Air-Gap DC Voltage Breakdown and Partial Discharge Measurement Experiment Lab

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***Abstract*— The primary objective of this paper is to present results and discussion based on the voltage breakdown and partial discharge experiments. The breakdown voltage for the rod estimated using Calva method is found more to be more accurate than the iterative method with 11.88% less than the obtained 36.88kV obtained from the lab. The position of the unknown device for partial discharge experiment is concluded to be at the centre due to the phase resolve patterns being equal for both the negative and positive half-cycles. The corona is concluded to occur only in conductors with air surrounding due to the phase-resolved patterns appearing in different phases at a time symbolizing the types of corona inceptions and exceptions occurring. The partial discharge was concluded to occur in void cavities after the phase-resolved patterns where observe to appear equal distributed along both half-cycles, and only the inception and extinction voltages for the discharge were observed until flashover occurred.**

I. INTRODUCTION

The growth of the economy leads to demand for electrical power, which results in the need for engineers to develop and understand the insulation mechanism to allow efficient transmission and distribution of high voltage. The breakdown voltage study is important to assist in the design of high voltage protection insulators such as bushing [1].

The aim of this paper is to provide lab results and analysis for the lab experiments carried out for air-gap DC voltage breakdown and partial discharge measurement. Section II gives the background for the experiments, section III provides the experimental arrangements, section IV gives the lab 1 results, section V provides the results for lab 2 and finally, section VI and section VII provides the discussion and conclusion respectively.

II. BACKGROUND

A. Requirements

- To determine the breakdown voltage for 5cm air gap rod-plane.
- To determine the accurate method between Calva and iterative.
- To determine the position of the within the unknown device.

B. Assumptions

- The environmental conditions of the lab are similar to that of the given data for the 0.4m gap.
- The DC voltage breakdown experiment will be repeated multiple times to check the validity of the results.

C. Literature Review

Reference [2] shows how partial discharge occurs by commencing the experiment with a void where discharge has not occurred. The discharge will occur as follows: The voltage across the void increases until the breakdown voltage is reached for the void. The discharge will eventually extinguish as a result of charge build-up at the surfaces of the void. Reference [3] argues that the Paschen value cannot exactly be true due to essential conditions to be fulfilled, he shows that to start a partial void breakdown, a free electron has to be present, this electron should be supplied by external sources or by previous discharge.

The most common requirement the insulating fluid should meet is the prevention of the breakdown [4]. The surface discharge occurs at high voltages before the cavity discharge of insulating material occurs when the set-up is not immersed in oil. This is due to the electrodes being exposed to air that is compromised at that point [5]. Immersing the setup in the transformer prevents the surface flashover due to its high electric field strength compared to the air [6].

The impact of the radius of curvature has been studied by [7]. In his study, he shows that the metal surface is at the same potential with the sharp point, whereby the local electric field goes as one over the radius of curvature at that point. The electric field strength is proportional to the local charge density. The net effect is that charges will concentrate at a sharp point.

Reference [8] argues that the partial discharge occurs within voids, cracks and within solid of dielectric material. He further shows that corona occurs due ionization of fluid, such as the conductor electrically charged surrounded by air.

III. CONDUCTION OF THE EXPERIMENTS

A. LAB 1

The aim of this experiment was to determine the breakdown voltage for the 5cm air-gap using the conical rod. The conical rod was used, the Variac was used to change the voltage applied to the rod. The experiment was repeated five times while recording the breakdown voltage on every trial. Three minutes delay was imposed between every trial, this was to ensure that the air within the surrounding of the rod regains its dielectric properties after being broken down. The used set-up of the experiment shown in Figure 1 on the pre-lab, was isolated within a given area, this area is known as servitude and it is required to ensure that the electric field strength distribution in the air does not affect the individuals outside that range [9].

B. LAB 2

The aim of this experiment was to determine the partial discharge within the void available in the Polyethylene insulator and further locate the position of the void with reference to the copper electrodes. The second part of the experiment was to determine the breakdown voltage for the Oguro needle. The setup for the experiment was present in the pre-lab in Figure 4. For the Oguro needle, the lights were switched off to allow visualization of the glow and register the voltage at which it appeared. The ICM compact was employed to observe and record the data of the charge with changing voltage with the help of the computer. The ICM compact was calibrated before used. The Flashback software was also employed to record the graphs portrayed by the ICM compact.

IV. LAB 1 RESULTS

Table 1 below shows the breakdown voltages of the rod-plane with the air-gap distance of 5cm, with the experiment being repeated 5 times.

TABLE I: Experimental breakdown results for five tests.

Test Number	Breakdown Voltage
1	37.00 kV
2	37.50 kV
3	36.50 kV
4	36.60 kV
5	36.80 kV
Average	36.88 kV

A. Determining sum of K_1 and K_2 values of the experiment

Table 2 below showcases the environmental conditions under which the experiment was carried out. The information provided in the Table will be used to calculate the sum of K_1 and K_2.

TABLE II: Environmental conditions under which the lab was conducted.

Parameter	Value	SI units
Temperature	20	˚C
Pressure	0.8392	B
Humidity	49	%

With the provided information the relative air density is calculated as shown below employing equation 4 from the pre-lab.

$$\delta = \frac{P}{P_o} \cdot \left[\frac{273 + T_o}{273 + T}\right] = \frac{0.8392}{1.01325} \cdot \left[\frac{273 + 20}{273 + 20}\right] = 0.8282 \quad (1)$$

The air density correction factor is therefore calculated using equation 3 from the pre-lab with the knowledge that m = 1.4 for positive polarity.

$$K_1 = \delta^m = 0.8282^{1.4} = 0.7680 \quad (2)$$

The humidity correction factor is calculated below using equation 5 from pre-lab.

$$K_2 = 1.3\delta^{-0.83} \times \left[\frac{h - 11}{100}\right] = 0.5776 \quad (3)$$

Finally, the summation of the two factors is calculated as shown below.

$$K_1 + K_2 = 1.309 \quad (4)$$

V. LAB 2 RESULTS

A. Oguro Needle

*1) **Negative Inception**:* Figure 1 below showcases the Trichel pulse of the negative inception voltage. The pulse decreases with increasing increasing voltage and fully disappears once the the inception voltage occurs. The negative corona occurs at 2.522kV with the charge accumulation of 23.35pC.

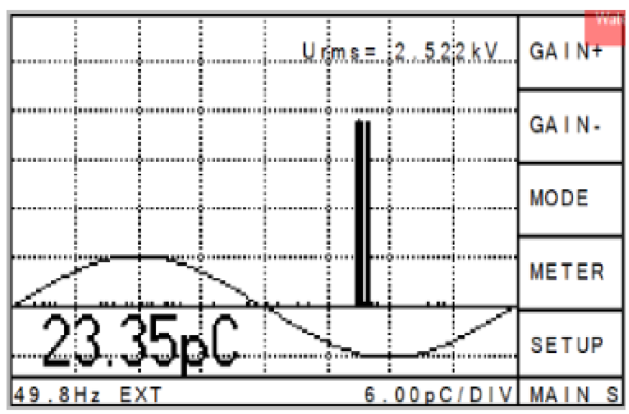

Fig. 1: Negative corona inception voltage.

*2) **Positive Inception Voltage**:* Figure 1 below shows the reading of the ICM compact before positive inception voltage occurred, the noise is still existing. The inception voltage will occur when the spike occurs after the noise settles. From Figure 1 it can be observed that the inception voltage is 16.86kV. This results can also be observed from Figure 2, where charge starts to spike at the voltage of 16.86kV. The Orange curve in Figure 3 below shows the relationship of the charge against the voltage. It is also observed that the inception voltage is 16.86kV.

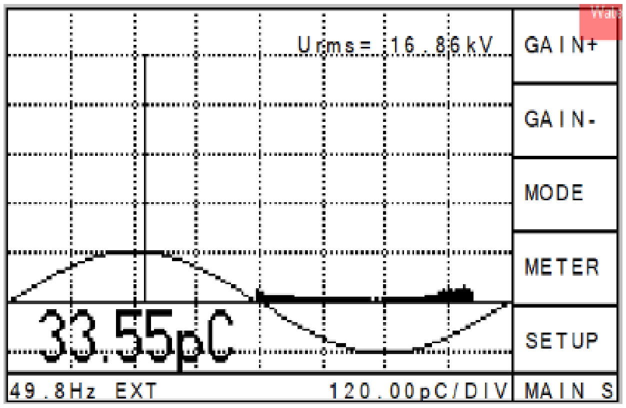

Fig. 2: Positive Inception voltage of Oguro needle.

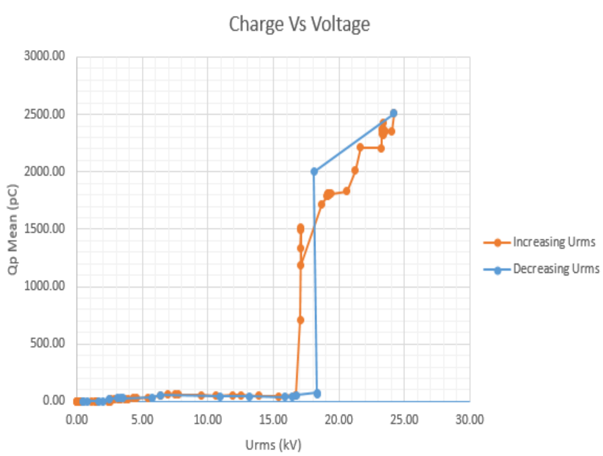

Fig. 3: U_{rms} VS Q_p Mean for both increasing and decreasing U_{rms}.

*3) **Positive Extinction Voltage**:* Figure 4 below shows the reading of the ICM compact for positive extinction voltage, which is obtained to be 18.09kV at the charge of 90.32pC. The same results are shown in Figure 1, with the blue curve.

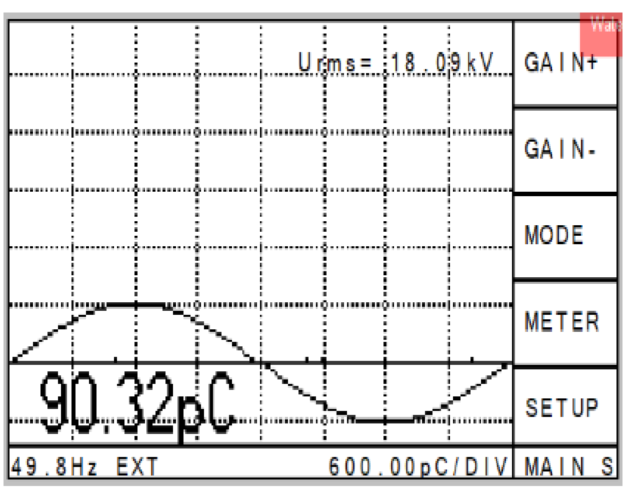

Fig. 4: Positive extinction voltage for Oguro needle.

*4) **Negative Extinction Voltage**:* Figure 5 below shows the reading of the ICM compact for negative extinction voltage of the Oguro needle. From the figure, it is observed the extinction occurs at 2.871kV at the charge of 26.13pC.

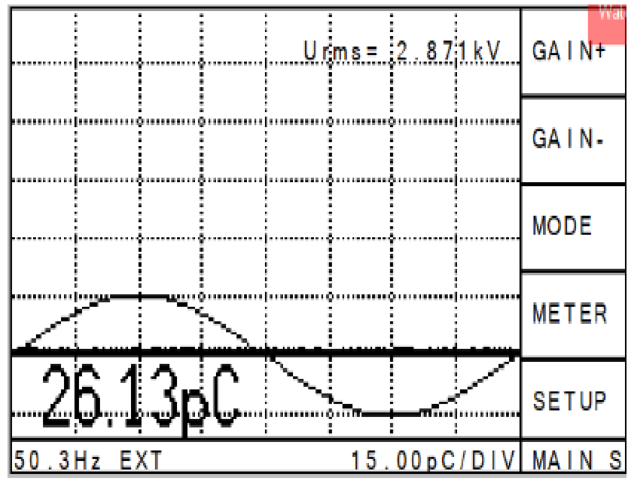

Fig. 5: Negative extinction voltage for Oguro needle.

B. Unknown Device

*1) **Inception**:* The inception voltage of the unknown device is found to be 14.89kV as shown in Figure 5, with the charge of 1.38pC. This inception voltage was selected after observing the charge rise quickly from 0.75pC. The Orange curve in Figure 6, also shows that the inception voltage occurs within that point since it is the point where the charge starts to accumulate.

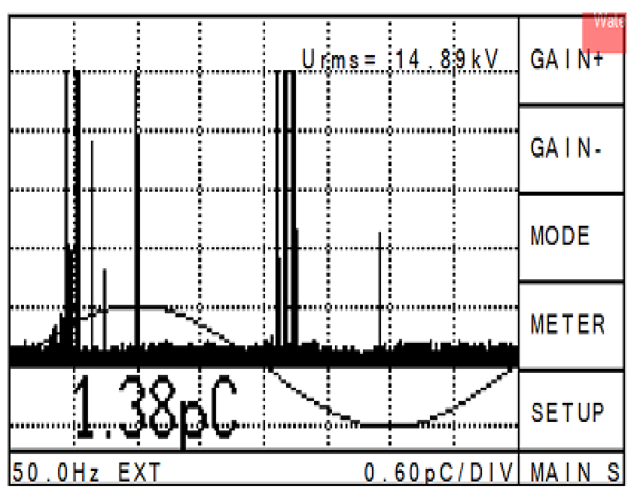

Fig. 6: Unknown device inception voltage

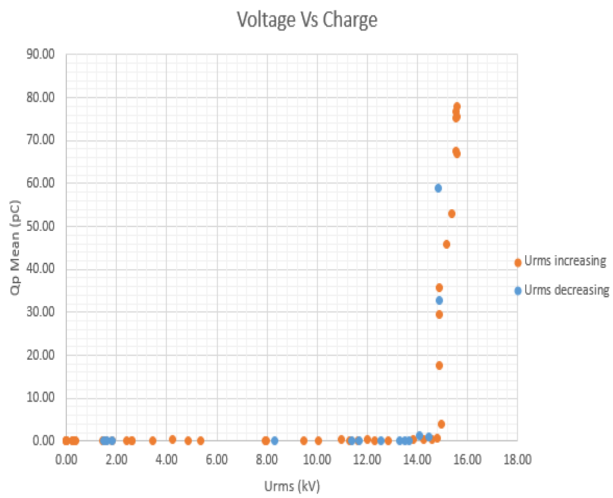

Fig. 7: U_{rms} VS Q_p Mean for both increasing and decreasing U_{rms}.

*2) **Extinction Voltage**:* The extinction voltage was obtained by observing the point where the charge of the device will decrease quickly within time. The extinction voltage from ICM compact was recorded to be 14.46kV as depicted in Figure 8 with the charge of 0.39pC, this value is also observed in Figure 7 above on the blue scatter plot.

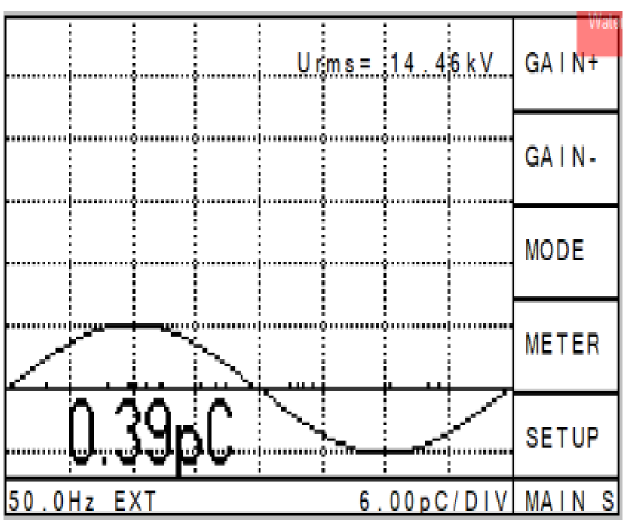

Fig. 8: Extinction voltage for unknown device.

*3) **Position of the void**:* The partial discharge measurement was observed after the occurrence of the inception voltage. Figure 9 below shows the phase-resolved patterns during partial discharge. The magnitude of the phase-resolved patterns for the partial discharge is in both the positive and negative circle are equal in magnitude and density which shows that the void the in the middle.

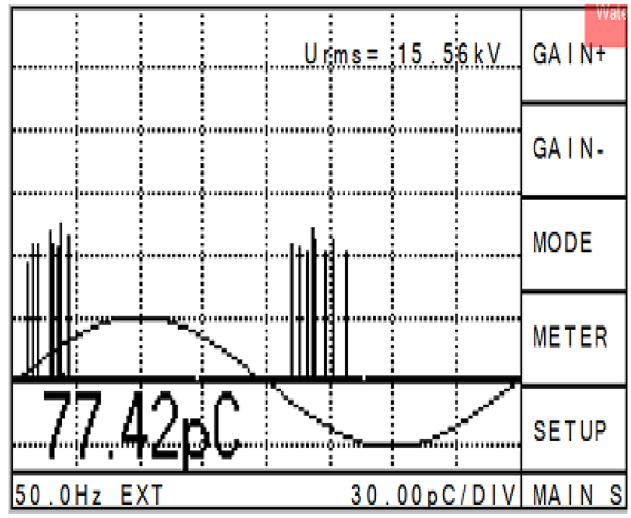

Fig. 9: Partial discharge measurement

VI. Discussion and Analysis

A. Lab 1

The air-gap DC voltage breakdown experiment was conducted. Table 1 showcases the breakdown voltage obtained by repeating the experiment 5 times. The average voltage is calculated to be 36.88kV. Using the Calva method the breakdown voltage was calculated to be 32.5kV, which is 11.88% less than the lab average breakdown voltage. Using the iterative method with the assistance of FEMM, the breakdown voltage was determined to be 52.3kV at the breakdown of streamer threshold, which is 41.81% greater than the actual lab obtained results. With these results it can be concluded that the Calva method is more accurate than the iterative method.

The Calva method is more accurate than the iterative method due to the fact that the Calva method involves the actual environmental conditions under which the experiment will be conducted. It is observed from the results that the summation of K_1 and K_2 from the experiment gives the value of 1.309 and from the pre-lab, the summation was calculated to be 1.300. The sums are similar for both the lab and pre-lab. This result shows that the environmental conditions used to breakdown using Calva method and that of the lab are similar, which is the reason why the Calva method was accurate.

During the lab, the gap distance could not be calibrated exactly to 5cm due to the pull system used to adjust the height of the rod, as such, the observed distance was actually slightly above 5cm. According to equation 2 specified in the pre-lab, it can be observed that the gap distance is directly proportional to the breakdown down voltage. This effect could be the reason for the 11.88% difference between the Calva solution and the measured breakdown.

If the same experiment is to be conducted under standard conditions, it can be observed that the value of the factor δ

will be equal to 1 using equation 1, this will give the value of air density correction factor to be 1 also from equation 2. The standard humidity is defined to be 11% which will result in the value of the humidity correction factor equal to 0 from equation 3. This will result in breakdown voltage fully dependent on the product of the gap distance and the electric field strength required for streamer propagation when substituted into equation 2 provided in the pre-lab since the value of S is 1 for conical rod-plane.

B. Lab 2

Using the phase-resolved patterns depicted in Figure 9, it was observed that the void is at the centre of the electrodes since both the magnitude and density of the phase-resolved patterns are equal for the negative and positive cycle. If the magnitude of the phase-resolved pattern was greater on the positive cycle, then that would mean the void is in closer to the positive electrode and vice verse.

The unknown device experiment was conducted successful, this is due to immersing the set-up inside the oil preventing the surface flashover of electrodes. This results support the argument of [6] in literature.

The experiment results also proved the argument of [7] in the literature to be true regarding the charge developed in a sharp point. It was observed during the Aguro needle experiment that the charge was concentrated more on its sharp point. The light was also developed in that point.

Comparing the results of the needle-plane and the unknown device, it is observed that the partial discharge occurs on the void of the unknown device while the corona is only observed in the needle-plane. Focusing on the needle-plane results, Figure 1 shows the inceptions voltage for negative corona observed at 2.522kV. The amplitude of the negative corona pulses decreases with increasing voltage until the inception voltage for the positive corona was obtained at 16.86kV as shown in Figure 2 when the positive corona was introduced the hissing sound started to be heard and the glow was formed at the sharp point of the needle. Both the extinction voltages for the negative and positive corona were obtained as shown in Figure 5 and 4. This results fully shows that the corona is observed in needle-plane but the discharge is not observed instead going beyond the positive corona inception voltage resulted in the breakdown. Moving on to the unknown device results, it is observed that only the inception voltage and extinction voltage for the partial discharge exist within the void. This case was observed by assessing the phase-resolved patterns for which it is observed that the patterns always appear on both the negative and positive cycle unlike in the needle-plane were the phase-resolved patterns only appear in one cycle at the time to symbolize the types of coronas. This overall results further conclude that the corona only appears in the conductor surrounded by air while the partial discharge occurs in the void, this results further proves the arguments of [8].

VII. CONCLUSION

The partial discharge and voltage breakdown experiments have been presented. It was observed from the voltage breakdown experiment that the Calva method with an error of 11.88% is more accurate than the iteration method with an error of 41.81%. The accuracy of the Calva was due to its ability to include the environmental conditions in its calculation of the breakdown. The 11.88% is mainly due to human error. The position of the unknown device was concluded to be in the centre due to phase resolve pattern magnitudes being equal on both positive and negative half-cycles. The partial discharge experiment showed that the partial discharge only occurs in the void while the corona only occurs on the conductor surrounded by the air.

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PRACTICAL LAB ASSESSMENT FORM (INDIVIDUAL REPORT)

Student Name: Lekeno Teboho
Student Number: 1130992

Final Mark: 74

	Unacceptable	Poor	Acceptable	Good	Excellent	Brief description of outcome	Justification for outcome rating if NOT rated *Acceptable*
Background & Problem Understanding			x			Identification of requirements, assumptions, success criteria and constraints. Contextualisation with respect to relevant literature and existing solutions.	
Quality of Engineering Output					x	Quality of output achieved (functionality, maintainability, reliability). Evidence of insight, originality or attention to detail. Application of appropriate engineering methodology to arrive at output.	
Critical Analysis & Evaluation			x			Validation and critique of final output. Discussion of tradeoffs. Recommendations for future work and possible improvements.	
Technical Communication				x		Quality as a professional & technical document: target audience; logical structure; style, language and tone; support material (graphical/tabular/math); Format; citation & referencing.	

Rating	General Interpretation
Unacceptable	No evidence provided; invalid/irrelevant approach, method, execution; completely flawed.
Poor	One or more major flaws, otherwise complete; one or more components very poor.
Acceptable	No more than minor flaws, otherwise complete; no distinguishing features.
Good	Shows insight; some distinguishing feature(s).
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All outcomes are weighted equally.

Late Submission *(Penalty on Final Mark)*	**Submitted deliverables late?** Within 1 Hour: -5% Before 16h30: -15 **Penalty:** 0 *See School policy on late submissions.*

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