# LIGHTNING IMPULSE TESTS ON AIR-BREAKDOWN LEVEL IN POINT-PLANE ELECTRODE CONFIGURATION

MOHD DASRI BIN CHE MOK @ ADNAN

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Faculty of Electrical and Electronics Engineering
Universiti Tun Hussein Onn Malaysia

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*Dedicated and thankful appreciation for the love, pray and encouragement.*
*To my beloved wife, Siti Nuridayu binti Md Yusof,*
*special son, Muhammad Akif Rifqi and daughter, Nur Arissa Raisya,*
*lovely father, Adnan bin Mat Saat and mom, Mek Limah binti Ab Rahman,*
*wonderful siblings, Mohd Herman and Noor Idayu.*

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# ABSTRACT

In the past several decades, extensive amount of research 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. Many factors that lead to the breakdown voltage are still not fully discovered. These factors are including the physical parameters of the electrodes (sphere, plane, point etc.) and also the environmental conditions. In electrical power system, high voltage (HV) power equipment is mainly subjected with spark over voltage. In this study, point electrode and plane electrode have been used for the experimental study of the short air gap. The electrodes are vertically aligned. In order to simulate the performance characteristic of the air breakdown voltage and maximum electric field between the conducting point and plane electrodes, the electrodes is taken into considered in this work using FEMM simulation. The air breakdown voltages between the electrodes (point and plane) are measured by conducting the air breakdown voltage experiment in high voltage laboratory and corresponding electrical field strength. The electrodes gap distances are being varied to 5 different gaps which are 5mm, 10mm, 15mm, 20mm and 25mm. In order to achieve maximum strength in such a field, the point of the highest stress is controlled. From the experiment, it was established that the point at the electrode that produces maximum electric field is at the point with the smallest area or width. As for point electrode, the smallest area is at the angle of the electrode. Besides, it shows that the electrical breakdown characteristic is affected by the strength of the impulse voltage. Higher gap distance between the electrodes will result higher breakdown-impulse voltage while higher breakdown-impulse voltage will produce higher field intensity.

# ABSTRAK

Sejak berdekat yang lalu,pelbagai kajian telah dijalankan untuk memahami ciri-ciri asas bagi kejatuhan voltan. Kejatuhan voltan merupakan satu fenomena di mana suatu jumlah daya elektrik diperlukan untuk menukar perakuan elektrikal sesuatu objek. Kebanyakan faktor yang menyebabkan kejadian kejatuhan voltan masih belum dikenal-pasti sepenuhnya. Di antara faktor-faktor ini ialah parameter fizikal elektrod (sfera, *'plane'*, *'point'* dll) dan juga keadaan persekitaran. Dalam sistem kuasa elektrik, peralatan bagi voltan tinggi (HV) kebiasaannya dipengaruhi oleh voltan *'spark over'*. Dalam kajian ini, *'point'* elektrod dan *'plane'* elektrod telah digunakan untuk menjalankan ujikaji dengan jarak perantaraan yang kecil. Elektrod-elektrod ini disusun secara menegak. Bagi mendapatkan karektor kejatuhan voltan di udara dan juga medan elektrik yang maksimum di antara elektrod *'point'* dan *'plane'* ini, simulasi telah dijalankan menggunakan FEMM Simulation. Kejatuhan voltan di udara antara elektrod (*'point'* dan *'plane'*) telah diperolehi melalui kajian kejatuhan voltan di udara bertempat di makmal voltan tinggi dengan mengambil kira kekuatan medan elektrik. Jarak di antara elektrod dikelaskan kepada 5 jarak yang berbeza iaitu 5mm, 10mm, 15mm, 20mm dan 25mm. Untuk mendapatkan kekuatan maksimum bagi setiap medan, batasan bagi tekanan tinggi adalah dikawal. Ujikaji telah membuktikan titik pada elektrod yang menghasilkan medan elektrik yang maksimum adalah pada titik yang mempunyai permukaan atau lebar yang paling kecil. Bagi elektrod *'point'*, permukaan yang paling kecil adalah pada bucu elektrod. Di samping itu, karektor kejatuhan voltan adalah dipengaruhi oleh kekuatan voltan denyut. Semakin jauh jarak perantaraan akan mengakibatkan nilai kejatuhan voltan denyut yang tinggi manakala kejatuhan voltan denyut yang tinggi akan menghasilkan kekuatan medan yang lebih tinggi.

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# CHAPTER 1

# PROJECT OVERVIEW

## 1.1 Introduction

In the past several decades, extensive amount of research 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. In other words, breakdown voltage is also called as the striking voltage or the dielectric strength.

There are many situations that show the level of breakdown voltage occurs, which one of them is the electrodes gap breakdown. The factors that lead to the breakdown voltage such as the physical parameters of the electrodes itself which are including the effective area of an electrode and the electrodes gap length. Besides, the environmental conditions also contribute in the electrodes gap breakdown voltage, for example the humidity, pressure and the temperature. There are many previous experimental works done that show the effects of these factors to the breakdown voltage.

The plane gaps are seldom used for measurements of peak values of high voltages instead of sphere gap. Many materials are used to make point/plane electrode like aluminum, steel, brass, light alloys, bronze and copper. The electric breakdown strength of a gas-insulated gap between two metal electrodes can be improved considerably when one or both of the electrodes are covered with a dielectric coating. The effect of the coating depends on the electrode shape, voltage polarity, pre-charging and the duration and form of the applied voltage [1].

Therefore, electrical breakdown characteristic of small air gap under 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 at UTHM, a standard point and plane electrodes are going to be used for measurement of air breakdown voltages and electric field of the high voltage equipment. Yet, the simulation of such air breakdown voltage also has been carried out in the FEMM environment.

## 1.2 Problem Statement

Many factors that lead to the breakdown voltage are still not fully discovered. These factors are including the physical parameters of the electrodes (sphere, plane, point etc.) and also the environmental conditions.

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

## 1.3 Objective

The main objectives of the project are:

- To plan and conduct the practical experiment of air breakdown voltage in high voltage laboratory.
- To find the air breakdown voltage for different gap between point and plane electrodes using standard point-plane experimental setup.
- To find the air breakdown voltage for different value of impulse voltage between point and plane electrodes using standard point-plane experimental setup.
- To clarify the point at the electrode that produces maximum electric field.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Lightning Overview

Lightning primarily occurs when warm air is mixed with colder air masses, resulting in atmospheric disturbances necessary for polarizing the atmosphere. 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 [2].

From the beginning of written history, lightning has fascinated mankind. It was the magic fire from the sky that man captured and used to keep warm at night. It kept the savage animals away. As primitive man sought answers about the natural world, lightning became a part of his superstitions, his myths and his early religions. Lightning research is divided into various disciplines, some of which are:

- Atmospheric Physics and Electrostatics
- Electrical Engineering
- Climatology, including thunderstorm morphology and dynamics
- Meteorology and other sub-sectors

Figure 2.1: Lightning [2]

## 2.2 Electrical Breakdown of Gasses

Under normal circumstances atmospheric air is considered as a good insulator and a charged insulator or insulated body bill loose it's charge slowly when surrounded by air. The reason for this to happen is that air, as a rule, contains very few mobile charge carriers, atmospheric ions. But sometimes a charge body may interact with grounded surroundings in such a way that the ion concentration is substantially increased locally. Such an event is called *an* ***electrical breakdown*** [3].

The breakdown is usually caused by the effect of an electrical field on the already existing mobile charge carriers in the air, atmospheric ions an a few free electrons both originating from natural radioactive decay. The ions as well as the free electrons participate in the random, thermal movement of the molecules. It should be stressed that the thermal energy of ions as well as of electrons is far too low to make a thermal collision result in an electron being knocked off an air molecule, i.e. causing ionization.

However, if an electric filed exists in the gas, the charged particle will be accelerated in the field and gain an extra kinetic energy. If a particle with the charge q is moved a distance $\Delta x$ by a filed with the strength E the particle gains an increase in it's kinetic energy provide the particle doesn't collide with other particles over the distance $\Delta x$. Since an electron and a negative air ion both carry an elementary charge (e) they will gain the same increase in energy if they travel the same distance.

Moreover, due to the difference in size, the electron is able to travel much longer between collisions with other particles than is the ion. The mean distance to be traveled between collisions is called the ***mean free path*** [4].

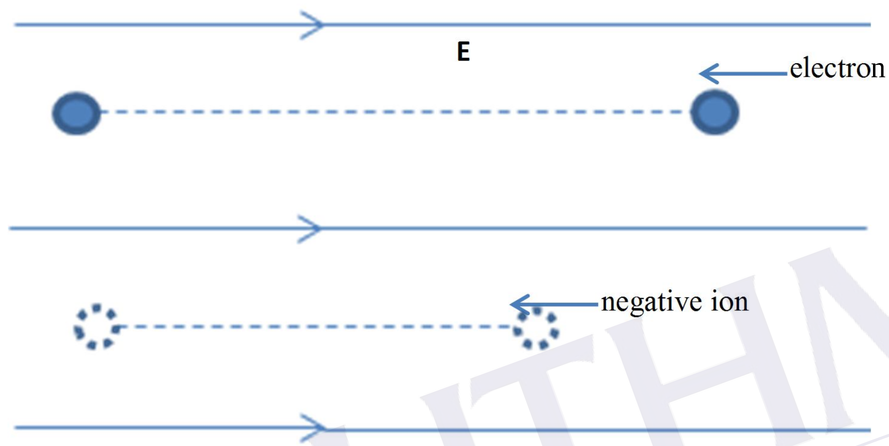


Figure 2.2: Mean free path in Homogenous Electric Field E [3]

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## 2.3 Spark Over

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. An electric current then flows until the path of ionized gas is broken or the current reduces below a minimum value called the "holding current".

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, light and heat [5].

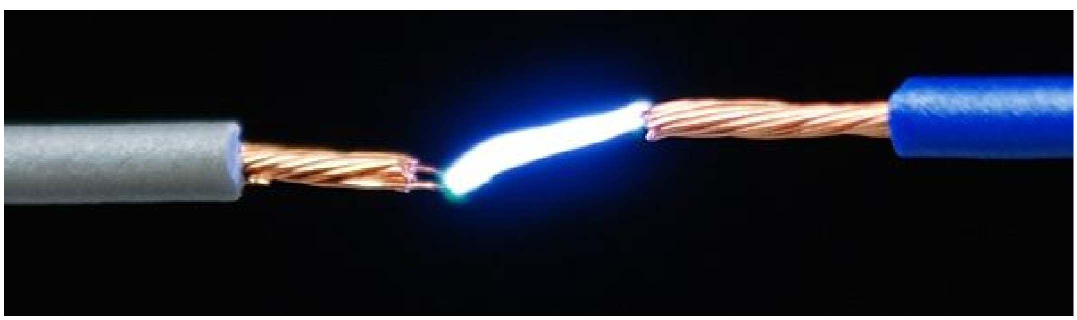

Figure 2.3: Spark over [5]

## 2.4 Flashover

Flashover is one of the most-feared Phenomena among firefighters. A flashover is the 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 is heated to their auto ignition temperature and emits flammable gases [6].

Flashover normally occurs at 500 C (930°F) or 1,100°F for ordinary combustibles, and an incident heat flux at floor level of 1.8 Btu/ft$^2$*s (20 kW/m$^2$). The flashover behavior of several materials is mostly investigated for spark length longer than 1 cm. It is well known that, for example, the surface conductance or rather partly conductive coatings on insulator surface.

Figure 2.4: Flashover [6]

## 2.5 High Voltage Test

In order to ensure each of electrical equipment is capable of withstanding overvoltage during operation, suitable testing procedure should be done through the equipment. High voltage testing can be broadly classified into testing of insulating materials (samples of dielectrics) and tests on completed equipment. The tests carried out on samples of dielectric consist generally of the measurement of permittivity, dielectric loss per unit volume, and the dielectric strength of the material.

The high voltage test can be made in AC or DC. If the high voltage test is made in DC, it is then combined with insulation; if the high voltage test is made in AC, it is then, more stressful for the sample and made according to the sketch below.

Measurement of high voltage test under alternating current is performed using an alternating voltage (50Hz) adjustable to an effective 50V to 1,500V. As is the case with direct current, the high voltage test detects any sudden rise of current up to a programmed threshold [7].

The short circuit test is maintained by default. The rise time is more than 500 ms and the application time at least one period. The high voltage test under alternating current is penalized by the capacitive value of the tested equipment. It must be remembered that the generator power is limited to 5 mA.

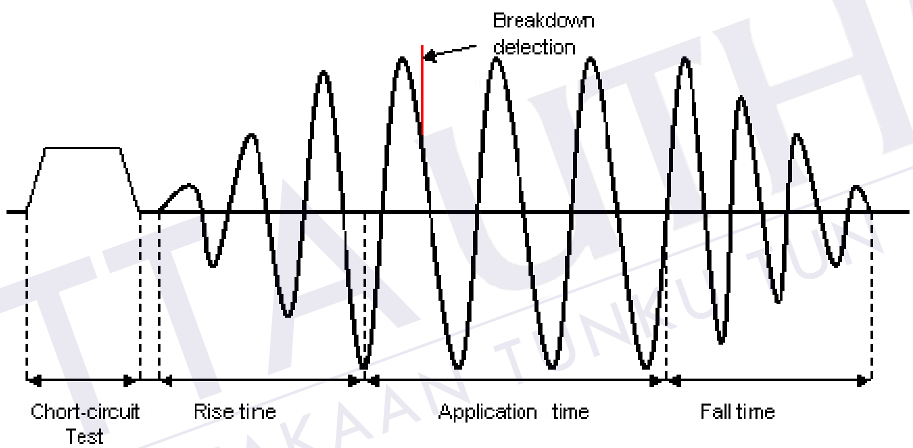


Figure 2.5: Breakdown Detection [7]

## 2.6 Marx Generator

Marx generators can produce high voltage pulses using multiple, identical stages that operate at a fraction of the total output voltage without the need for a step-up transformer that limits the pulse rise times and lowers the efficiency of the system. Each Marx stage includes a capacitor or pulse forming network and a high voltage switch. Typically these switches are spark gaps resulting in Marx generators with low repetition rates and limited lifetimes [8].

The development of economical, compact, high voltage, high di/dt, and fast turn-on solid state switches makes it easy to build economical, long lifetime, high voltage Marx generators capable of high pulse repetition rates.

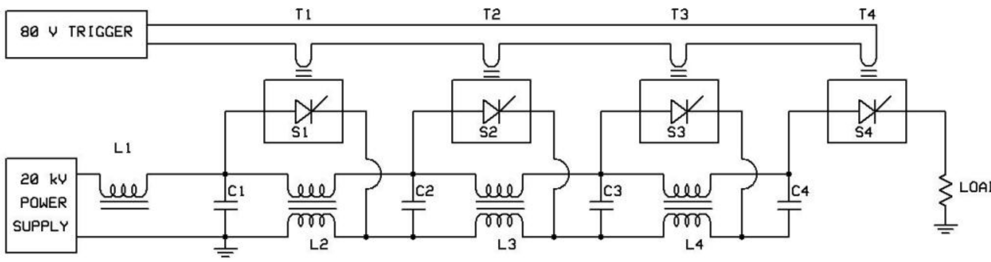


Figure 2.6: Simplified schematic of the solid state Marx generator [8]

The Marx generator uses FOUR (4) stages operating at up to 20 kV, which are effectively charged in parallel and discharged in series to produce up to an 80 kV pulse.

A simplified schematic of the modulator is shown in Figure 2.6. The 20 kV power supply, charges C1 through C4 via common mode chokes, L1 – L4. S1 – S4 are the 24 kV solid state switches. The primaries of trigger transformers T1-T4 are connected in series to insure simultaneous triggering. As a result an 80 V trigger pulse is required. The primary winding is a single turn of Belden Type 8866 high voltage cable looped [9].

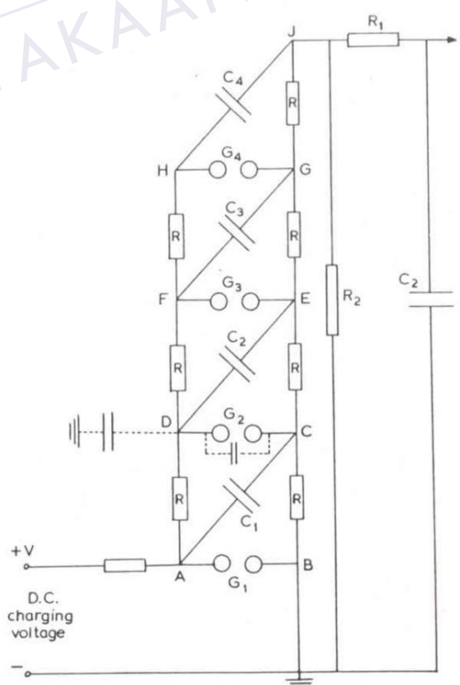


Figure 2.7: Basic circuit of a 4 stages impulse generator [9]

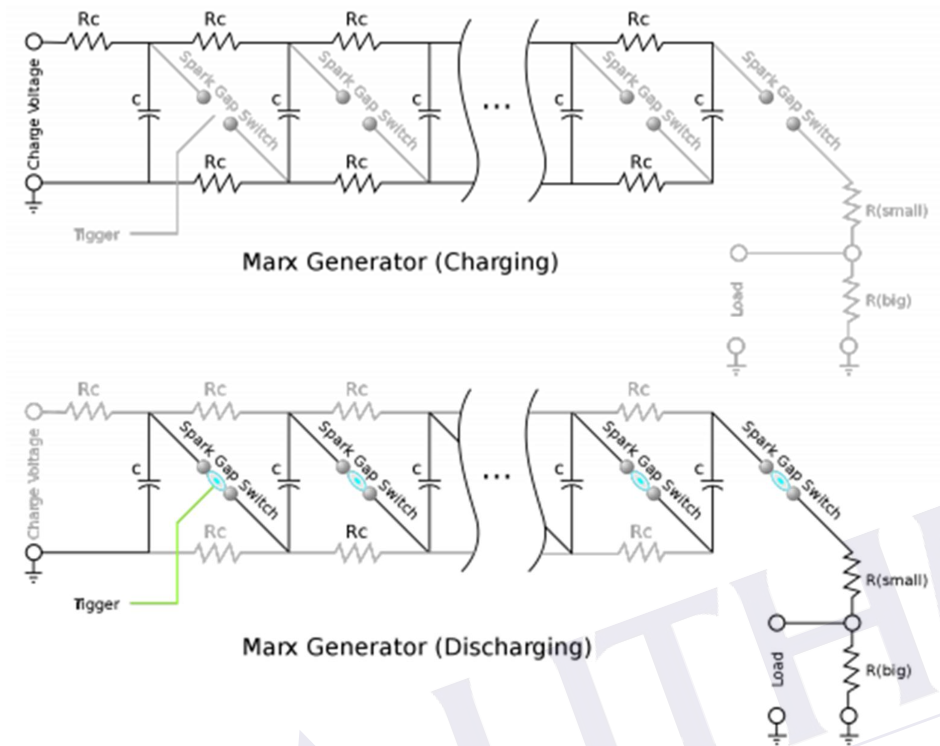


Figure 2.8: Mark Generator (Charging and Discharging) [10]

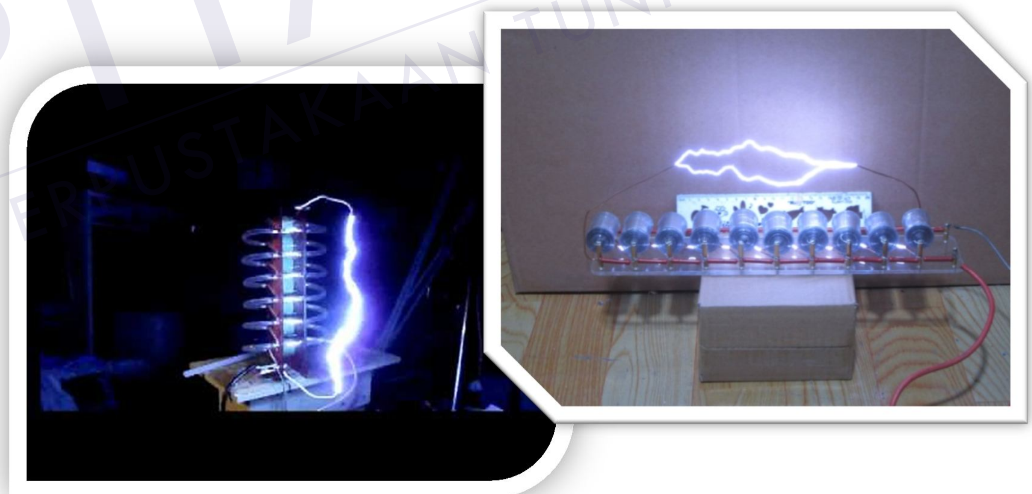

Figure 2.9: One of the DIY Mark Generator [10]

## 2.7 Paschen's Law

Paschen's Law which is named after Friedrich Paschen is often referenced when in voltage breakdown calculations. It's an empirical relationship that predicts electrical breakdown (sparking) based on gap, pressure and gas properties. The equation gives the breakdown voltage, which 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.

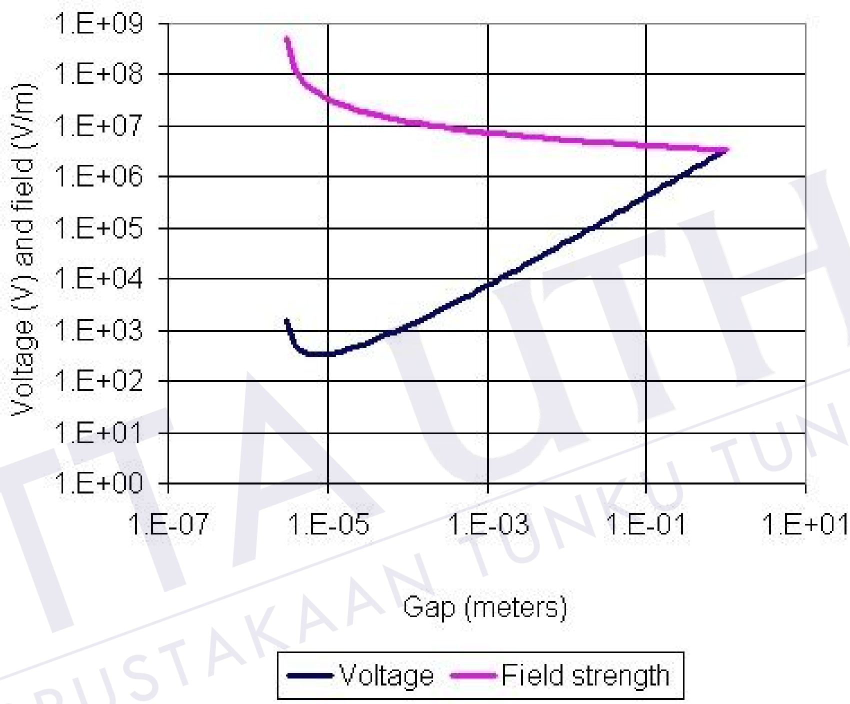


Figure 2.10: Paschen's Law Breakdown Voltage and Field Strength [11]

The breakdown voltage of various gases between parallel metal plates being studied as the gas pressure and gap distances were varied. The voltage necessary to arc across the gap decreased as the pressure was reduced and then increased gradually, exceeding its original value. 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 of voltage versus the pressure-gap length product (right) is called Paschen's curve [10].

## 2.8 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].

FEMM is divided into THREE (3) parts which are:

• Interactive shell (femm.exe).

- This program is a Multiple Document Interface pre-processor and a post-processor for the various types of problems solved by FEMM. It contains a CADlike interface for laying out the geometry of the problem to be solved and for defining material properties and boundary conditions. Autocad DXF files can be imported to facilitate the analysis of existing geometries. Field solutions can be displayed in the form of contour and density plots. The program also allows the user to inspect the field at arbitrary points, as well as evaluate a number of different integrals and plot various quantities of interest along user-defined contours.

• triangle.exe.

- Triangle breaks down the solution region into a large number of triangles, a vital part of the finite element process. This program was written by Jonathan Shewchuk and is available from his Carnegie-Mellon University web page at http://www.cs.cmu.edu/˜quake/triangle.

• Solvers (fkern.exe for magnetics; belasolv for electrostatics);

- hsolv for heat flow problems; and csolv for current flow problems. Each solver takes a set of data files that describe problem and solves the relevant partial differential equations to obtain values for the desired field throughout the solution domain [12].

## 2.9 Breakdown Application

### 2.9.1 Spark Gap

Spark gaps were used historically in early electrical equipment, such as spark gap radio transmitters, electrostatic machines, and X-ray machines. Their most widespread use today is in spark plugs to ignite the fuel in internal combustion engines, but they are also used in lightning arrestors and other devices to protect electrical equipment from high-voltage transients [13].

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 [14].

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. An electric current then flows until the path of ionized gas is broken or the current reduces below a minimum value called the "holding current" [15].

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 [16].

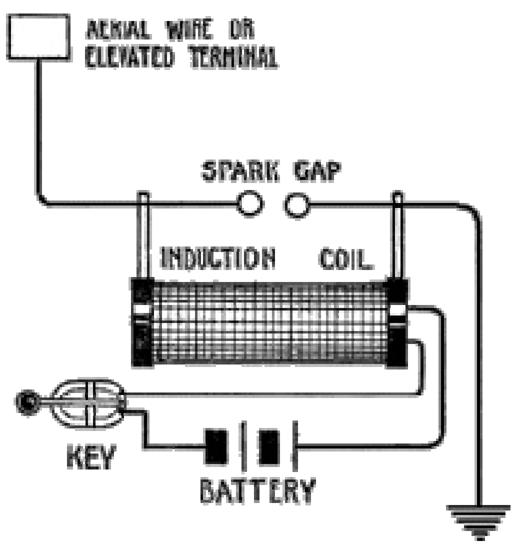


Figure 2.11: Simple Spark Gap Transmitter [17]

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