EFFECT OF GAP LENGHTS OF SPHERE-SPHERE ELECTRODES ON AIR
BREAKDOWN LEVEL UNDER LIGHTNING IMPULSE

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A project report submitted in partial
fulfillment of the requirement for the award of the
Degree of Master of Electric Power

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JULY 2014

ABSTRACT

Rapid growth of high voltage technology gives the opportunity to engineer to do a study on the environmental protection. Production high voltage power is due to natural conditions that could harm and damage the ecosystem of the human condition. In electrical power system, HV power equipment are mainly subjected with spark over voltage. These over voltage which may causes by the lighting strokes, switching action, Normally, the standard sphere gaps are widely used for protective device in such electrical power equipment. The sphere gaps are commonly used for measurements of peak values of high voltages and have been adopted any designing in HV equipment. This project is study about the effect of gap length of sphere-sphere electrodes on air breakdown level under lightning impulse. This project is started by experimental setup and producing standard impulse voltage. The lightning impulse produce should be meets the specifications required by BS EN 60060-1:2010. The standard characteristic of impulse voltage T_1 / T_2 where T_1 is the front time while T_2 is time to half value also discussed. The procedure of the lab which implement also referred from Terco High Voltage Experiments. The method that will use in this project is Up and Down Method to obtain U_{50}. From this method, we can examine the average value of breakdown of an impulse lightning voltage is applied to the electrodes. The project also discusses about the electric field density while the impulse voltage is loaded into the sphere to sphere electrode and separated it at desire air gap by using the FEMM software. The characteristic either uniform or non-uniform results also present in this project. Level of insulations at desire gaps between the sphere's gap also obtain after complete this project.

ABSTRAK

Kepesatan teknologi voltan tinggi memberi peluang kepada jurutera untuk melakukan kajian dalam sektor pelindungan persekitaran. Penghasilan voltan tinggi daripada alam semulajadi mendatangkan bahaya dan kerosakan kepada ekosistem kehidupan manusia. Dalam sistem kuasa elektrik, *HV* peralatan kuasa tertakluk kepada voltan percikan. Voltan percikan tersebut boleh disebabkan oleh kilat dan petir, aksi pensuisan, Pada kebiasaannye, jurang antara sfera dalam rekabentuk perkakasan elektrik digunakan secara meluas untuk perlindungan kepada perkakasan elektrik. Projek yang dijalankan adalah mengkaji kesan perubahan jarak antara sfera dalam persekitaran udara biasa di bawah tekanan voltan *impulse*. Projek ini dimulakan dengan penghasilan voltan *impulse*. Voltan *impulse* yang diperolehi sepatutnya mengikut spesifikasi BS EN 60060-1:2010. Voltan *impulse* yang diperolehi mempunyai T_1/T_2 di mana T_1 adalah masa hadapan manakala T_2 adalah masa ketika separuh. Prosedur makmal yang dilaksanakan berdasarkan Eksperimen *Terco High Voltage*. Semasa di makmal, langkah Naik dan Langkah Turun dijalankan untuk mendapatkan nilai voltan U_{50}. Projek juga membincangkan tentang kekuatan medan voltan apabila sfera sfera diberikan voltan impulse dan dijarakkan pada jarak yang hendak dikaji menggunakan perisian FEMM. Hasil dapatan data kemudian diproses kemudiannya ditentukan ciriannya samada seragam atau sebaliknya .

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CHAPTER 1

PROJECT OVERVIEW

1.1   Introduction

Nowadays, the study of high voltage rapidly expanding in tandem with technology. Various studies and new findings about the high voltage that can offer security to users has attracted a lot more to learn about the science of high voltage. When discussing about the high voltage, the impression is the danger of high voltage electric shock that enables including fatal accidents, spark causing injury to humans and can also cause damage to electrical equipment. This project is discusses one of the important phenomenon in high voltage is breakdown voltage.

Breakdown voltage, sometimes also called dielectric strength or striking voltage, is the quantity of electrical force required to transform the electrical properties of an object. Most commonly, it is used with respect to insulators[1]. Many researches work has been done to understand the fundamental characteristics of the electrical breakdown. Breakdown voltage is a phenomenon where the quantity of an electrical force is required to transform the electrical properties of an object.

1.2   Problem Statement

In electrical power system, high voltage (HV) power equipment are mainly subjected breakdown voltage. These over voltage which may causes by the lightning strokes,

switching action, determine the safe clearance required for proper insulation level. In order to avoid these problems in high voltage power equipment, sphere-sphere electrodes on air breakdown level under lightning impulse is study and will present in this report. The characteristic of the breakdown voltage obtained from the study is used as an improvement in the design of any electrical equipment. For example in designing of transmission line, height is analyze accurately and to avoid voltage breakdown.

1.3 Objective

The main objective of the project is:
1. To study about the performance characteristic of impulse voltage.
2. To setup impulse voltage circuit.
3. To arrange sphere to sphere electrodes in breakdown voltage test.
4. To get U_{50} value using the Up and Down Method.
5. To simulate and analysis the air breakdown voltage for different gap between sphere to sphere using FEMM software
6. To analyze the effect of voltage applied and gap size against a field intensity produce by sphere-sphere electrodes.

CHAPTER 2

LITERATURE REVIEW

2.1 Breakdown voltage

Electrical breakdown or dielectric breakdown refers to a rapid reduction in the resistance of an electrical insulator when the voltage applied across it exceeds the breakdown voltage[2]. This results in a portion of the insulator becoming electrically conductive. Electrical breakdown may be a momentary event (as in an electrostatic discharge), or may lead to a continuous arc discharge if protective devices fail to interrupt the current in a high power circuit[3].

Under sufficient electrical stress, electrical breakdown can occur within solids, liquids, gases or vacuum. However, the specific breakdown mechanisms are significantly different for each, particularly in different kinds of dielectric medium[4].

2.2 Flashover

Flashover occurs due to the insulation resistance between the two rods is decreasing while the voltage between the two rods is increasing, causing the insulation is turned into a conductor and sustained arc[5]. This explanation is delegated shown at Figure 2.1.
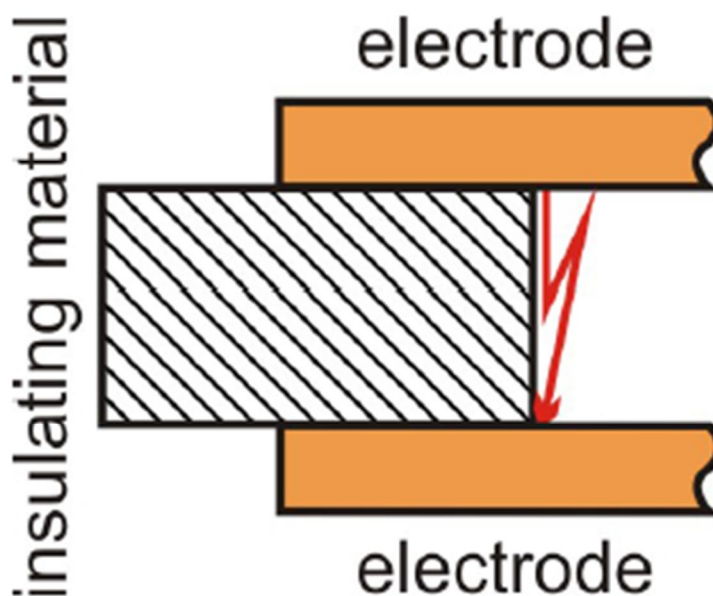
Figure 2.1: Electrode configuration for flashover [6].

2.3 Spark over voltage

A spark gap consists of an arrangement of two conducting electrodes separated by a gap usually filled with a gas such as air, designed to allow an electric spark to pass between the conductors as shown at Figure 2.2. When the voltage difference between the conductors exceeds the gap's breakdown voltage, a spark forms, ionizing the gas and drastically reducing its electrical resistance[6]. This usually happens when the voltage drops, but in some cases occurs when the heated gas rises, stretching out and then breaking the filament of ionized gas. Usually, the action of ionizing the gas is violent and disruptive, often leading to sound (ranging from a *snap* for a spark plug to thunder for a lightning discharge) light and heat[7].
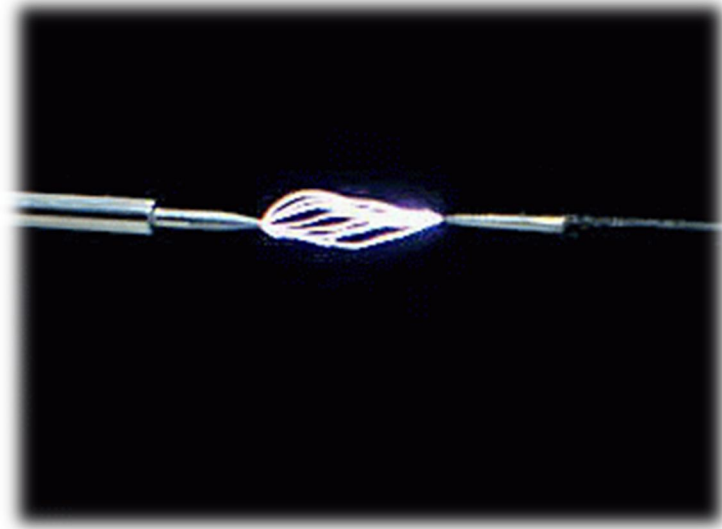
Figure 2.2: Spark over voltage occurred [7].

2.3.1   Townsend theory

Consider a simple electrode arrangement as shown in the Figure 2.1, having two parallel plate electrodes separated by a distance d and immersed in a gas at pressure *p*. A uniform *E* is applied between two electrodes. Due to any external radiation (ultra violet illumination) free electrons are liberated at the cathode. When an electron, *e* is placed in an *E* it will be accelerated with a force *eE* towards the anode.

This electron collides with the other gas molecules while it is traveling towards the anode. If the energy of the electron is sufficiently large (about 12.2 eV for N_2 or 15.5 eV for O_2), on collision it will cause a break-up of the atom or molecule into positive ion and electron, so the new electrons and positive ions are created. Thus created electrons form a group or an avalanche and reach the anode. This is the electric current and if it is sufficiently large it results in the formation of a conducting path between the electrodes resulting in the breakdown of the gap[8]. The Townsend theory also visual at Figure 2.3.

Visualisation of a Townsend Avalanche

Figure 2.3: Visualation of a Townsend Avalanche **[8].**

2.3.2   Paschen's Law

Paschen's Law is an equation that gives the breakdown voltage, that is the voltage necessary to start a discharge or electric arc, between two electrodes in a gas as a function of pressure and gap length. It is named after Friedrich Paschen who discovered it empirically in 1889[9].

Paschen studied the breakdown voltage of various gases between parallel metal plates as the gas pressure and gap were varied. The voltage necessary to arc across the gap decreased as the pressure was reduced and then increased gradually, exceeding its original value. He also found that at normal pressure, the voltage needed to cause an arc reduced as the gap size was reduced but only to a point. As the gap was reduced further, the voltage required to cause an arc began to rise and again exceeded its original value. For a given gas, the voltage is a function only of the product of the pressure and gap length. The curve he found of voltage versus the pressure-gap length product is called

Paschen's curve. He found an equation that fitted these curves, which is now called Paschen's law.

At higher pressures and gap lengths, the breakdown voltage is approximately proportional to the product of pressure and gap length, and the term Paschen's law is sometimes used to refer to this simpler relation[10]. However this is only roughly true, over a limited range of the curve as shown at Figure 2.4.
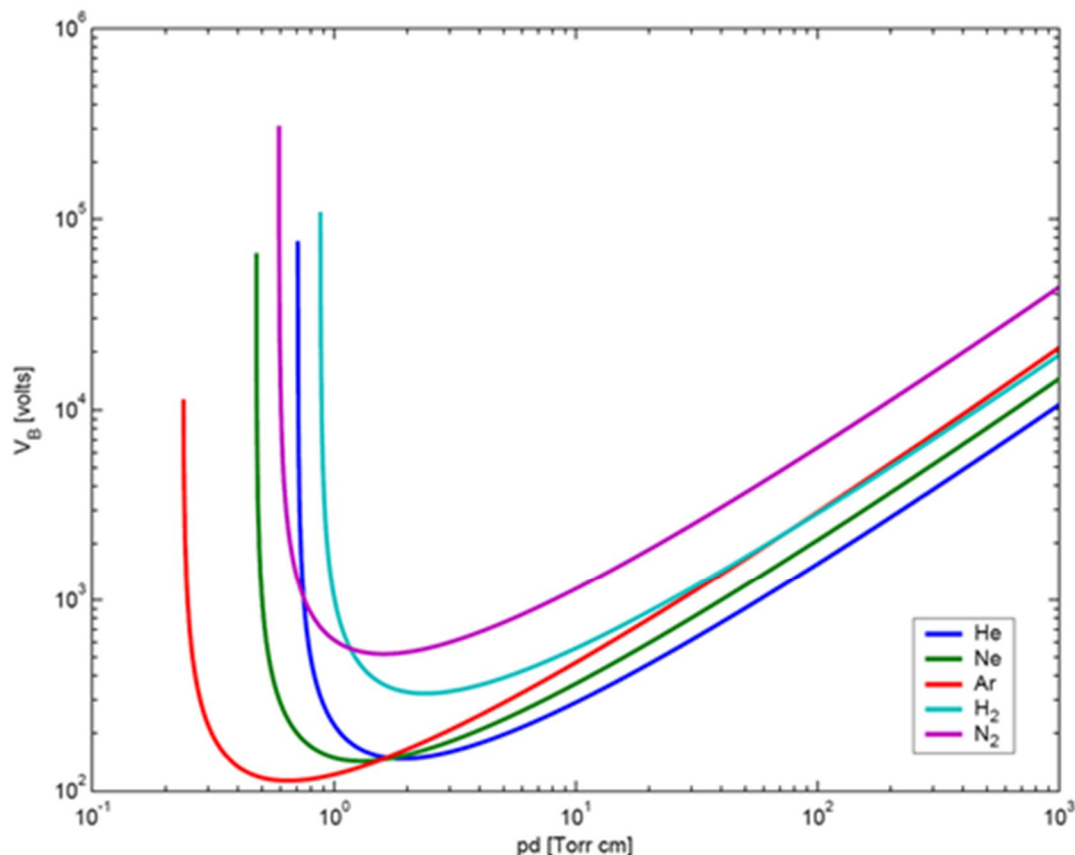
Figure 2.4 : Paschen Law Curve Characteristic [10].

2.4   Marx Generator

A Marx generator is an electrical circuit first described by Erwin Otto Marx in 1924. Its purpose is to generate a high-voltage pulse. Marx generators are used in high energy physics experiments, as well as to simulate the effects of lightning on power line gear and aviation equipment. A bank of 36 Marx generators is used by Sandia National Laboratories to generate X-rays in their Z Machine. The circuit generates a high-voltage

pulse by charging a number of capacitors in parallel, then suddenly connecting them in series[11]. See the circuit at Figure 2.5, at first, n capacitors (C) are charged in parallel to a voltage V by a high voltage DC power supply through the resistors (R_C). The spark gaps used as switches have the voltage V across them, but the gaps have a breakdown voltage greater than V, so they all behave as open circuits while the capacitors charge. The last gap isolates the output of the generator from the load; without that gap, the load would prevent the capacitors from charging. To create the output pulse, the first spark gap is caused to break down (triggered); the breakdown effectively shorts the gap, placing the first two capacitors in series, applying a voltage of about $2V$ across the second spark gap. Consequently, the second gap breaks down to add the third capacitor to the "stack", and the process continues to sequentially break down all of the gaps. The last gap connects the output of the series "stack" of capacitors to the load. Ideally, the output voltage will be nV, the number of capacitors times the charging voltage, but in practice the value is less. Note that none of the charging resistors R_c are subjected to more than the charging voltage even when the capacitors have been erected[12]. The charge available is limited to the charge on the capacitors, so the output is a brief pulse as the capacitors discharge through the load (and charging resistors). At some point, the spark gaps stop conducting and the high voltage supply begins charging the capacitors again.

The principle of multiplying voltage by charging capacitors in parallel and discharging them in series is also used in the voltage multiplier circuit, used to produce high voltages for laser printers and cathode ray tube televisions, which has similarities to this circuit[13]. The difference is that the voltage multiplier is powered with alternating current, and produces a steady DC output voltage, while the Marx generator produces a pulse[14]. The example of Marx Generator is shown at Figure 2.6.
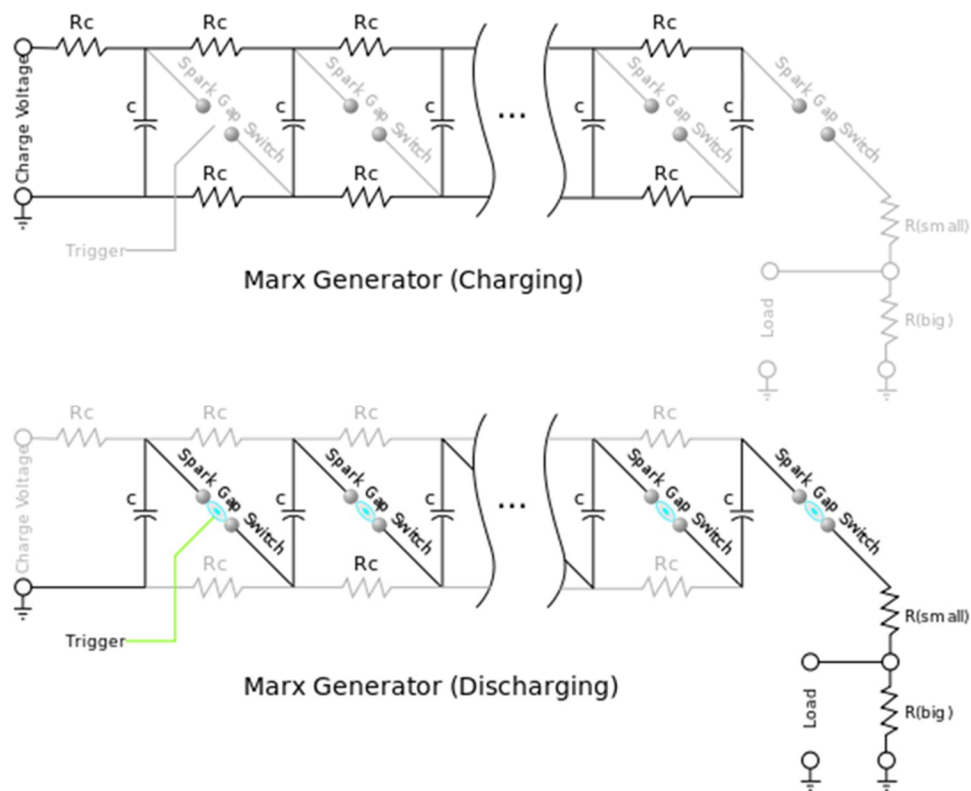
Figure 2.5 : Marx Generator connection during charging and discharge [12].

Figure 2.6: Marx Generator [14].

2.5   Lightning in Malaysia

Lightning strike comes about every day in the world. The lightning strike towards the surface on earth has been estimated at 100 times every second[15]. United State National Lightning Safety Institution reported that Malaysia has highest lightning activities in the world while the average thunder day level for Malaysia's capital Kuala Lumpur within 180 - 260 days per annum Isokeraunic level is approximately 200 thunderstorm days a year. The lightning ground flash density is about 15-20 strike per km per year[15].
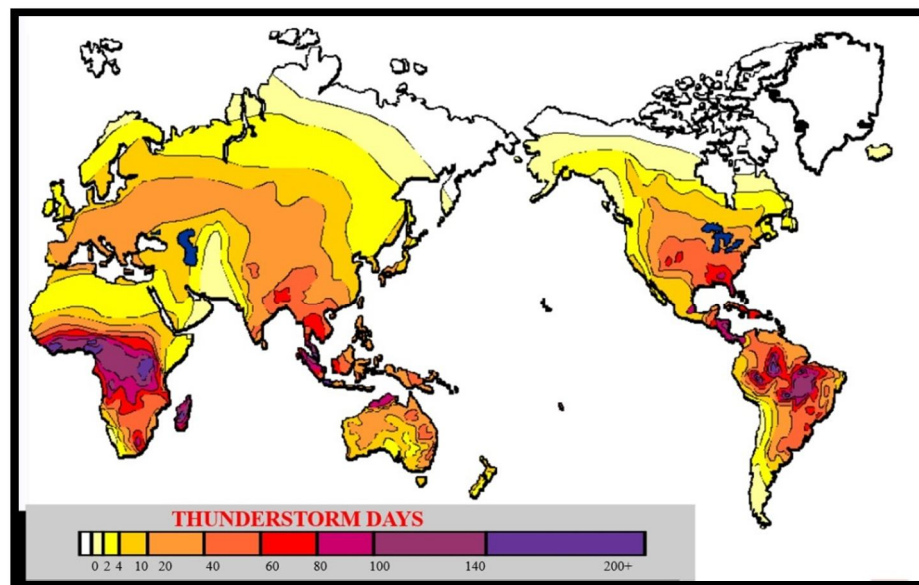
Figure 2.7 : World Isokeraunic Map [15].

Lightning has an extremely high current, high voltage and transient electric discharge. It is transient discharge of static electricity that serves to re-establish electrostatic equilibrium within a storm environment Malaysia lies near the equator and therefore it is categorized as prone to high lightning and thunderstorm activities[16]. Observations performed by the Malaysian Meteorological Services indicate that thunders occur 200 days a year in Malaysia. Thunderstorms have been suspected to have caused between 50% and 60 % of the transient tripping in the transmission and distribution networks for Tenaga Nasional Berhad (TNB), Malaysia's electric power provider[17]. The main reason could be short of precise and consistent.

CHAPTER 3

METHODOLOGY

This chapter discusses about the method have been done to develop this research. Before we discuss about the methodology of air breakdown voltage's experiment, the Impulse Voltage Generator test setup is shown in Figure 3.1. The main supply of the voltage generator is AC supply then convert into the DC supply which will used as input voltage of Impulse Voltage Generator. Table 3.1 shows the equipment used in the Impulse Voltage Generator test setup. Figure 3.2 also is present about the block diagram on operation the Impulse Voltage is produced.
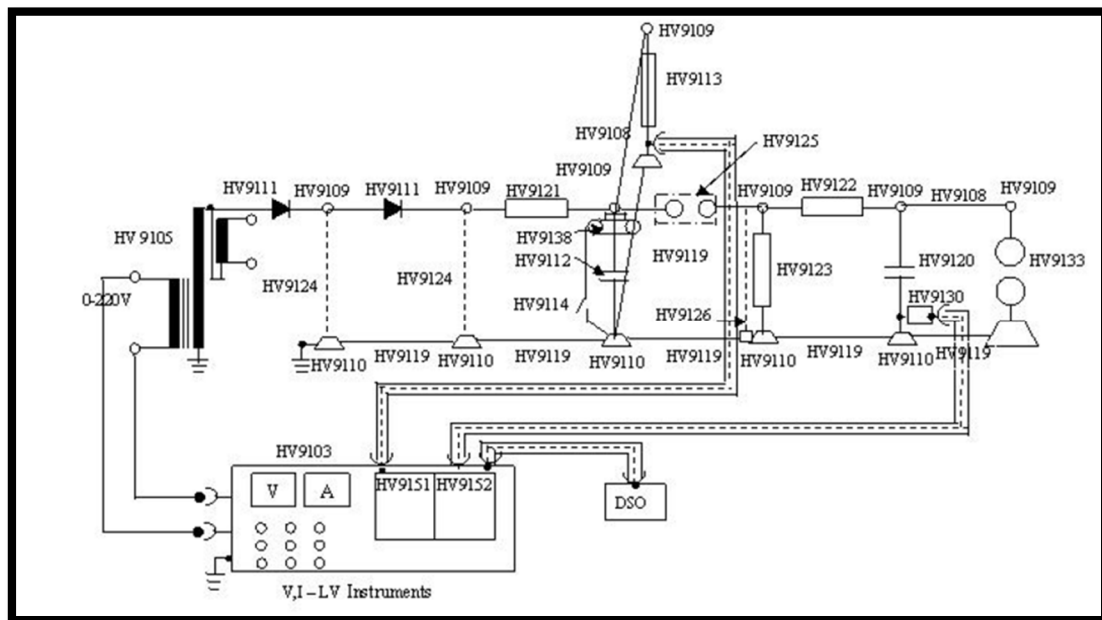
Figure 3.1: Impulse Voltage Generator test setup [14]

Table 3.1: Table of list equipment

Component Description	TERCO type	Quantity
HV Test Transformer	HV9105	1
Control Desk	HV9103	1
Smoothing Capacitor	HV9112	1
Load Capacitor	HV9120	1
Silicon Rectifier	HV9111	2
Measuring Resistor	HV9113	1
Charging Resistor	HV9121	1
Wavefront Resistor	HV9122	1
Wavetail Resistor	HV9123	1
Sphere Gap	HV9125	1
Drive for sphere gap	HV9126	1
Insulating Rod	HV9124	2
Connecting Rod	HV9108	2
Connecting cup	HV9109	7
Floor Pedestal	HV9110	6
Space Bar	HV9119	4
Electrode	HV9138	1
Earthing Switch	HV9114	1
Earhting Rod	HV9107	1
DC Voltmeter	HV9151	1
Impulse Peak Voltmeter	HV9152	1
Measuring Spark Gap	HV9133	1
Spacer Bar (for HV9133)	HV9118	1
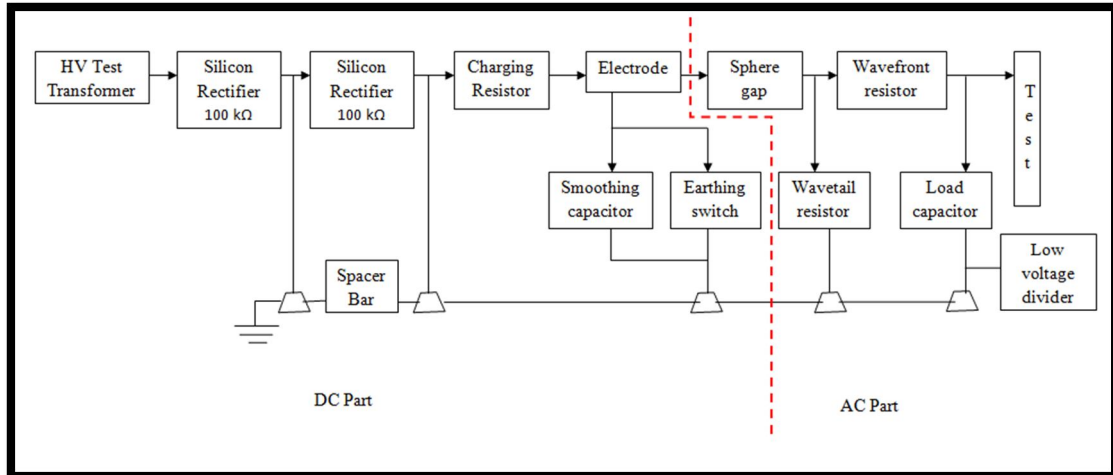
Figure 3.2 : Block Diagram [14]

In our test, we used the Single Stage Test Set Up as shown at Figure 3.3, which contain Silicon Rectifier as Figure 3.4 and Charging Rectifier as Figure 3.5. Silicon Rectifier used to convert the AC input from the transformer into DC output to produce the Impulse Voltage.

Figure 3.3:Single Stage Test Set-Up

Figure 3.4: Silicon Rectifier

Figure 3.5: Charging Rectifier

Figure 3.6: Control Desk

The Control Desk is used to control and operate high voltage AC/DC Impulse test equipment. The desk contains operating and signal elements for the control circuit of the test equipment for warning and safety. The control desk is made to house the measuring instruments (Peak, Impulse and DC Voltmeters) and also the Trigger Device.

The electrode as shown in Figure 3.7 is sphere to sphere which used in this research. The sphere to sphere is separated at desired gap and gaps will be measured every time of changes.

Figure 3.7: Sphere gap

3.1 Impulse Voltage

The impulse voltage produced then were measured and compared it's characteristic to the theoretical impulse voltage as shown in Figure 3.8. The value of the test voltage is the maximum voltage that was sketched in the graph also the total value of the test voltage on the circuit switching impulse[18]. Time to peak is the time needed from the true origin voltage to the maximum voltage value of the switching impulse voltage. The standard lightning-impulse voltage is a smooth full lightning-impulse voltage having a front time of 1.2 μs and a time to half-value of 50μs and described as a 1.2/50 impulse. The important terms that we should know about the lighting impulse characteristic is the front time, which label as a virtual parameter defined as the time interval between the virtual origin O_1, and the instant when the test voltage curve has decreased to half the test voltage value
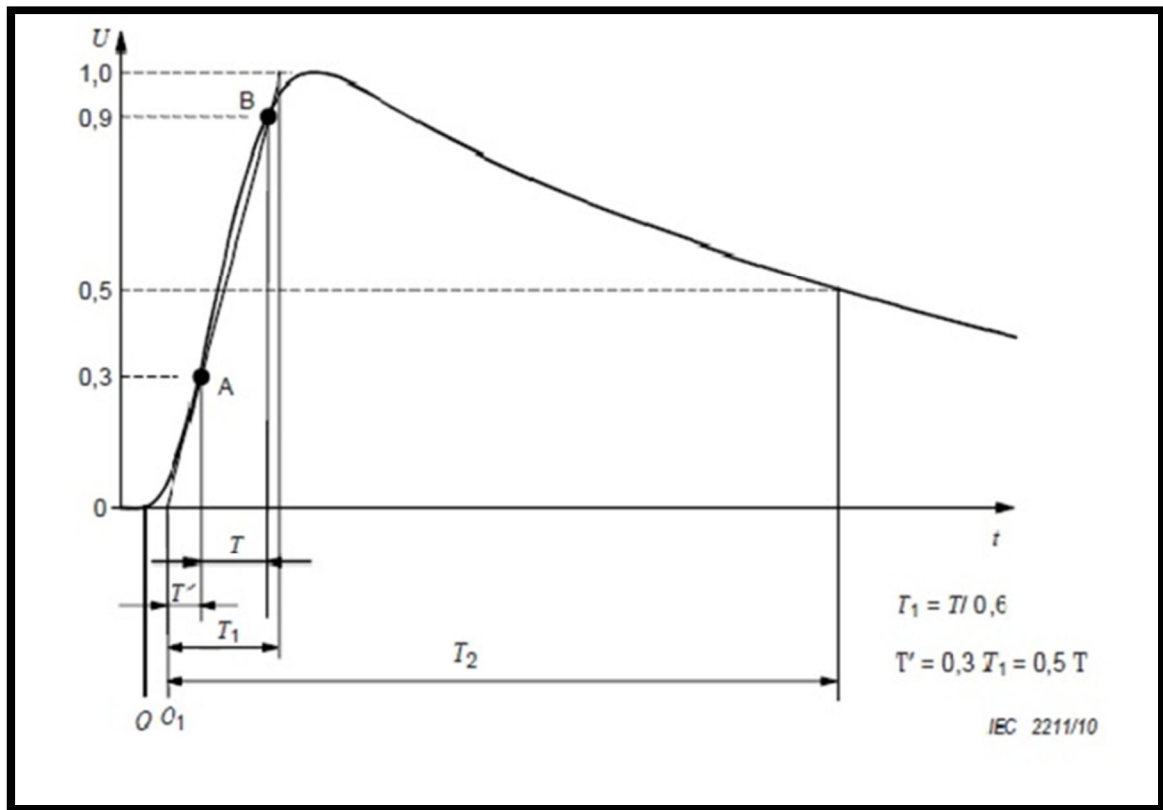
Figure 3.8 : Switching impulse voltage [18].

3.1.1   Tolerances

When we are getting the impulse voltage during our test, we need to consider about the tolerance. Tolerance is the value that we are accepted from the test voltage curve compare to the calculated value from the test curve. The test voltage value is accepted if ±3 % from test voltage, front time accepted ±30 %, and time to half value ±20 % vary from standard curve.

3.2   Test Setup U_{50}

This section discusses the procedures carried out in these experiments in the High Voltage Laboratory. Safety measures must be taken into consideration before doing this

experiment to avoid any untoward incidents happen. The measures carried out are set out below.

1. Make sure all switches are in the off state. This is important to make sure to start the test.

2. Entering the cage, grounding the component as transformer, capacitor, silicon rectifier, sphere gap and other components by using the earthing rod as shown in Figure 3.9. This is important to make sure that the power is totally discharged before starts a new test.

Figure 3.9: Grounding the component using earthing rod

3. The electrodes sphere to sphere is installed at the desired gap. The minimum is set up at the initial lab then, continued to increase the gap between the electrodes. As shown in Figure 3.10, the gap is measured accurately at every change of gaps.

Figure 3.10 : Gap measuring

4. After than that, the cage is locked. We are only able to start the test after the cage is properly locked.

5. First of all, the control desktop is ON by the key. The main switch is now can ON till the green is light indicated.

6. The voltage regulator knob is reduced at minimum value to confirm that the input of the rectifier is zero. Figure 3.11 shows the interface on the control desktop during the startup of testing

Figure 3.11 : Control Desktop interface

7. Sphere gap is observed to make sure that the sphere didn't touched each other. Figure 3.12 is show the sphere gap is not touch each other while figure 3-13 shows the measuring gap between the spheres. If the spheres connected, the impulse voltage can't to produce to for our test. The gap can be controlled Impulse Sphere Gap's knob at control desk.

Figure 3.12 : Sphere to sphere cant touched each other

Figure 3.13: Measuring gap between sphere to produce Impulse Voltage

8. The button primary and secondary is ON. The voltage now can be increased till the impulse voltage occurred. The impulse voltage's waveform is captured by the oscilloscope and will be discussed in the next chapter.

9. The voltage now is increased and decreased by using the up and down method at the minimum gap till 20 times to get the U_{50} value.

10. The up and down method also repeated after increased the gap between the electrode.

3.2.1 Up and down method.

The technique we used in this research is the up-and-down method. The up-and-down method the voltage level is increased by an amount ΔU if no disruptive discharge occurs in a group of n voltage applications, otherwise the voltage level is decreased by the same amount after there is a breakdown is occur. In the discharge procedure, the voltage level is increased by ΔU if one by the same amount. In all cases the voltage interval between levels ΔU should be approximately from 1.5 % to 3 % of the estimated value of u_{50}

Up and down method is used to get the U_{50} from our test. By referring the Figure 3.14 shows the flow on doing our test. The test per gap is repeated for 20 times by averaging the value of voltage. This step is applied at the 1cm, 1.5cm, 2cm, 2.5cm and 3cm sphere – sphere's gap.
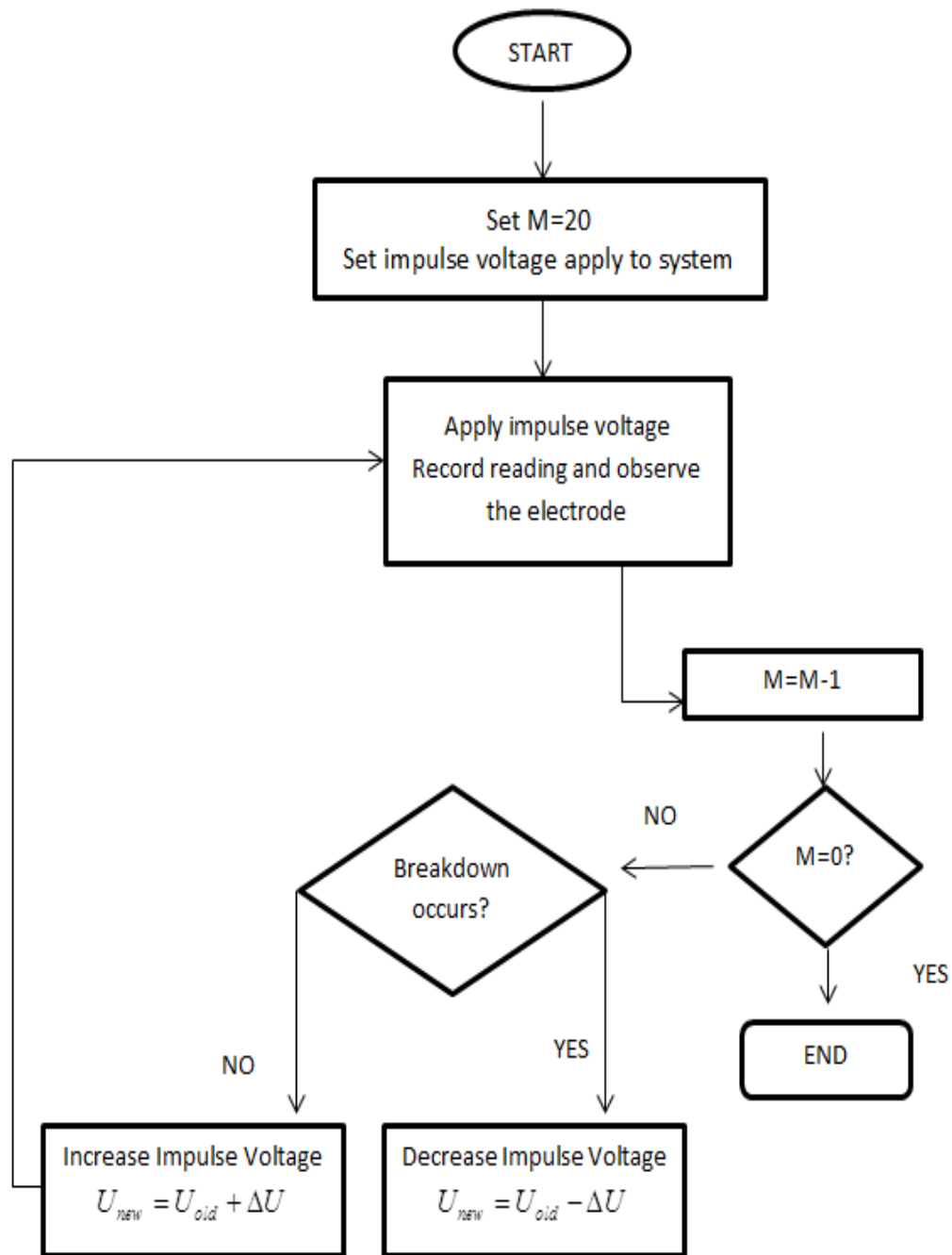
Figure 3.14 : Flow Chart Up and Down Method

3.3   Drawing the electrode using FEMM software.

At this stage, we are using FEMM software to simulate the Field Intensity Voltage at desired gap. When draw the sphere to sphere in this software, we are using the actual diameter sphere electrode that we use in the lab. The sphere electrodes that used in this test was 5cm diameter as shown in Figure 3.15.

Figure 3.15 : Diameter of sphere's electrode

Regarding to the Figure 3.16, the actual diameter is using to our simulation using FEMM software. While draw the sphere is set to axisymmetric so that only need draw half of sphere's dimension.

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