AIR BREAKDOWN UNDER LIGHTNING IMPULSE WITH PLANE-PLANE ELECTRODE

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ABSTRACT

Breakdown voltage is a phenomenon where the quantity of an electrical force is required to transform the electrical properties of an object. In other words, breakdown voltage is also called the striking voltage. This breakdown voltage of an insulator is the minimum voltage that can cause some part of the insulator to become electrically conductive. The high voltage power equipment is mainly subjected to spark over voltage. Spark over can be useful in some cases (for example spark plug) and may give side effect or damage (sparking in switching devices) to machine. Therefore the research about the behavior of spark over and breakdown voltage is significant in electrical engineering designing process. The project is started with experimental setup to get the standard impulse voltage. This lightning impulse voltage is ensured to follow the standard of BS EN 60060-1:2010. The procedure of this experiment follows the TERCO catalogue documentation. In this project, the standard plane to plane gap is used to measure the peak value of DC impulse voltages. The gap length between the planes will be varied. Lightning-impulse voltage is an impulse voltage with a front time less than 20µs. In this project, the FEMM software is used for modeling and analysis of electric field distribution in plane to plane electrode. This software provides a wide range of simulation applications for controlling the complexity of both modeling and analysis of a system. The electrodes gap distances are being varied to 5 different gaps which are 10 mm, 15 mm, 20 mm, 25 mm and 30 mm. The simulation of electric field was done for plane to plane electrode arrangement with 5 different gaps and the result of analyzing using FEMM will be discussed here.

ABSTRAK

Voltan Jatuhan adalah satu fenomena di mana kuantiti satu kuasa elektrik diperlukan untuk mengubah sifat-sifat objek elektrik . Dalam erti kata lain, voltan jatuhan juga dikenali sebagai voltan yang bercahaya (kilat). Voltan jatuhan penebat yang minimum boleh menyebabkan beberapa bahagian dalam penebat untuk menjadi elektrik konduktif. Peralatan kuasa voltan tinggi terutamanya tertakluk untuk mencetuskan voltan lebihan. Percikan api yang lebih amat berguna dalam beberapa kes (contohnya palam pencucuh) dan ianya boleh memberi kesan sampingan atau kerosakan dalam mencetuskan peranti beralih kepada mesin. Oleh itu penyelidikan tentang tingkah laku palam pencucuh voltan jatuhan adalah penting dalam proses bentuk kejuruteraan elektrik . Projek ini bermula dengan eksperimen untuk dapatkan nilai voltan 'impulse standard'. Voltan gerak kilat ini adalah untuk memastikan mengikut standard BS EN 60060-1:2010. Prosedur eksperimen ini selaras dengan dokumentasi Katalog TERCO. Dalam projek ini, standard 'Plane to Plane' di gunakan untuk mengukur nilai puncak voltan impuls DC . Panjang jurang antara 'Plane to Plane' akan diubah. Voltan kilat-impuls adalah voltan impuls dengan masa depan kurang daripada 20µs. Dalam projek ini, perisian FEMM di gunakan untuk pemodelan dan analisis taburan medan elektrik dalam 'Plane to Plane ' elektrod. Perisian ini menyediakan pelbagai aplikasi simulasi untuk mengawal kerumitan kedua-dua model dan analisis sistem. Jarak jurang elektrod 'Plane to Plane' diubah untuk 5 jurang yang berbeza iaitu 10 mm, 15 mm, 20 mm, 25 mm dan 30 mm. Simulasi medan elektrik telah dilakukan untuk 'Plane to Plane' elektrod dengan 5 jurang yang berbeza dan hasil daripada analisis yang dilakukan dengan menggunakan perisian FEMM akan dibincangkan di sini.

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CHAPTER 1

PROJECT OVERVIEW

1.1 Introduction

Rapid growth in power sector of nation has given the opportunity to empower engineers to protect the power equipment for reliable operation during their operating life. It has been seen from the studies conducted by power engineers that one of the main problems in high voltage power (HV) equipment is the degradation of insulation quality of power equipment. As the high voltage power equipment are mainly subjected with spark over voltage causes by the lightning strokes, a protective device is used to determine the safe clearance required for proper insulation level. The plane gaps of different configuration are commonly used for this purpose.

The electric breakdown strength of an air-insulated gap between two plane metal electrodes can be improved considerably by an experiment. In the past several decades, extensive amount of research work has been done to understand the fundamental characteristics of the electrical breakdown [1]. Therefore, electrical breakdown characteristic of small air gap under the different applied voltage has its great significance for the design of overhead line, substation equipment and various air insulated HV equipment.

In this study to simulate the air breakdown voltage experimentally in high voltage laboratory is used for measurement of air breakdown voltages and electric field of the high voltage equipment. The above experiment is conducted at the normal temperature and pressure. In addition the influence of the air breakdown test has also been considered in this study. The simulation of such air breakdown voltage has been carried out in the FEMM software. Finally, the experimental result has been compared with theoretical, and simulation results.

1.2 Problem Statement

Over the past few years, the advancement of simulation tools technology have shown a great increase of researches done on Air breakdown under lightning impulse. These factors include the physical parameters of the electrodes (Plane, sphere, point and needle).

In electrical power system, high voltage (HV) power equipment is mainly subjected with spark over voltage. There have many advantages and disadvantages for that issue.

One of the advantage, is to produce high voltages for laser printers and cathode ray tube televisions, which has similarities to auto ignition for the spark plug to start the engine**.** Such example can be seen if a Transmission line (High Voltage) is not properly installed at actual distance or gap. It can be a disadvantage to human and can bring an effect like a sparking. So the technology is important and must be designed for our safety and benefit.

1.3 Objective

In electrical power system, high voltage (HV) power equipment is mainly subjected with spark over voltage. These over voltage may be cause by the lighting strokes will determine the safe clearance required for proper insulation level.

To avoid these problems in high voltage power equipment, plane gap method is considered as one of the standard methods for the measurement of peak value of DC impulse voltages. This method is used for measuring air breakdown under lightning impulse. The plane gap method is not complex and the accuracy is acceptable.

The main objectives of the report are:

a. To study setup circuit to generate impulse voltage lightning of air breakdown voltage with plane to plane electrode.
b. To study the method in finding the U_{50} voltage of impulse voltage using standard plane to plane for experimental setup in different gap plane electrode.
c. To find the electric field intensity |E| using FEMM software comparison in all the studies.
d. To clarify the point of the electrode that produces the maximum electric field.

CHAPTER 2

LITERATURE REVIEW

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. Under sufficient electrical stress, electrical breakdown can occur within air, gases, liquids and solids [3]. However, the specific breakdown mechanisms are significantly different for each, particularly in different kinds of dielectric medium.

2.1 Breakdown Voltage of Air

The breakdown in air (spark breakdown) is the transition of a non-sustaining discharge into a self-sustaining discharge. The buildup of high currents in a breakdown is due to the ionization in which electrons and ions are created from neutral atoms or molecules, and their migration to the anode and cathode respectively leads to high currents [4].

Townsend theory are the present types of theories which explain the mechanism of breakdown under different conditions as temperature, pressure, nature of electrode surfaces, electrode field configuration and availability of initial conducting particles . Normally air medium is widely used as an insulating medium in different electrical power equipment and overhead lines as its breakdown strength is 30kV/cm [5].

2.2 Lightning

Lightning is a massive electrostatic discharge between the electrically charged regions within clouds or between a cloud and the surface of a planet. The charged regions within the atmosphere temporarily equalize themselves through a lightning flash, commonly referred to as a *strike* if it hits an object on the ground [6].

Lightning is also the occurrence of a natural electrical discharge of a very short duration and high voltage between a cloud and the ground or within a cloud, accompanied by a bright flash and typically also thunder.

Hazards due to lightning obviously include a direct strike on human or property. However, lightning can also create dangerous voltage gradients in the earth, as well as an electromagnetic pulse, and can charge extended metal objects such as telephone cables, fences, and pipelines to dangerous voltages that can be carried many miles from the site of the strike. Although many of these objects are not normally conductive, very high voltage can cause the electrical breakdown of such insulators, causing them to act as conductors [7]. Lightning strikes also start fires and explosions, which result in fatalities, injuries, and property damage. (See Figure 2.1)

Figure 2.1: Lightning [6]

2.3 Spark Over

A spark gap (see Figure 2.2) 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. When the voltage difference between the conductors exceed the gap's breakdown voltage, a spark forms, ionizing the gas and drastically reducing its electrical resistance [8]. This usually happens when the voltage drops, but in some cases 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.

The dielectric breakdown the strength of dry air, at Standard Temperature and Pressure (STP), the spherical electrodes is approximately 33 kV/cm. This is only as a rough guide, since the actual breakdown voltage is highly dependent upon the electrode shape and size. Strong electric fields (from high voltages applied to small or pointed conductors) often produce visible sparks [9]. Even a small 9 V battery can spark noticeably by this mechanism in a darkened room.

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Figure 2.2: Spark Over [8]

2.4 Flashover

A flashover (Figure 2.3) is a near-simultaneous ignition of most of the directly exposed combustible material in an enclosed area. When certain organic materials are heated, they undergo thermal decomposition and release flammable gases. Flashover occurs when the majority of the exposed surfaces in a space are heated to their auto-ignition temperature and emit flammable gases [10].

An example of flashover is when a piece of furniture is ignited in a domestic room. The fire involving the initial piece of furniture can produce a layer of hot smoke which spreads across the ceiling in the room. The hot buoyant smoke layer grows in depth, as it is bounded by the walls of the room. The radiated heat from this layer heats the surfaces of the directly exposed combustible materials in the room, causing them to give off flammable gases via pyrolysis [11]. When the temperatures of the evolved gases become high enough, these gases will ignite, throughout their extent.

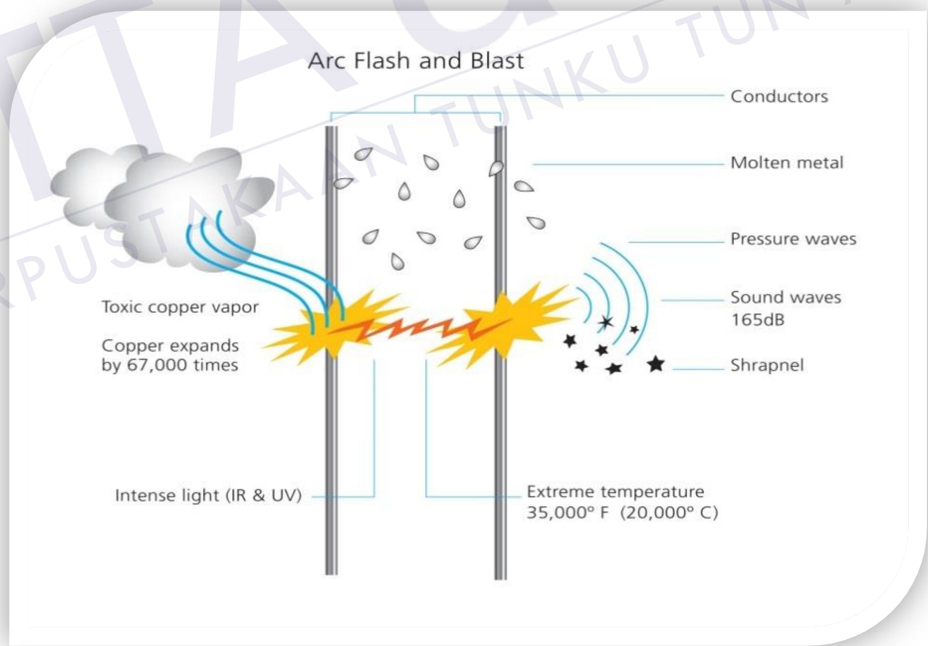

Figure 2.3: Flashover [10]

2.5 Finite Element Method Magnetic (FEMM)

FEMM is a suite of programs for solving low frequency electromagnetic problems on two-dimensional planar and axisymmetric domains. The program currently addresses linear/nonlinear magneto static problems, linear/nonlinear time harmonic magnetic problems, linear electrostatic problems, and steady-state heat flow problems [12].

Finite element method is used in a wide variety of engineering problems like solid mechanics, dynamics, heat problems, fluids and electrostatic problems. Finite element analysis cuts a structure into several elements (pieces of the structure). This process results in a set of simultaneous algebraic equations. The behavior of electric field is based on the nature of electrodes (uniform and non-uniform). Finite element method uses the concept of piece wise polynomial interpolation. By connecting elements together, the electric field quantity becomes interpolated over the entire structure in piece wise fashion. In this method indeterminate structures are solved [13]. It can handle complex loadings like nodal load (point loads), element load (pressure, thermal and inertial forces) and time or frequency dependent loading.

The modeling and analysis of electric field distribution in plane to plane electrode is done by using FEMM software. In this software to construct plane gap arrangement using all the required numerical and physical parameters. And find out maximum electric field in between plane electrodes. The apparatus, shown in Figure 2.4, consists mainly of two vertically fixed plane electrodes separated with a gap. The electrodes serve as the electrodes that are connected to a high-voltage transformer driven by the frequency-convertible power supply. Two planes were made with aluminum.

Figure 2.4: Plane to Plane

2.6 Townsend Theory

The Townsend discharge is a gas ionization process where free electrons, accelerated by a sufficiently strong electric field, give rise to electrical conduction through a gas by avalanche multiplication caused by the ionization of molecules by ion impact. When the number of free charges drops or the electric field weakens, the phenomenon ceases [14].

The Townsend discharge is named after John Sealy Townsend, who discovered the fundamental ionization mechanism by his work between 1897 and 1901. It is also known as a "Townsend avalanche".

Townsend mechanism when applied to breakdown at atmospheric pressure was found to have certain drawbacks. Firstly, according to the Townsend theory, current growth occurs as a result of ionization processes, only. But in practice, breakdown voltages were found to depend on the gas pressure and the geometry of the gap [15].

While the Townsend mechanism predicts a much diffused form of discharge, in actual practice, discharges were found to be filamentary and irregular. (See Figure 2.5)

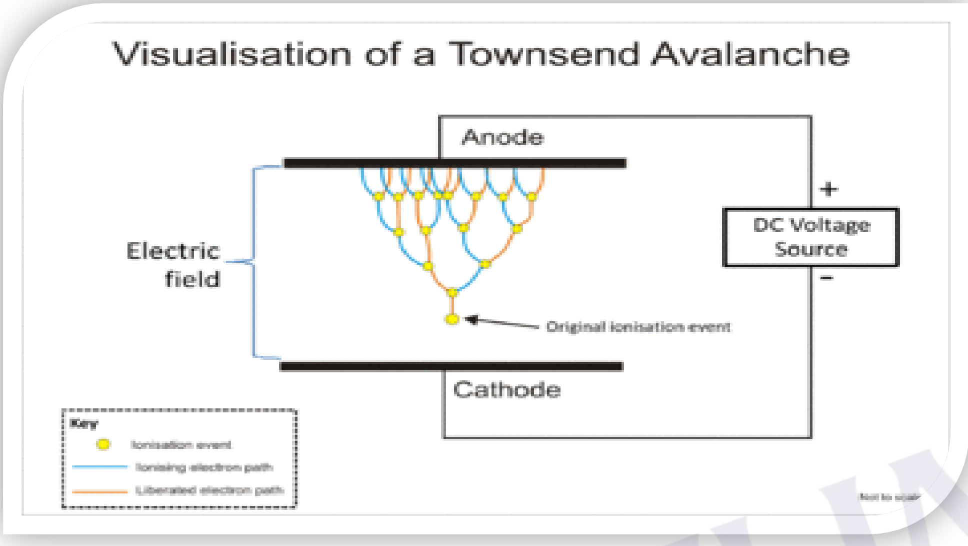

Figure 2.5: Townsend [14]

2.7 Paschen's Law Theory

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 [16].

Paschen studied the breakdown voltage of various gases between parallel metal plates as the gas pressure and gap distance 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 [17]. 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 *(right)* is called **Paschen's curve**. He found an equation that fitted these curves, which is now called Paschen's law. (See Figure 2.6)

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. However this is only roughly true, over a limited range of the curve.

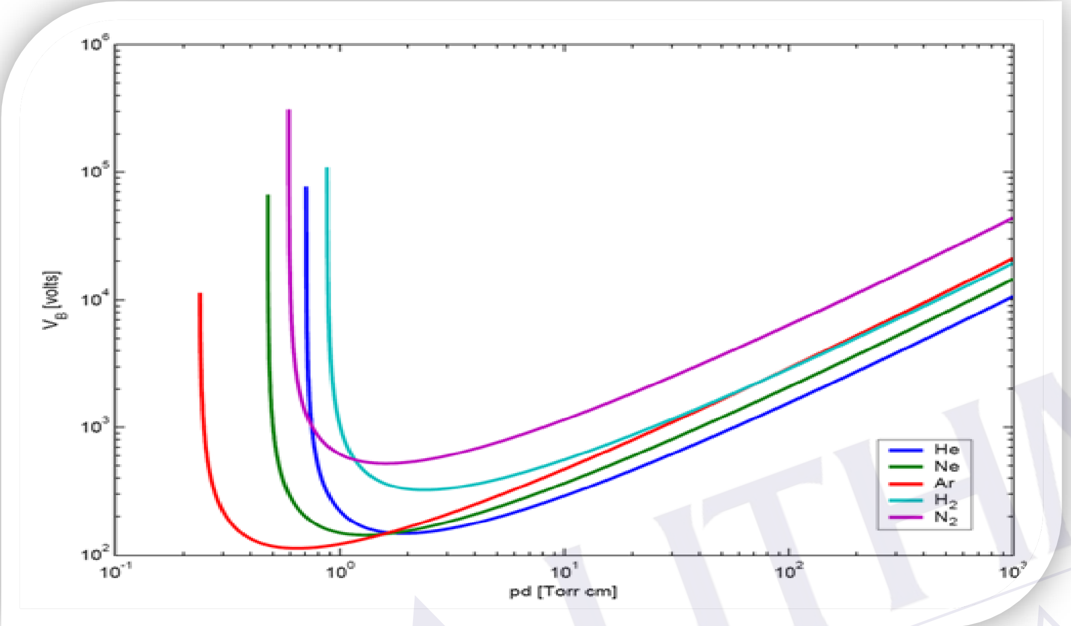

Figure 2.6: Paschen's Law [16]

2.8 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 [18].

The circuit generates a high-voltage pulse by charging a number of capacitors in parallel, then suddenly connecting them in series. See (Figure 2.7). 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.

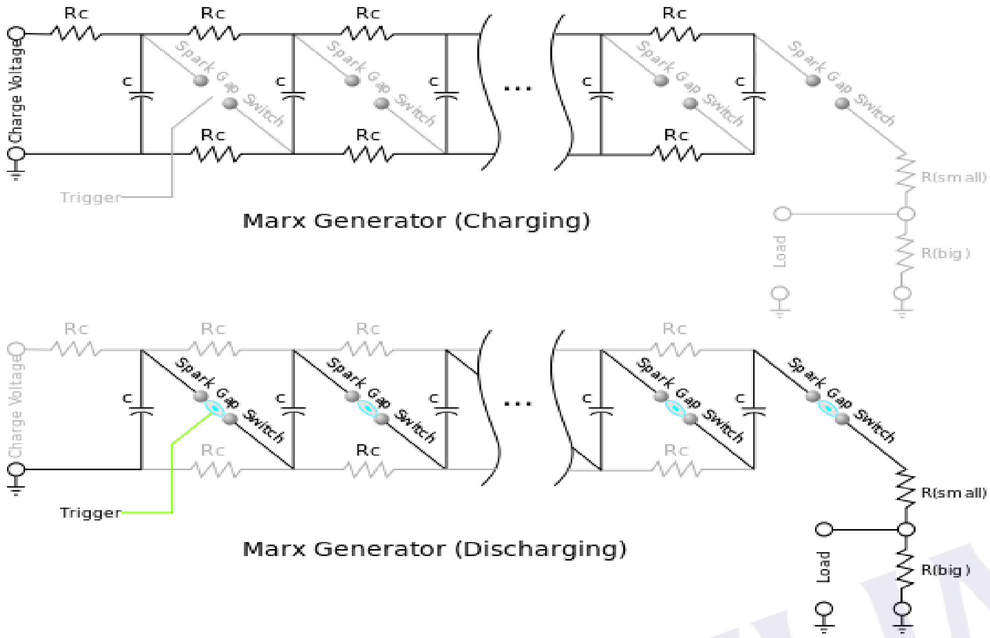

Figure 2.7: Circuit Marx Generator

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 2*V* 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. 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, it is used to produce high voltages for laser printers and cathode ray tube televisions, which has similarities to this circuit. Marx generators are used to provide high-voltage pulses for the testing of insulation of electrical apparatus such as large power transformers, or insulators used for supporting power transmission lines. Voltages applied may exceed 2 million volts for high-voltage apparatus. (See Figure 2.8)

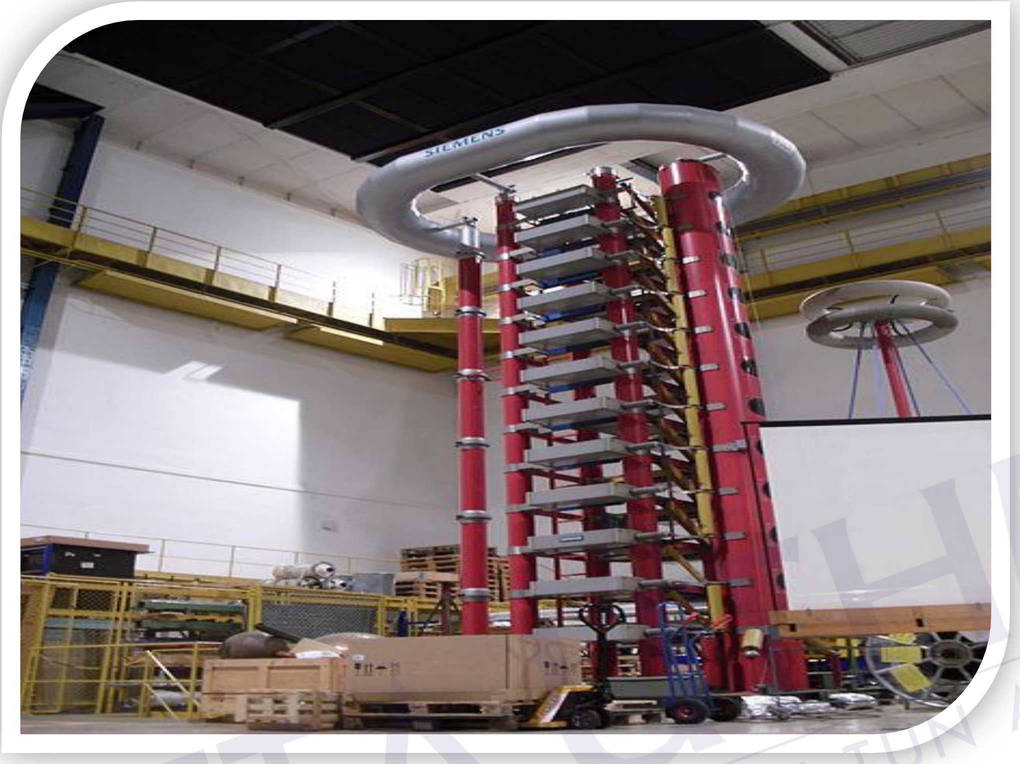

Figure 2.8: Marx Generator [18]

CHAPTER 3

METHODOLOGY

3.1 Safety Regulations for High Voltage Experiments

Experiments with high-voltages could become particularly hazardous for the participants should the safety precautions be inadequate. To give an idea of the required safety measures, an example of the safety regulations followed in several High Voltage Laboratories shall be described below.

These supplement the appropriate safety regulations and as far as possible prevent risks to human. Strict observance is therefore the duty of every one working in the laboratory. Here any voltage greater than 250 V against earth is understood to be a high voltage.

The fundamental rule before entering a high-voltage setup area is everybody must convince themselves by personal observation that all the conductors assume as high potential and lie in the contact zone are earthed, and that all the main leads are interrupted. The equipment, schematic diagram (test setup) and block diagram must be used when conducting this experiment. This is shown in Table 3.1, Figure 3.1 and Figure 3.2

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