ELEN4003: HIGH VOLTAGE ENGINEERING LABORATORY REPORT

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67%

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Abstract: This document reports on the experimented results performed at the lab to determine the 50 % electric breakdown of air using the U_{50} test [1]. The U_{50} test was performed using 1.2/50 µs standard impulse voltage waveform on the sphere-sphere electrode configuration, with the air gap distance of 10 cm. The up and down method was used to determine the U_{50} voltage, with the guide of SANS60060-1 to meet the required U_{50} test standards. The initial breakdown voltage is at 160.6 kV and is changed by voltage level of 3.1 kV. The U_{50} voltage is 167.32 kV.

1 Introduction

The breakdown voltage of an insulator is important for the design of any high voltage electrical equipment. These insulators are used to protect electrical equipments [2]. The breakdown of air depends on several environmental conditions such as humidity, temperature, pressure and the latitude. As described Appendix C, section 4, tests done at areas where the altitude is closer to sea level have higher breakdown voltage than those done at higher altitudes.

2 Calculated V_b

The initial breakdown voltage, V_b is calculated using equation 1 [1], where d is the air gap distance in the testing circuit of figure A1.

$$\begin{aligned} V_b &= 500d^{0.6} \\ &= 500(10)^{0.6} \\ &= 1.99\text{ kV} \end{aligned} \tag{1}$$

Distance needs to be in metres.
You were required to do the sphere to sphere iterative method.

3 The U_{50} Experiment

The aim of the lab was to determine the breakdown voltage between two spheres separated by air gap of 10 cm, using the U_{50} method.

3.1 Experiment Procedures

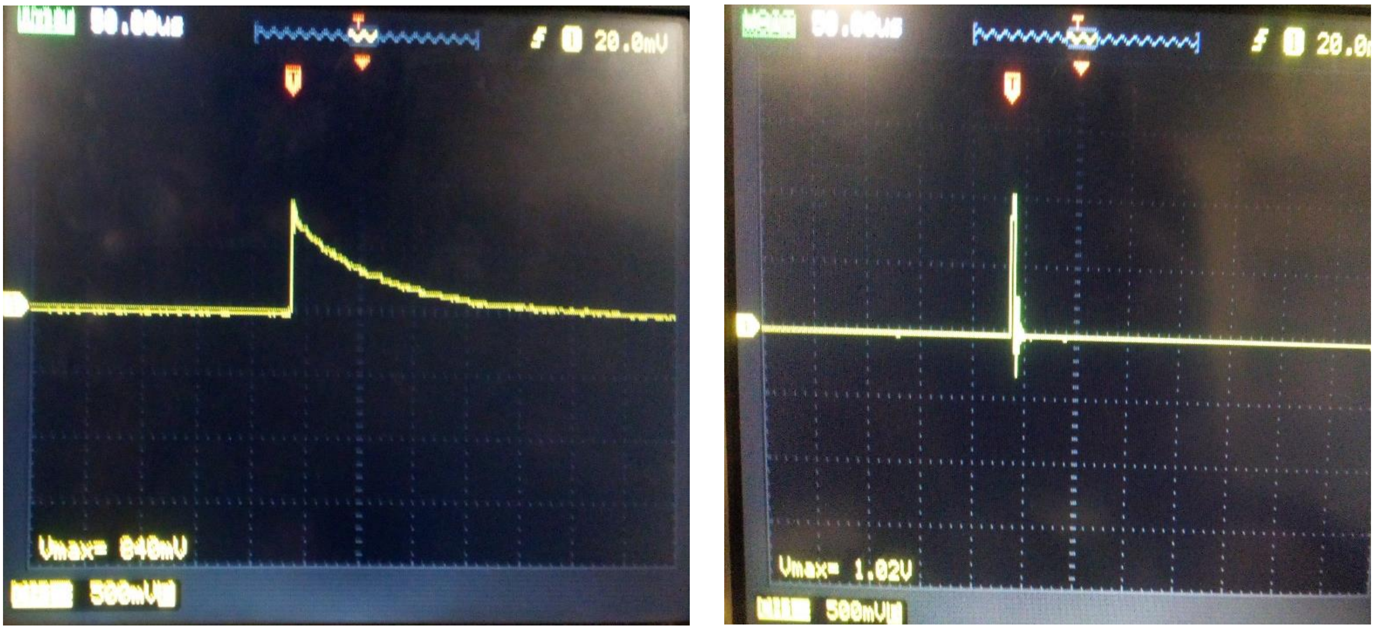
Before the experiment could start, the following setup had to be implemented for successful completion of the experiment. Figure A1 shows the setup circuit. The setup starts with the 220/140 k variac transformer to step up voltage from the power supply. The output of the variac transformer is connected to the Marx generator, trough a forward bias diode that had resistance of 6.2 Ω and rated at 5 kV_{rms}. The Marx generator is configured in 5 steps. The output of the Marx generator is connected to testing circuit trough a tape resistor of low resistance. The total circuit has a flat copper ground to reduce the inductance and to quickly discharge all the circuit. The testing circuit consist of two spheres separated by air gap of 10 cm, connected in parallel with the capacitor and the resistor of 24 kΩ. The capacitor and the resistor shape the voltage to produce an impulse. The potential divider is connected in parallel with the shaping circuit (24 kΩ resistor and the capacitor) which is connected to the oscilloscope to measure the voltage and offer a discharge path. The measured output can be scaled by a factor of 157453 to get the actual voltage reading of the testing circuit, as shown in table A1.

3.2 The Up and Down Method [3].

The up and down procedure that is documented in SANS60060-1 is used in the experiment. This is one of the three methods that was approved by the IEC standards for testing the 50 % breakdown of insulators. The up and down procedure is prescribed below:

- The initial voltage is chosen to a value which is closer to the projected breakdown voltage .
- Thereafter, equally spaced voltage levels are selected, ΔV. These voltage values are 3 % of the projected breakdown voltage, V_b.
- First shot is applied at the initial value chosen. If breakdown occurs, the next shot will be applied at the initial value minus the change in the voltage levels, (V_i - ΔV). If, breakdown does not occur, the next shot will be applied at the value which is at the initial value plus the change in the voltage levels, ($V_i + \Delta V$). This process is repeated for 20 shots.

The results were taken using the digital oscilloscope. When there is the occurrence of a breakdown or withstand, the voltage is either decreased or increased by decreasing or increasing the gap between the spheres of the first stage. The rotation of was fixed at quarter of the sphere. The preview of impulse generated during breakdown or withstand is shown in figure 1 below.



(a) (b)

Figure 1: oscilloscope preview of voltages at the testing circuit when shots different were fired, (a) is the withstand voltage and (b) is the breakdown voltage.

4 Experimental Results

The fixed rotation at quarter of the sphere changed the voltage, ΔV by 3.1 kV. The initial breakdown, V_b is at 160.6 kV. Table A1 shows the results taken during the experiment, from the results in figure A2, table 1 below can be competed:

Table 1: number of breakdowns and withstands in 20 shots

Voltage Level	Breakdowns	Withstands
1	0	│
2	│	0
3	│	││
4	0	𝍸
5	││	│
6	│	││
7	│	││
8	0	│
Total	**6**	**14**

From table 1 above, number of withstands are greater than number of breakdowns. Using equation C2 - C4, from Appendix C, the U_{50} voltage for the experiment can be determined.

$$A = \sum_{i=0}^{7} i n_{ib}$$

$$= 0(0) + 1(1) + 2(1) + 3(0) + 4(2) + 5(1) + 6(1) + 7(0)$$

$$= 22$$

$$N = \sum_{i=0}^{7} n_{ib}$$

$$= (0) + (1) + (1) + (0) + (2) + 1 + 1 + 0$$

$$= 6$$

$$U_{50} = (V_b - 2\Delta V) + \Delta V \left[\frac{A}{N} + \frac{1}{2}\right]$$

Explain why positive sign was chosen

$$= (160.6 - 6.2)\text{kV} + 3.1\text{kV}\left[\frac{22}{6} + \frac{1}{2}\right]$$

$$= 167.32 \text{ kV}$$

The experimental V_b is different from the calculated V_b, by a factor of 80. This is caused by environmental conditions in the lab.

5 Correction factor

The guide documented in SANS60060-1 is used to convert measured voltages to standard conditions [4]. The air density correction factor, K_1 and humidity correction factor, K_2 are considered in this section. The atmospheric correction factor is given by equation 2;

$$K_t = K_1 K_2 \tag{2}$$

By using equation 2, the experimental breakdown voltage, which was determined under the laboratory environmental conditions, can be converted into standard conditions [3]. To calculate the air density and humidity correction factors, parameters in table B1, in Appendix B are considered. Equation B1 - B3 in Appendix B are used to calculate K_t [3], which is used to calculate the corrected breakdown voltage as shown in equation 3 below.

$$U_{50} = \frac{U_0}{K_t} \tag{3}$$

$$= \frac{167.32\ kV}{1.08}$$

$$= 154.93 \text{ kV}$$

6 Answers to Lab Questions

6.1 What are the alternative ways of obtaining the U50 voltage?

The alternative ways to perform the U_{50} are the Multi-level method and the Extended up and down method [4]. In the Multi-level method test voltages are chosen. Then a pre-specified number of shots is applied at each level and the number of breakdowns are counted at each level. The results can be obtained by drawing a line of best fit on the graph of Probability vs Voltage [4]. The method is efficient since it does not assume normality of distribution. It is criticized for time consuming. The Extended up and down method determines the discharge voltages that corresponds the probabilities. If the applied impulse does not result in a discharge, the voltage is increase by uniform steps until breakdown occurs, and then the voltage will be decreased. This method is better that the U_{50} Up down test in that the IEC switching withstands voltages are defined as ten percent withstands [4]. The discharges on the test object are at a value closer to ten percent of the impulse unlike at U50 Up down which is at 50 percent [4].

6.2 Eenvironmental factors that can affect the experiment

Temperature, humidity and air pressure affect the U_{50} value of the experiment at high altitude, the pressure and temperature are lower and hence the U_{50} will be lower at any place that has a high altitude and lower at any place that has a lower altitude in the world [5].

Could have reffered to a Paschen curve

6.3 Can a multistage generator be approximated by a single stage generator?

Yes, but, restriction is the physical construction where sufficiently large generator becomes expensive and impractical [3]. How can it be approximated by a single-stage generator?

7 Conclusion

The experiment to determine the breakdown of air with sphere-sphere configuration was documented above. The method used for the experiment is the up and down method, which was documented in the SANS60060-1 standards. The calculated breakdown voltage is 1.99 kV and the experimental U_{50} voltage is 167.32 kV. After the correction factor was considered, the U_{50} voltage is now 154.93 kV. Environmental factors such as humidity, air pressure and temperature affect the value of the U_{50} voltage; the calculated U_{50} for the experiment will be different to that at place with a different altitude and environmental conditions.

Reference

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APPENDIX A

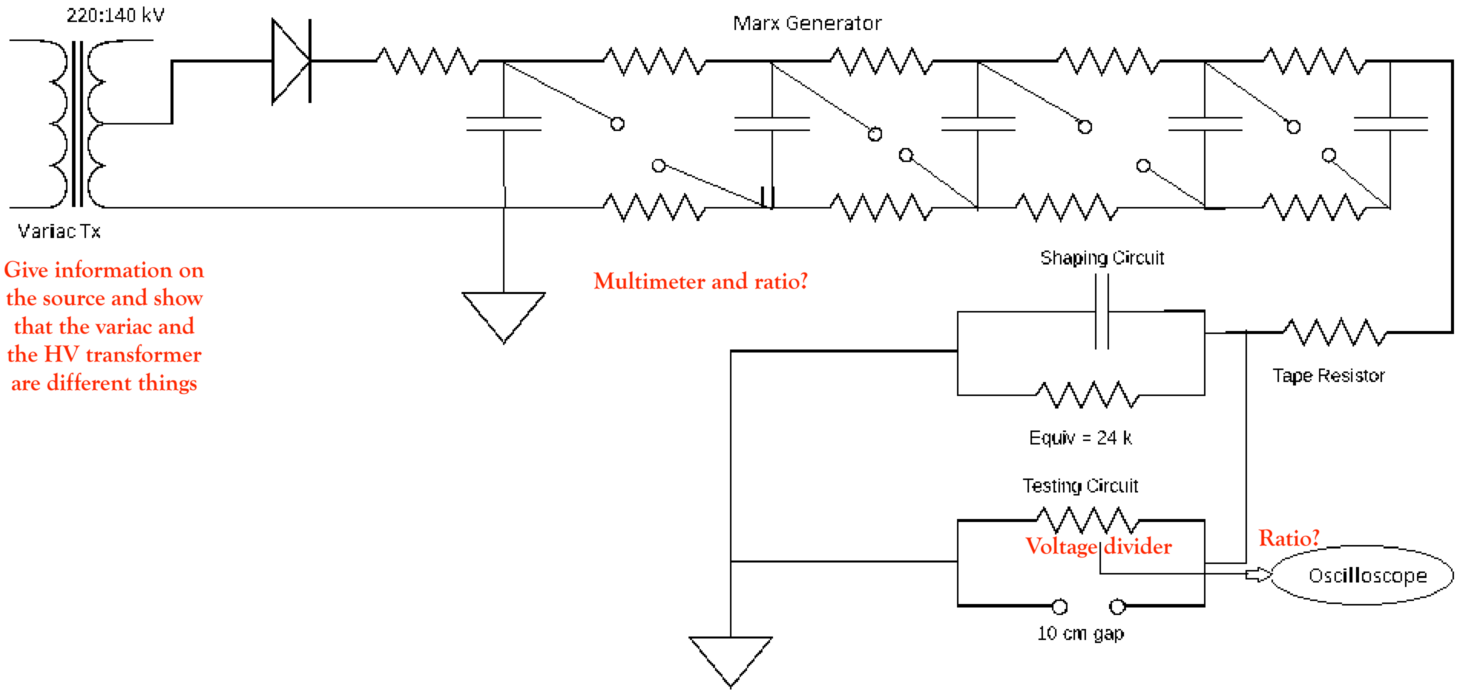

Figure A1: Experimental setup circuit diagram, with 5 stage Marx generator

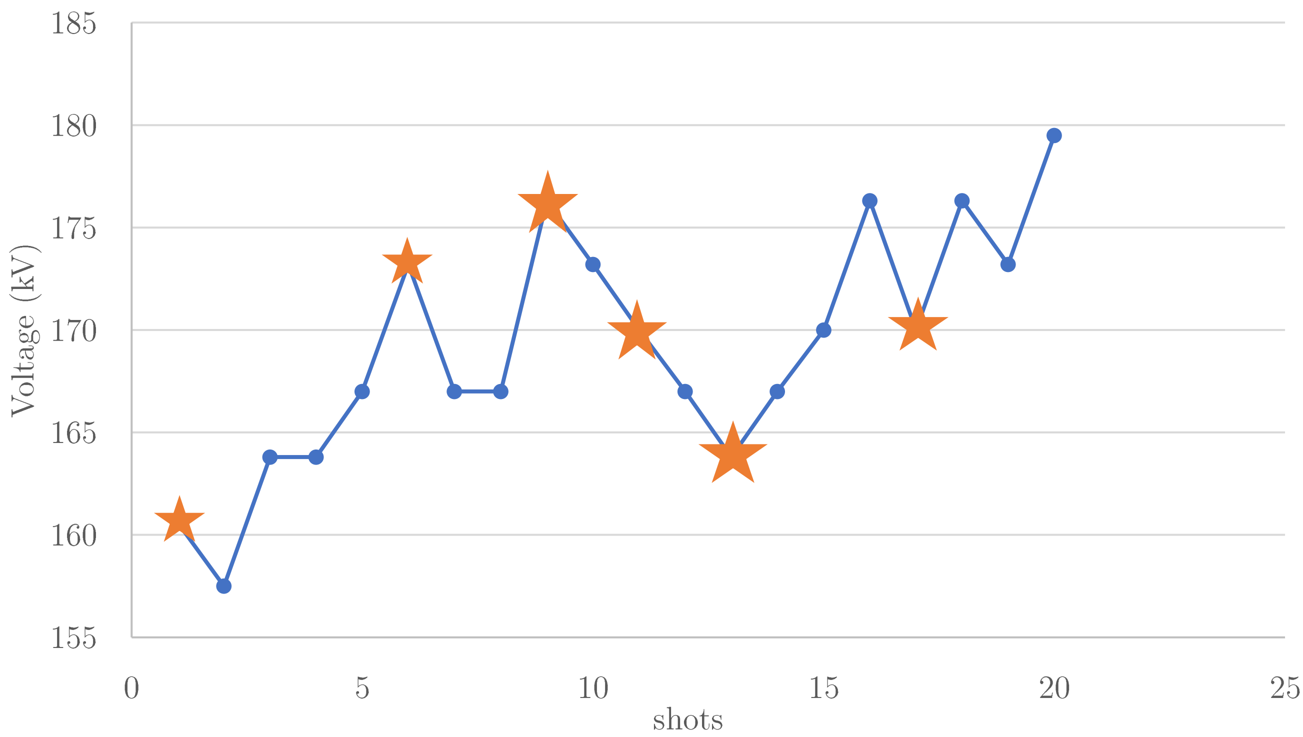

Figure A2: Representation of breakdown and withstand voltages after firing 20 shots in a U_{50} up-down test

Table A1: tabulated results of breakdown/withstand voltages in 20 shots

Shot	**$V_{oscilloscope}$ (V)**	**V_{true}(kV)**	**Breakdown/withstand**
1	1.02	160.6	B
2	1.00	157.5	W
3	1.04	163.8	W
4	1.04	163.8	W
5	1.06	167.0	W
6	1.10	173.2	B
7	1.06	167.0	W
8	1.06	167.0	W
9	1.12	176.3	B
10	1.10	173.2	W
11	1.08	170.0	B
12	1.06	167.0	W
13	1.04	163.8	B
14	1.06	167.0	W
15	1.08	170.0	W
16	1.12	176.3	W
17	1.08	170.0	B
18	1.12	176.3	W
19	1.10	173.2	W
20	1.14	179.5	W

APPENDIX B: Correction factor Equations and calculations

Table C1: Atmospheric conditions recorded in the laboratory

Parameters	Value	Standard Atmospheric
Temperature	24 °C	20 °C
Humidity	43 %	50 %
Pressure	110.92 kPa	101.3 kPa

Air density correction:

$$\delta = \frac{Pressure}{Standard\ pressure} \times \frac{273+standard\ Temperature}{273+\ Temperature} \quad \text{(B1)}$$

$$= \frac{110.92}{101.3} \times \frac{273+20}{273+24}$$

$$= 1.08$$

$$\mathrm{K}_1 = \delta^m = (10.81)^1 = 1.08$$

Humidity correction:

$$\mathrm{h} = \frac{6.11R}{0.4615(273+temperature)} * e^{\frac{17.6*temperature}{243+temperature}} \quad \text{(B2)}$$

$$= 5.34 \text{ g/m}^3$$

since humidity is greater than 2, the variable m and w are 1 and 0 respectively.

The ratio $\frac{h}{\delta} = \frac{5.34}{0.8238} = 6.43$

$$\mathrm{K} = 1+0.010\left(\frac{h}{\delta} - 11\right) = 0.9537$$

$$k_2 = \mathrm{k}^{w} \quad \text{(B3)}$$

$$= 0.9537^0$$

$$= 1$$

Atmospheric correction factor for gaps:

$$K_t = K_1 K_2$$

$$= (1.08)1$$

$$= 1.08$$

APPENDIX C: ELEN4003 - HIGH VOLTAGE ENGINEERING PRE-LAB

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Abstract: The following document determines the U_{50} voltage for an arbitrary electrode configuration using the up and down method. The assigned V_b of 540 kV was determined using the student number to the nearest 5000, this is used to calculate the U_{50} voltage. The calculated U_{50} voltage is 658.89 kV.

1. INTRODUCTION

In the following document the safety questions related to high voltage experiment are answered in section 2. The empirical formulas and equations used to determine the U_{50} voltage are presented in section 3. The altitude effects on the U_{50} voltage is discussed in section 4.

2. SAFETY

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

The earth stick is used to produce a protective path for short circuit conditions. To make sure that the equipment being used in the experiments can be discharged safely after the experiment [2].

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

To ensure that the electric charges in the capacitor banks are discharged and the energy in the capacitors does not discharge on people in the lab [3]. how does shorting it stop it charging? ambient electric fields?

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

To minimize the amount of short circuit currents on high voltage equipment in the event of short circuit failure, thus protect the equipment from excessive currents and arching [4].

2.4. Why is it not advisable for a person to point at an object in the HV laboratory?

Finger presents a small radius of curvature. This may result in high electric fields being formed around the finger surface since the electric field around a surface is inversely proportional to the radius of curvature. Therefore, this high electric field may induce a voltage that terminates through the human body and cause injury or death [5].

2.5. Individual electrocution

Electrocution happens when current travels through a human body, the amount of current flowing through a body can be determined using ohm's law; equation 1 below:

$$I = \frac{V}{R} \tag{C1}$$

Where:

R is the human body resistance, **V** is voltage across human body and **I** is the current flowing through the human body.

Due to the resistance in the body, heat may be produced when current flows through the body, this may lead to burn on the human skin [6]. Voltage of 110 kV and more may cause internal organs to fail and burn up because of the heat produced, the heart might stop pumping blood, which may result in heart failure, and the person might experience cardiac arrest [7].

Should an individual be electrocuted in the HV laboratory, the following cautions must be adhered to [6]:

- Do not touch an injured person with bare hands if s/he is still in contact with the electric source.
- Turn electric source off if possible, if not move the source away using wood or and dry insulated object.
- Administer CPR if the person is not breathing and call emergency services.

3. U_{50} VOLTAGE DETERMINATION

3.1. Up and down method

The up and down method was used to calculate the U_{50} breakdown voltage. For this method, the first shot is applied at $V_b - \Delta V$, if flashover occurs then the next shot will be applied at $V_b - 2\Delta V$ and if the insulator withstands then the next shot will be applied at $V_b + \Delta V$. For the lab, 20 shots will be applied; this is to comply with the IEC 60060-1:1989 standards for U_{50} tests [11]. From table 1 below, the total number of breakdowns n_b = 9 and total number of withstands n_w = 11. The lowest level at which a shot is applied = $V_b - 2\Delta V$. For this case, $n_w > n_b$, the expression for U_{50} is shown as equation C4 [8]. To get the A and N, equation C1 and C2 are used, where i refers to voltage levels and n_{iw} refers to number breakdowns at that level.

$$A = \sum_{i=0}^{3} i n_{ib} \tag{C2}$$

$$= 0(0) + 1(3) + 2(4) + 3(2)$$

$$= 17$$

$$N = \sum_{i=0}^{3} n_{ib} \tag{C3}$$

$$= (3) + (4) + (2) + (0)$$

$$= 9$$

should be a negative if withstands are greater than breakdowns

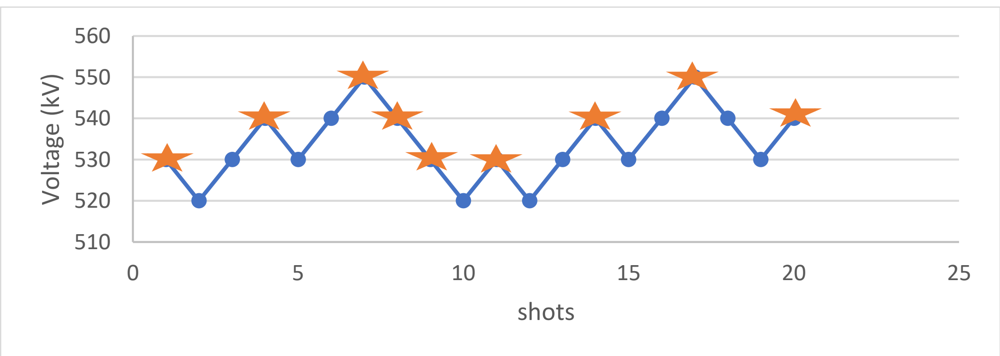
$$U_{50} = (V_b - 2\Delta V) + \Delta V \left[\frac{A}{N} + \frac{1}{2}\right] \tag{C4}$$

$$= (540 \text{ - } 20)\text{kV} + 10\text{kV}\left[\frac{17}{9} + \frac{1}{2}\right]$$

$$= 658.89 \text{ kV}$$

Table C1: number of breakdowns and withstands in 20 shots

Level (ΔV)	Breakdown (n_b)	Withstand (n_w)
1	0	$\vert\vert\vert$
2	$\vert\vert\vert$	$\cancel{\vert\vert\vert\vert}$
3	$\vert\vert\vert\vert$	$\vert\vert\vert$
4	$\vert\vert$	0
TOTAL	9	11



4. ELEVATION EFFECTS ON U_{50} VOLTAGES

The altitudes of University of Kwa-zulu Natal (UKZN) is 103 meters, and that of Wits is 1 740 meters above sea level. According to [10], the U_{50} voltage at high altitudes (Wits) is lower than the test at lower altitudes (UKZN). This is because the atmospheric pressure, humidity and temperatures at high altitudes are lower than that at lower altitudes [9]. The calculated U_{50} voltage would be higher at UKZN as opposed to Wits.

5. CONCLUSION

High voltage lab safeties are discussed above. The paper looks at the effects of electrocution on a human body as well as safety procedures to follow in case of an electrocution. The up and down method was used to calculate the U_{50} voltage break down of 535 kV, which is 5 kV below the assigned V_b of 540 kV. The calculated U_{50} voltage would be lower at Wits, as opposed to U_{50} voltage at UKZN. This is because Wits has higher altitude than UKZN.

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