LABORATORY EXERCISE – 2019

1 GENERAL INFORMATION

The High Voltage Laboratory (HV Lab) work contributes 20 % to your final course mark. Students are required to book their labs and will be notified when the booking form will be made available online. A fair amount of flexibility will exist, provided proper arrangements are made. There are two sections to the lab that will each be completed on the same day. The labs will be commence on the 5$^{\text{th}}$ of April 2019. The HV Lab is coordinated by teaching assistants. The labs work will be done under the supervision of Tapiwa Venge and Sophy Sitole, who can be contacted using `tapiwa.venge@students.wits.ac.za` and/or `sophy.sitole@students.wits.ac.za`, respectively.

2 INTRODUCTION

The function of insulation in electrical systems is to electrically separate points that are at different electric potentials. When the insulation fails to withstand the electric field stress, breakdown will occur. In high voltage equipment, common flash-over problems are due to:

- Electrical breakdown of gaps separated by two electrodes as shown in Figure 1.

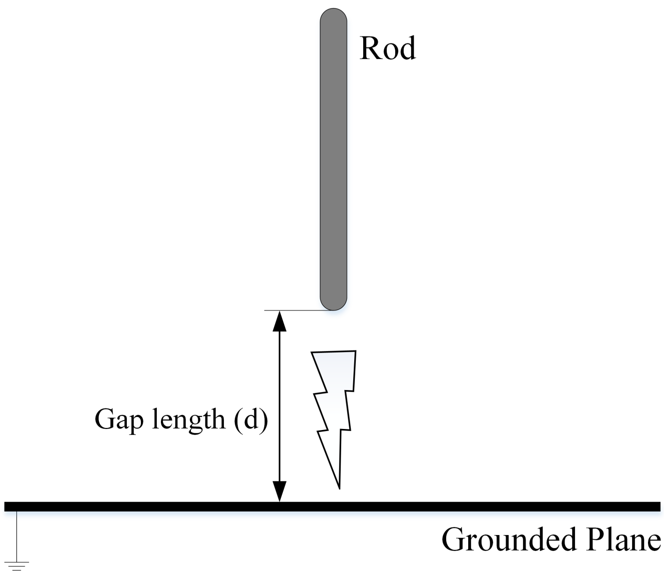

Figure 1: Electrical breakdown of a rod-plane air gap

- Solid insulation may contain defects such as air-filled cavities illustrated in Figure 2. Electric field enhancement occurs in the cavity and may be strong enough to cause electrical breakdown of the air in the cavity. This is termed "Partial discharge" (PD). Sustained PD activity in the cavity can lead to a complete short circuit across the solid insulator.

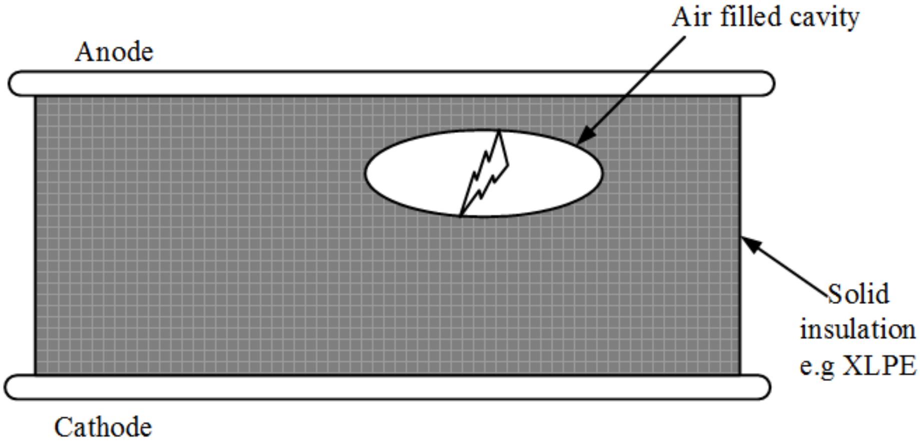

Figure 2: Electrical breakdown starting as a partial discharge in solid insulation

Atmospheric air is the cheapest and freely available insulation in high voltage systems. Other gas insulation include Nitrogen, Sulphur hexaflouride (SF_6) and its mixtures with N_2, CO_2, and N_2SF_6. The breakdown mechanism in gases is explained by the Townsend and Streamer theories. Under standard conditions the ionisation strength of air is 30 kV/cm.

3 PRE-LAB WORK AND REPORT

3.1 Preparation and Deliverables

The pre-lab must be submitted through the Sakai submission link no later than 16h00 three days before the commencement of the lab. For example: for a Friday lab (05/04/2019), pre-lab submission is before 16h00 on Tuesday (02/04/2019), and for a Monday lab (08/04/2019), pre-lab submission is before 16h00 on Friday (05/04/2019). After this time, standard rules for late submissions apply.

Failure to produce a satisfactory pre-lab report will result in a zero for that component of the laboratory mark and you will not be allowed to enter the lab. This report must not be long, but must clearly indicate that the student understands the reasons for the tests and the testing circuits involved. Any relevant equations and calculations must be presented and explained. The report should form a strong base for writing up the final report and must be included in the final lab report as an appendix. The pre-lab must be typed, neat and legible else it will be considered incomplete. More information on the expected content of the pre-lab report are in Sections 4, 5.1 and 6.1.

4 SAFETY

Every student is required to have read through the Safety Guidelines Document as handed out in the Course in conjunction with the Red Book.

NO STUDENT MAY ENTER THE LAB WITH OPEN SHOES OR EXPOSED JEWELLERY FURTHERMORE EVERY STUDENT SHOULD WEAR A LAB COAT!!! Certain information and understanding will be required by the student for each of the problems outlined previously:

Some Safety Questions:

- Why is it necessary that all experiments undertaken in the lab are equipped with an earth stick?
- Why should all capacitor banks in the lab, that are not in use, have their terminals shorted?
- Why are current limiting resistors necessary in certain high voltage experiments?
- Is it advisable for a person to point at object in the HV laboratory? Hint: Explain your answer using reference to electric fields.

NB: *The safety questions must be answered in the first part of the pre-lab report.*

5 LAB 1: AIR-GAP DC VOLTAGE BREAKDOWN EXPERIMENT

5.1 PRE-LAB 1

For the given rod-plane electrode set-up shown in Figure 1, calculate the voltage required to breakdown a specified gap (d). The rod diameter is 28 mm and the plane is 140 mm by 140 mm. To determine the length of your gap (d), take the last digit of each of your student numbers as a group of two. Orientate the numbers to give you the largest number combination possible. Divide the number by 40 and multiply the answer by 10. For example, if your student numbers are 313258 and 222445, then

$$d = \frac{85}{40} \times 10 = 21.25cm \tag{1}$$

N.B. You **may** use the iterative calculation method as follows:
<u>Steps:</u>

(i) It is known that the given set-up breaks down at 260 kV for a 0.4 m air gap. Using the **Calva method**, calculate or predict the starting voltage (V_{start}) for your iterative calculations.

(ii) Using V_{start} determined in (i), plot using a suitable FEM package the electric field profile across the entire gap of the given distance d.

(iii) Segment the plot into appropriate slots of as small width as possible. In each segment along the electric field curve, starting from the point of highest electric field, determine the average electric field in each slot. See Figure 3.

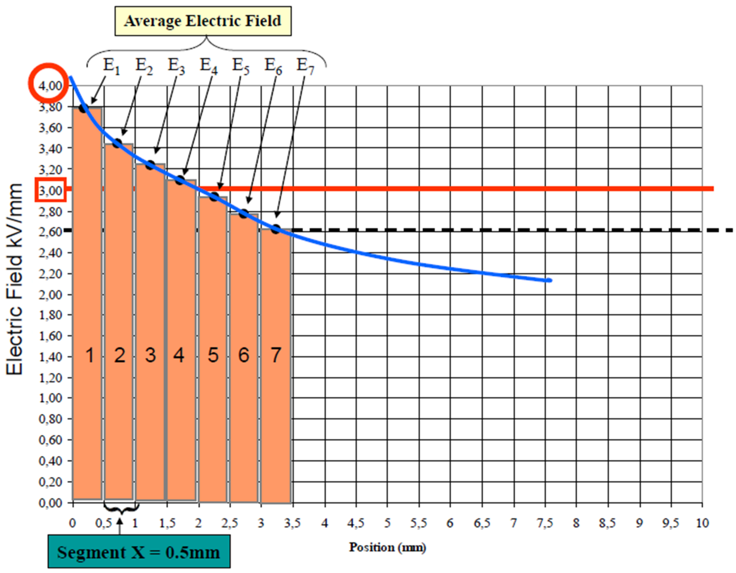

Figure 3: Segmented Electric Field Profile(This diagram was obtained from GD Tutorials 2014)

(iv) Calculate K_n for each segment using the formula

$$K_n = 1.605X[E_n - 2.165P]^2 - 0.2873PX \tag{2}$$

where X is the segment length in mm, E_n is the average field in kV/mm and P is the absolute pressure in bars. **N.B.** Consider only segments where E_n is greater than 2.6 kV/mm.

(v) Determine K, which is the sum of all K_n i.e

$$K = \sum_{1}^{n} K_n \tag{3}$$

N.B. Only sum the positive values of K_n.

(vi) Determine whether the streamer breakdown threshold is reached, i.e

$$n = e^K \approx 10^8 \tag{4}$$

or K≈18.

(vii) If K≪18, increase the gap voltage and plot the corresponding electric field (the opposite is also true). Repeat steps (iii)-(vi). If K≈ 18, take the corresponding voltage as the minimum breakdown voltage, otherwise increase or decrease the voltage and repeat (iii)-(vi) until K≈18.

5.2 Practical Test of the Air-Gap Breakdown Voltage

(i) Using the HVDC generator, starting from zero, increase the voltage in steps of 1 kV until the gap breaks down. Note the breakdown voltage.

(ii) Repeat the procedure after 3 minute intervals for 5 times.

(iii) Compute the average breakdown voltage and compare with the theoretical prediction. Comment on the similarities and differences and suggest possible improvements.

(iv) If the same experiment was conducted under standard conditions, what would the breakdown voltage be? (*Hint: An explanation will be helpful*)

6 LAB 2: PARTIAL DISCHARGES MEASUREMENT

A manufacturer has approached the HVRG (high voltage research group) to evaluate the performance of insulation devices, see Figure 5. You are required to test two devices, and make use of an electric field simulation package, and partial discharge (PD) results to infer on the type of devices investigated. The devices you are assigned will be randomly based on the day of the week and the student numbers of the group members.

The following reading material is strongly recommended:

- Partial discharge theory and technologies related to medium voltage electrical equipment [4].
- High voltage engineering fundamentals, partial discharges measurement chapter 7 [1].

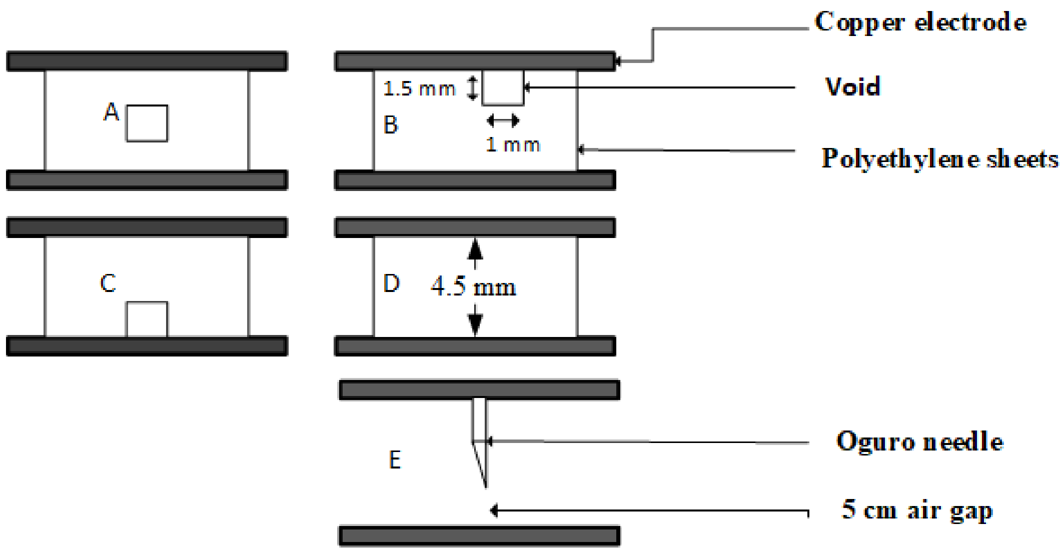

Figure 4: Devices to be investigated by HVRG. The dimensions shown for B and D are the same for A and C.

6.1 PRE-LAB 2

Perform FEM Simulations of all the devices shown in Figure 5 and answer the following questions:

- Describe the test circuit arrangement to be used in the experiments.

- Determine the voltage across the electrodes that would cause partial discharges.
- What are the differences in electric field profile of the different devices?
- Define the following; inception voltage, extinction voltage, Trichel pulses and residual charge.

6.2 Practical Partial Discharge Measurements

The unknown device will be set up when you arrive in the lab. After a safety induction, you are required to slowly increase the voltage at 1 kV every 30 seconds until a PD occurs; this is the PD inception voltage (PDIV). Hold at the PDIV for 2 minutes then you are required to slowly decrease the voltage at 1 kV every 30 seconds until 0 V. Take note of partial discharge inception voltage and extinction voltage. Remove the unknown device and set up the needle-plane (Figure 5). Perform the same procedure and take note of any sounds and visuals (turning lights off might be helpful). Make an informed guess about the unknown device using simulations and the PD measurement results obtained from the experiment (Take note of the phase-resolved-patterns). Bring a storage device to save data obtained from the experiment. Answer the following questions in your lab report:

- Based on your results, identify the unknown device you have tested.
- What physical processes cause the PD activity?
- Why is the polyethylene dielectric and electrode arrangement immersed in transformer oil?
- Why is it absolutely essential to avoid creating sharp points in the experimental set-up?
- What is the difference between corona and cavity discharges, how are the phase resolved patterns different?
- Compare and contrast the results obtained for the needle-plane vs the unknown device.
- Discuss any differences using your knowledge on PD mechanisms.

7 THE FINAL LAB REPORT

You are required to produce a detailed report on your findings. The report should not exceed 5 typed pages (excluding appendices and figures). Each student must submit an individual report. The reports must be of high engineering standard, i.e conforming to the Blue Book. The original pre-lab report should appear in the appendix of the final report.

The front cover of the report should include the course code and report title, student name and number, partner's name and number, lab demonstrators name with the section they demonstrated, and the date of submission.

Reports must be submitted through the Sakai submission link no later than 23h59, one week after lab experiment completion. For example if the lab was completed on Monday (08/04/2019), the report is due by 23:59 on Monday (15/04/2019). After this time, standard rules for late submissions apply. All reports will be checked for plagiarism and the appropriate penalties applied in accordance with the Red book.
NB: Both reports (pre-lab and final lab) will be assessed using the assessment grid in the next page.

Pre-lab and Final Lab Report Assessment Grid

University of the Witwatersrand, Johannesburg
School of Electrical and Information Engineering
ELEN4003A/ELEN5002A

Ver 4.2

PRELAB and FINAL ASSESSMENT FORM (INDIVIDUAL REPORT)

Student Name:
Student Number:

Final Mark:

	Unacceptable	Poor	Acceptable	Good	Excellent	Brief description of outcome	Justification for outcome rating if NOT rated *Acceptable*
Background & Problem Understanding						Identification of requirements, assumptions, success criteria and constraints. Contextualisation with respect to relevant literature and existing solutions.	
Quality of Engineering Output						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						Validation and critique of final output. Discussion of tradeoffs. Recommendations for future work and possible improvements.	
Technical Communication						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).
Excellent	Exceptional insight and multiple distinguishing features.

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.	

Mark Adjustment *(Examiners Discretion)* ±2%	

Examiner's Overall Comments:		Date:	
		Signature:	

Figure 5: Assessment grid that is used in marking the prelab and the final lab report

References

[1] E. Kuffel, W.S. Zaengl, and J. Kuffel, High Voltage Engineering Fundamentals, Newnes, chpt 8, 2000.

[2] L. Arevalo, V. Cooray, D. Wu. A Numerical Method for the Calculation of Breakdown Voltages. 30th Int Conf on Lightning Protection, Sept 2010.

[3] SANS 60060-1. "High Voltage Test Techniques Part 1: General Definitions and Test Requirements. South African National Standard, 1989.

[4] Partial discharge theory and technologies related to medium voltage electrical equipment. IEEE Trans Industry Applications, Vol 37, No 1, Feb 2001.

[5] Meeker, D., "FEMM 4.2 Electrostatics Tutorial", url: `http://www.femm.info/Archives/doc/tutorial-electrostatic.pdf`, last accessed: 25 July 2018.

[6] SABS method 1062. "High Voltage Tests: Atmospheric Correction Factors" South African.

[7] Power Diagnostix, "ICM manual Partial Discharge Detector User Manual Rev 3.15". Operation Manual. 1967.