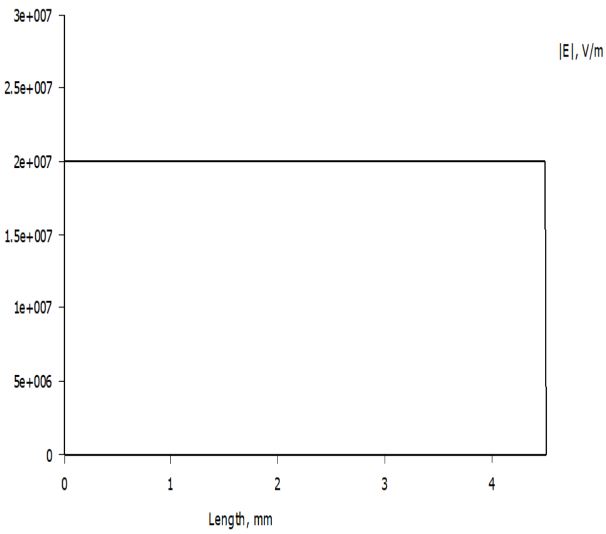

Figure 15: Electrical field strength distribution for device D

Figure 16 below also shows that the electric field is evenly distributed between the electrodes.

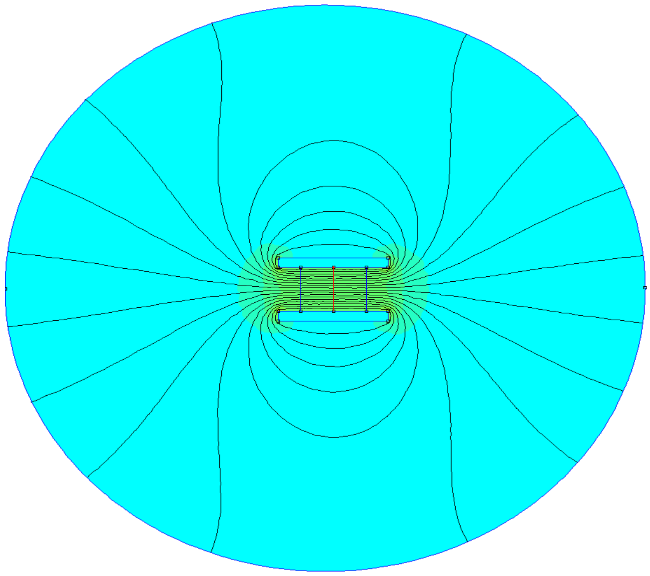

Figure 16: Device D to be investigated by HVRG

4.2.5 ***Device E*** The setup for device E is shown in Figure 17 below. The insulation present between the electrodes is only the air. The High voltage electrode has an Ogura needle pointing to the grounded electrode.

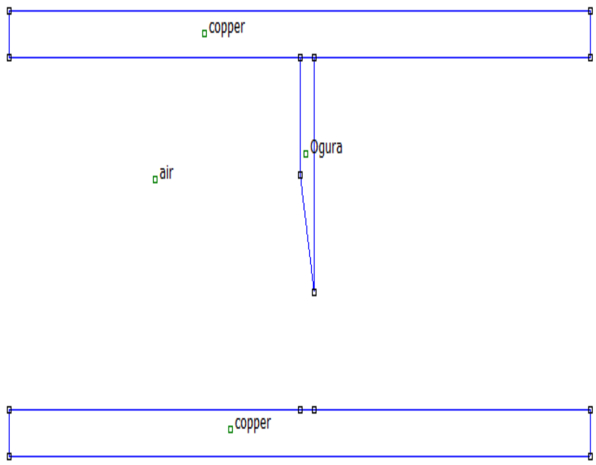

Figure 17: Device E to be investigated by HVRG

The iteration method was applied to determine the inception voltage required on the high voltage electrode to cause partial discharge. The voltage that causes partial discharge was determined to be 30 kV. Figure 18 below showcases the electric field distribution along the air gap measured from the tip of the needle to the inner surface of the grounded electrode.

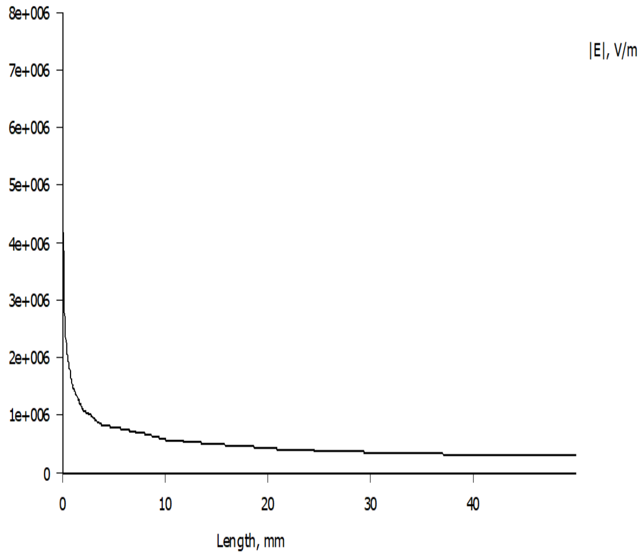

Figure 18: Equipotential lines for device E

Figure 19 below shows the equipotential lines for device C. It can be observed that the field is concentrated more on the tip of the needle inside within the air gap of the electrodes.

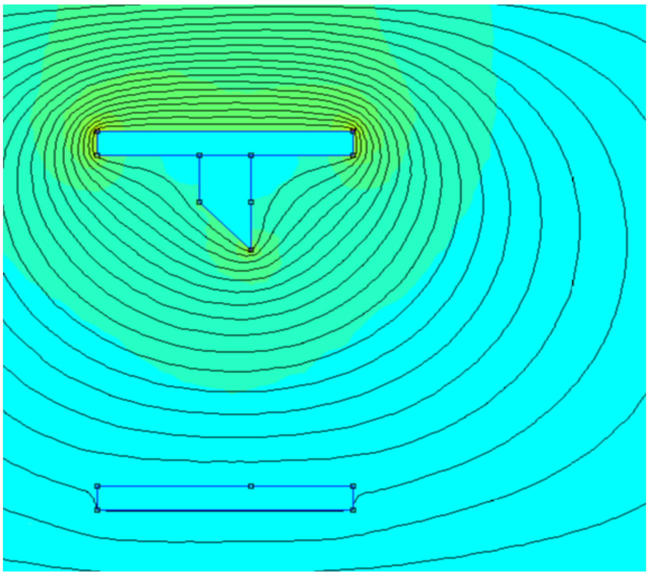

Figure 19: Equipotential lines for device E

4.3 Definitions of terms

4.3.1 ***Inception voltage*** (U_i) The partial discharge inception voltage is defined as the smallest voltage whereby the partial discharge will result in a test where the voltage of the electrode is slowly increased.

4.3.2 ***Extinction voltage*** (U_e) The partial discharge extinction voltage is defined as the voltage at which the partial discharge will no longer exist when the voltage of the electrode is slowly decreased from the value higher compared to the inception voltage.

4.3.3 ***Trichel pulses*** Trichel pulse is a typical negative corona current which has a high regular form. Trichel pulses are characterized by short rise time and period which are separated by long intervals between pulses [4].

4.3.4 ***Residual charge*** This define as the amount of charge left in the capacitor after it discharges.[5]

5. CONCLUSION

The pre-labs for air-gap DC voltage breakdown and partial discharge measurement had been presented. The safety measures required to be considered during the lab conduction has been presented as well. The used of Calva method is deemed successful as it managed to impose the determination of the breakdown voltage for pre-lab 1 to the nearest solution for which minor changes were performed to attain the required minimum breakdown. The lab will be conducted and results obtained from it will be compared with simulated results.

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