ELEN4003: HIGH VOLTAGE ENGINEERING LABORATORY REPORT

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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.

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

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

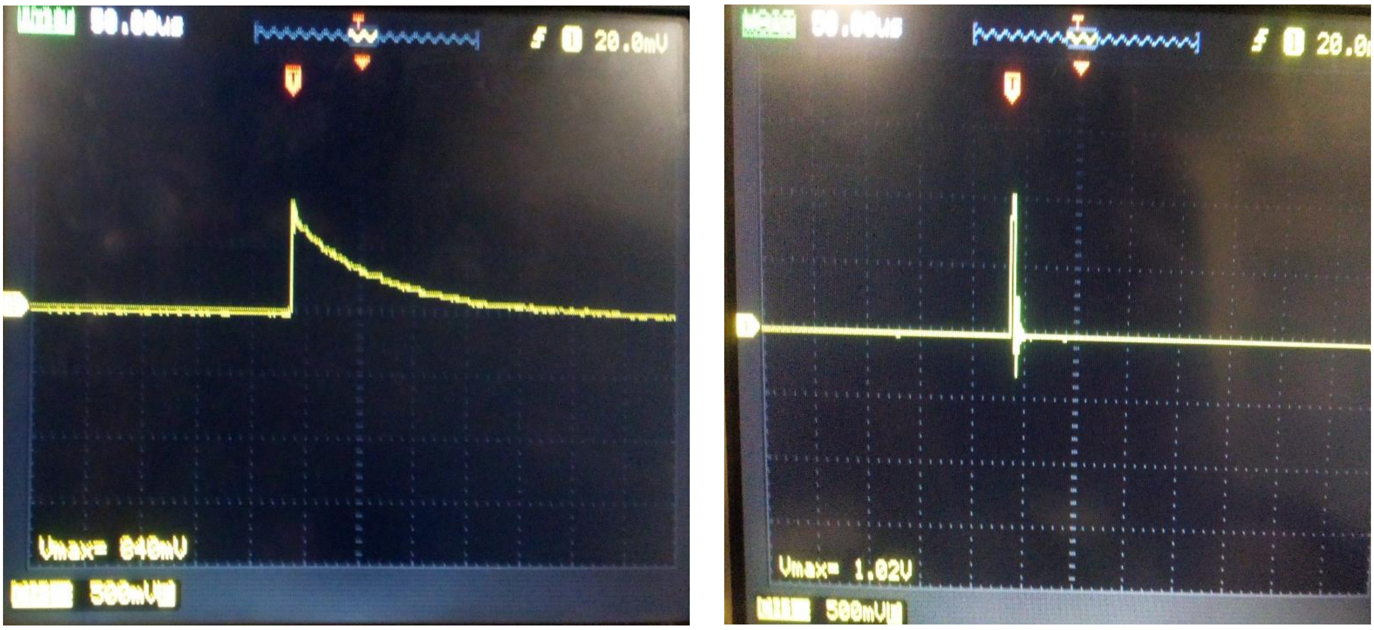
Before the experiment could start, the following setup had to be implemented for successful completion of the experiment. Figure A1 shows the setup circuit. The setup starts with the 220/140 k variac transformer to step up voltage from the power supply. The output of the variac transformer is connected 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, ($V_i - \Delta V$). 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

<table>
<tr><th>Voltage Level</th><th>Breakdowns</th><th>Withstands</th></tr>
<tr><td>1</td><td>0</td><td>|</td></tr>
<tr><td>2</td><td>|</td><td>0</td></tr>
<tr><td>3</td><td>|</td><td>||</td></tr>
<tr><td>4</td><td>0</td><td>卌</td></tr>
<tr><td>5</td><td>||</td><td>|</td></tr>
<tr><td>6</td><td>|</td><td>||</td></tr>
<tr><td>7</td><td>|</td><td>||</td></tr>
<tr><td>8</td><td>0</td><td>|</td></tr>
<tr><td>Total</td><td>6</td><td>14</td></tr>
</table>

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.

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

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

$$= 22$$

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

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

$$= 6$$

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

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

$$= 167.32 \text{ kV}$$

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 environmental 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].

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].

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

[1] Lab brief, Laboratory Exercise 2018, School of Electrical and Information Engineering, University of the Witwatersrand, Johannesburg, LEN4003-High Voltage Engineering, 2018

[2] Lab Brief, "Laboratory Exercise 2017", School of Electrical and Information Engineering, University of the Witwatersrand, Johannesburg, ELEN4003-High Voltage Engineering, 2017

[3] South African National Standards, High-Voltage Test Techniques, SANS60060-1:201, edition 2

[4] E.Kuffel, W.S. Zaengl, J.Kuffel, High VoltageEngineering, Fundamentals, Butterworth Heinemann, 2nd ed, 2000, U.S.A.

[5] T.Gora, "Investigating the Effects of Altitude (Air Density) on the HVDC Breakdown Voltage of Small Rod-Plane Air Gaps", University of the Witwatersrand, Master's Dissertation, 2016.

[6] V.N Narancic, "Arc Energy and Critical Tests for HV Current-limiting Resistors", IREQ, Varennes, Quebec, 2000

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

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

[9] South African National Standards, High-Voltage Test Techniques, SANS60060-1:201, edition 2

APPENDIX A

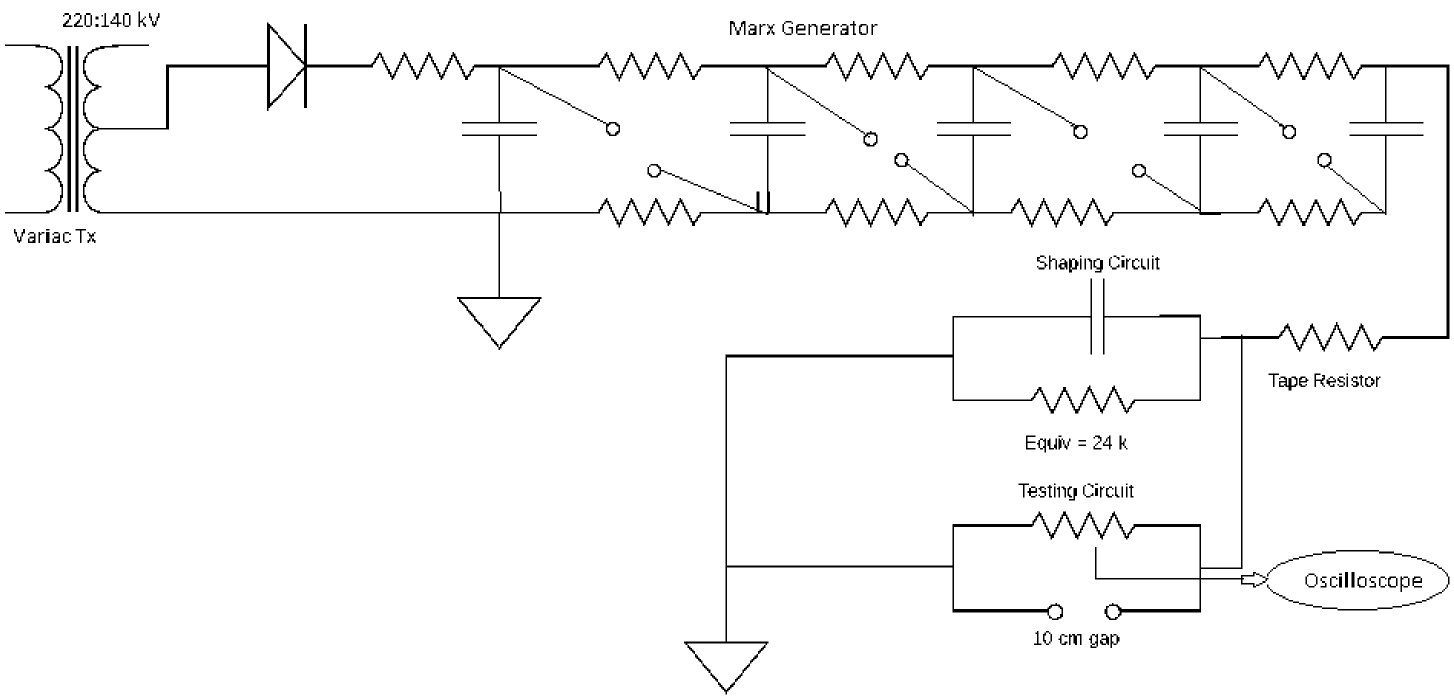


Figure A1: Experimental setup circuit diagram, with 5 stage Marx generator

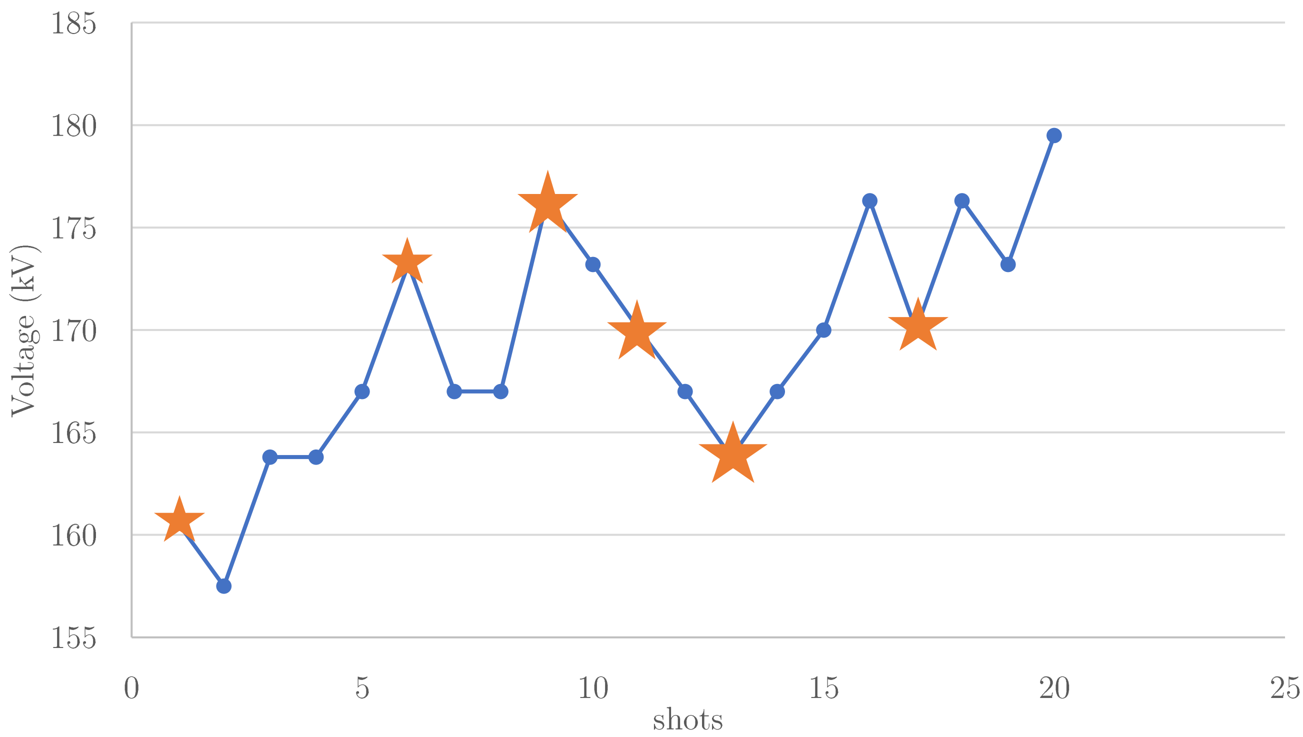


Figure A2: Representation of breakdown and withstand voltages after firing 20 shots in a U_{50} up-down test

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:

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

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

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:

$$K_t = K_1 K_2$$

$$= (1.08)1$$

$$= 1.08$$