EFFECT OF FIELD UTILIZATION FACTOR ON AIR BREAKDOWN LEVEL UNDER IMPULSE LIGHTNING IN POINT-SPHERE ELECTRODE SYSTEM

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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

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious and the Most Merciful Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this thesis. Firstly, I would like to express my deepest thanks to, and appreciation to my supervisor, Dr Muhammad Saufi bin Kamarudin, for his supervision and constant support. His invaluable help of constructive comments and suggestions throughout the experimental and thesis works have contributed to the success of this research. Not forgotten, my appreciation to UTHM High Volatge Lab assistant engineer En. Norazizi bin Hamisan for his support and knowledge regarding this topic. I would like to express my appreciation to all PESISIR Lecturer for their support and help towards my postgraduate affairs.

Sincere thanks and appreciation to my mother, my family, to all my friends especially Ahmad Azlan bin Hamzah, Mohd Dasri bin Che Mod @ Adnan, Nik Aznan bin Abdul Hadi, Hafizah Binti Nor Azmuddin, Hairierosniza Binti Rosdi and others for their kindness and moral support during the final year project progress till it is fully completed. Thanks for the friendship and memories.

Last but not least, my deepest gratitude goes to my mother Khatijah Binti Mohd Ghani and my Wife, Suzie Masayu binti Abdul Rahman for their endless love, prayers and encouragement. Also not forgetting to those who indirectly contributed in this research, your kindness means a lot to me. Thank you very much.

Suhaimi Abdullah @ Abdul Rahman, June 2014

ABSTRACT

Nowadays, the high voltage power is very important to industries. Due to growing of technology, the power equipment also improves and innovates to have the best performance. The high voltage power equipment is mainly subjected to spark over voltage. Spark over can be useful in some cases and may give bad effect or damage the machine. Therefore the research on the behavior of spark over, breakdown voltage is signified in the electrical engineering designing process. The project is started with an experimental setup to get the standard impulse voltage. This lightning impulse voltage is ensuring 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 point-sphere gap is use to measurements of U_{50} breakdown voltages. A metallic point electrode is separated by a certain distance form a sphere gap. Also, the gap length between the spheres will be varied from 1 cm to 3 cm. The procedure to get U50 is followed to Up and Down method. FEMM software is use for simulation and analysis of electric field distribution for point-sphere electrode. This software provides a wide range of simulation applications for controlling the complexity of both modelling and analysis of a system. The value of U_{50} obtained is used in this simulation. The characteristic of field intensity will be analysed for all gaps. The average of field intensity and field utilization factor F.U.F will be analysed by using this software

ABSTRAK

Dalam era ini, sumber kuasa voltan tinggi sangat penting kepada industi. Dengan perkembangan teknologi pada hari ini, perlalatan sistem kuasa juga berkembang dan berinovasi dari segi prestasi dan keupayaanya. Voltan *spark over* sangat meberi kasan keatas peralatan kuasa voltan tinggi. Dalam sesetengah kes, kewujudan *spark over* mampu memberi manfaat dan pada sesetengah kes ianya mungkin mendatangkan keburukan. Denga itu, kajian keatas perilaku spar over sangat penting teruatmanya dalam proses rekabentuk elektrikal. Projek ini dimulakan dengan menyediakan keperluan eksperimen untuk menghasilkan voltan *impulse* yang standard.. voltan *impulse* ini dipastikan berlaku mengikut piawaian yang telah ditetapkan oleh BS EN 60060-1:2010. Prosedur melakukan eksperimen ini dilakukan dengan mengikut arahan dalam dokumen TERCO. Untuk projek ini, point – sfera electrod digunakan untuk menetukan nilai kejatuhan voltan U_{50}. Elektrod metalik berbentuk point dan sfera akan dipisahkan oleh udara dalam jarak yang tertentu. Jarak pemisah juga ditepkan dan diubah-ubah dalam linkungan 1 cm hingga 3 cm. Dalam eksperimen ini, kaedah *Up and Down* digunapakai dalam menetukan nilai U_{50}. Perisian FEMM juga digunapakai dalam proses mensimulasi dan menganalisa medan elektrik keatas radas elektrod point-sfera tersebut. Perisian ini mampu memberikan analisa yang tepat dan pelbagai khusus untuk model yang kompleks seperti projek ini. Nilai U_{50} yang diperolehi dalam eksperimen ini akan digunapakai untuk proses simulasi. Analisa keatas intensiti medan elektrik akan dianalisa untuk semua gap. Juga purata intesiti medan elektrik dan faktor penggunaan F.U.F akan dianalisa menggunaka perisian ini.

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CHAPTER 1

PROJECT OVERVIEW

1.1 Introduction

Nowadays, the high voltage power is very important to industries. Due to growing of technology, the power equipment also improves and innovates to have the best performance. The high voltage power equipment's is mainly subjected to spark over voltage. For example, the lighting strikes, switching action and a protective device are related to the air gap breakdown studied especially to determine the safe clearance required for proper insulation level. Thus the study of air breakdown voltage is important and is needed in the power system.

There are many of research has been done before to understand the fundamental of the voltage breakdown. The research result of voltage breakdown characteristics has a great significance to power technology, especially for designing an overhead line, substation equipment and various air insulated HV equipment.

The study of breakdown voltage is important to see the spark over behavior between two electrodes with the specific gap in the air. In this project two different shapes of conductor (point-sphere), will be experimental to measure the voltage breakdown value. Impulse lightning voltage will be generated by single stage HV impulse voltage circuit. The procedure to get U_{50} is being by followed the standard that describes in BS EN 60060-1:2010. The field intensity in electrode is simulated using FEMM simulation software. This great software enables the user to clearly see the field intensity, magnitude and way of field vector graphically. The comparison of voltage value and gap size against the field intensity of the electrode also easily can be simulated by this software.

1.2 Problem statement

Lightning, spark-over, flashover breakdown voltage is a part of electric fundamental that significant to our technology especially in high voltage equipment. Spark over can be useful in some cases (for example spark plug and ignition devices) and may give side effect or damage (sparking in switching devices) to the machine. Uncontrolled spark over phenomenon in the electrical equipment also cause an increasing of maintenance cost, wasting time and manpower, also effect to productivity especially in the manufacturing sector. Air can be a good natural insulation, but in some cases, it can transform into conductive nature. This phenomenon is subjective to physical condition such as a shape, gap, gas temperature and etc. Therefore the research on the behavior of spark over, breakdown voltage is important in the electrical engineering designing process.

1.3 Project objective

1. To understand the lightning impulse voltage characteristic
2. To setup a circuit for generating lightning impulse voltage
3. To arrange the vertical 'point to sphere' electrode apparatus in normal air condition.
4. To get the U_{50} value, using 'up and down method' by follow to BS EN 60060-1:2010.
5. To simulate and analysis the field intensity of point-sphere electrode vertical arrangement by using FEMM software.
6. To analyze the effect of voltage applied and gap size against a field intensity produce by point-sphere electrode.

CHAPTER 2

LITERATURE REVIEW

2.1 Understanding of lightning

Lightning is a natural phenomenon, strikes almost every day in our world. About 100 times are noted that lightning strike towards the surface eon earth for every second. Because of this phenomenon, the governments suffer major losses at every year. It also would cause horrific injury and fatality to humans and animals. Though the amount of people struck by lightning might appear very minor, lightning is one of the leading natural disaster caused deaths in the world. The survivors of lightning strikes often suffer from long term memory loss, attention deficits, sleep disorders, numbness, dizziness, stiffness in joints, fatigue, muscle spasms, irritability and depression. The lightning may affect almost every organ system as the current passes through the human body taking the shortest pathways between the contact points. Srinivasan & Gu [1] stated that there are 25.9% of lightning strike occurrences for victims who have sheltered under trees or shades, whereas 37% at open space area. Head and neck injury is two common areas which have an effect on the lightning strike victims with 77.78% and 74%respectively. Only 29.63% of the cases presented with ear bleeding. United State National Lightning Safety Institution reported that Malaysia has highest lightning activities in the world whilst the average-thunder day level for Malaysia's capital Kuala Lumpur within 180 - 260 days per annum. The lightning ground flash density is about 15-20 strike per km per year [2].

Lightning has an extremely high current, high voltage and transient electric discharge. A single lightning bolt is very powerful, releasing enough energy to light a

100-watt light bulb for more than three months! This electrical surge is created by a buildup and discharge of positively charged and negatively charged electrical energy. Air rises and descending from the thunderstorm and water and ice particles separate the positively charged areas and the negatively charged areas. The lightning strike begins as an invisible channel of electrically charged air, trying to get to the ground. Then a surge of electricity from the ground moves upwards, creating a lightning strike [3].

L.M. Ong & Ahmad [4] on their paper of Lightning Air Terminals Performance Under Conditions Without Ionization And With Ionization in 2003 found that Malaysia lies near the equator and therefore it is categorized as prone to high lightning and thunderstorm activities. 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. The main reason could be short of precise and consistent.

Figure 2.1: Lightning at Kuala Lumpur city [2]

2.2 Theory of breakdown

The breakdown voltage is the minimum voltage applied that causes a portion of an insulator become electrically conductive. The fundamental of rapid reduction in the resistance of an electrical insulator when the voltage applied across it exceeds the breakdown voltage it's called Electrical Breakdown. According to Meek & Craggs [5] on their book of Electrical Breakdown of Gases in 1978, breakdown voltage is a characteristic of an insulator that defines the maximum voltage difference that can be applied across the material before the insulator collapses and conducts. This results in a portion of the insulator becoming electrically conductive. In solid insulating materials, this usually creates a weakened path within the material by creating permanent molecular or physical changes by the sudden current. Electrical breakdown may be a momentary event (as in an electrostatic discharge). Breakdown voltage is also sometimes called the "striking voltage"[6].

2.3 Breakdown in gas

Electrical breakdown occurs within a gas (or in the air) when the dielectric strength of the gas is exceeded. Regions of high electrical stress can cause nearby gas to partially ionize and begin conducting. In standard conditions at atmospheric pressure, gas serves as an excellent insulator, requiring the application of a significant voltage before breaking down [7]. Although air is normally an excellent insulator, when stressed by a sufficiently high voltage, air can begin to break down, becoming partially conductive. If the voltage is sufficiently high, complete electrical breakdown of the air will culminate in an electrical spark or an Electric arc or spark over that bridge the entire gap. While the small sparks generated by electrostatic electricity may barely be audible, larger sparks are often accompanied by a loud snap or a bang. Lightning is an example of an immense spark that can be many miles long [8]

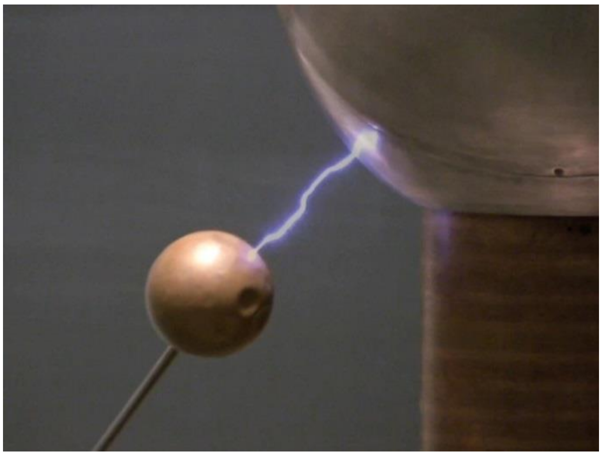

Figure 2.2 : Electrical breakdown in air cause small spark over [7]

2.4 Sparkover

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 (or we called spark over) to pass between the conductors [9]. When the voltage difference between the conductors exceeds the gap's breakdown voltage, a spark is formed, 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 (ranging from a snap for a spark plug to thunder for a lightning discharge), light and heat [10].

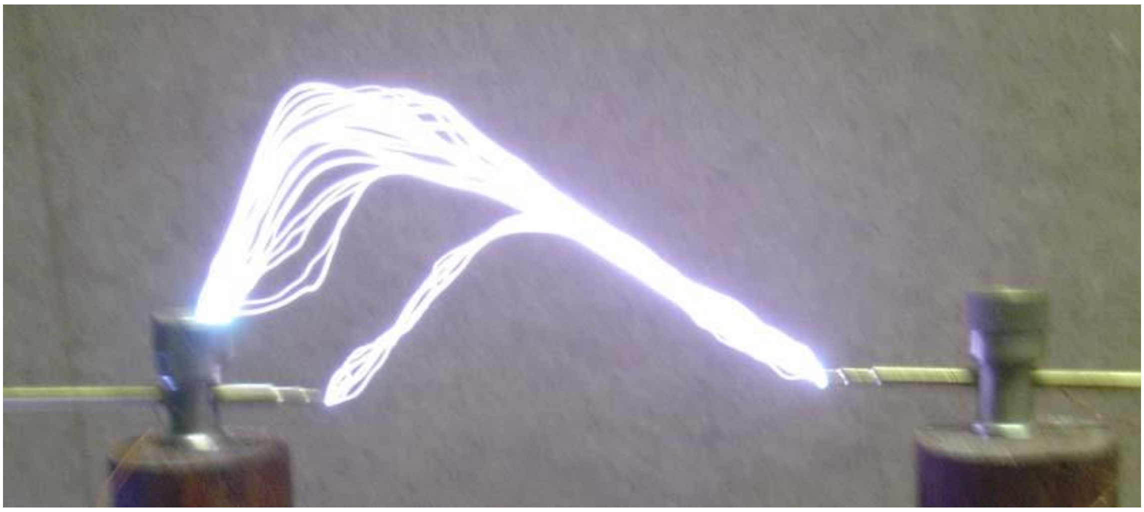

Figure 2.3: Spark over strikes between of two electrodes in spark gap [9]

2.5 Flashover

Compare to spark over, the flashover arc is a breakdown and the conduction of the air around or along the surface of the insulator, causing an arc along the outside of the insulator. Surface flashovers are generally defined as electric discharge phenomena that develop on the interfaces between adjacent dielectrics leaving conducting traces that cause further degradation of surface dielectric strength. When subjected to a high enough voltage, insulators suffer from the phenomenon of electrical breakdown. When the electric field applied across an insulating substance exceeds in any location the threshold breakdown field for that substance, the insulator suddenly becomes a conductor, causing a large increase in current, an electric arc through the substance [11].

Electrical breakdown occurs when the electric field in the material is strong enough to accelerate free charge carriers to a high enough velocity to knock electrons from atoms when they strike them, ionizing the atoms [12]. These freed electrons and ions are in turn accelerated and strike other atoms, creating more charge carriers, in a chain reaction. Rapidly the insulator becomes filled with mobile charge carriers, and its resistance drops to a low level.

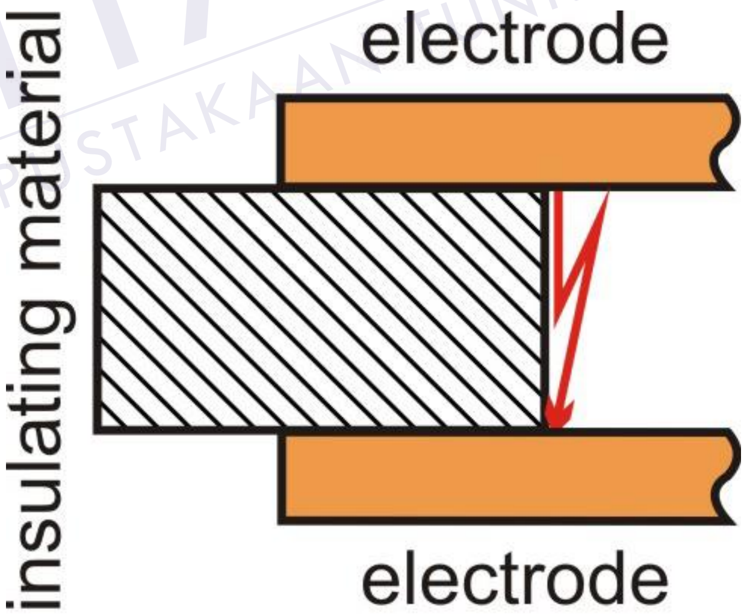

Figure 2.4: Flashover between insulating material [12]

In a solid, the breakdown voltage is proportional to the band gap energy. The air in a region around a high-voltage conductor can break down and ionize without a catastrophic increase in current; this is called "corona discharge". However if the region of air breakdown extends to another conductor at a different voltage it creates a conductive path between them, and a large current flows through the air, creating an electric arc.

Figure 2.5: Flashover in HV insulator equipment or called “corona discharge” [12]

2.6 Paschen law

When deal the gas pressure / type and a gap to analyze the voltage breakdown, the pashens law is considering use**.** According to Wadhwa [13] in High Voltage Engineering book, Paschen's Law is an equation that gives the breakdown voltage, that is the voltage necessary to start a discharge (spark over), 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.

Paschen studied the breakdown voltage of various gases between parallel metal plates as the gas pressure and varied of gap distance. The voltage necessary to spark over 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 spark over reduced as the gap size was reduced but only to a point. As the gap was reduced further, the voltage required to cause spark over 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 [14].

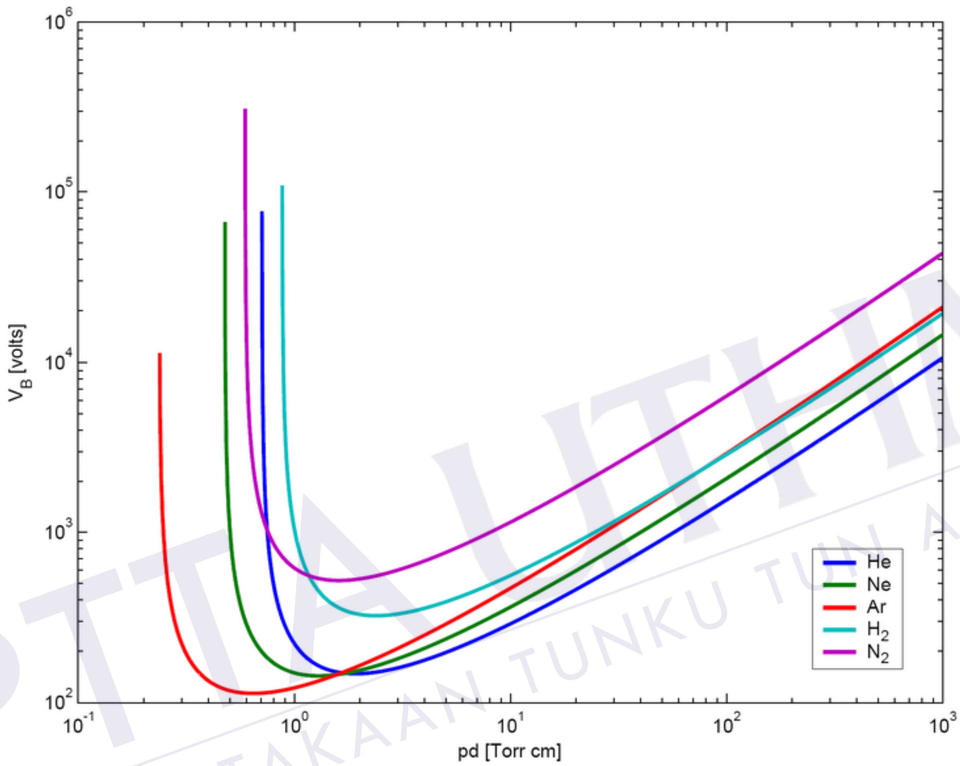

Figure 2.6:Paschen’s curve for various gas type [14]

2.7 Townsend

Between 1897 and 1901 John Sealy Edward Townsend discovered the process of Free Energy, were free electrons are accelerated in an electric field between two electrodes [15]. As the electrons are accelerating they are ionizing *more* atoms that liberates *more* electrons that are moving toward the anode (the positive (+)). The ionized atom moves toward the cathode (the negative (-)).This is known as the Electron avalanche also known as Townsend discharge or Townsend avalanche. 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 cease.

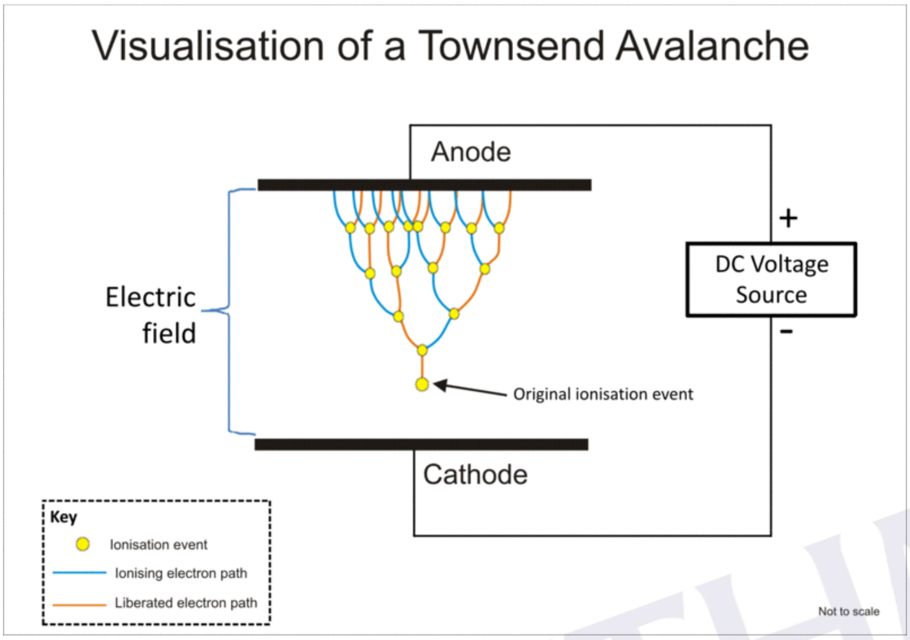

Figure 2.7: Townsend avalanche visualization [15]

The avalanche is a cascade reaction involving electrons in a region with a sufficiently high electric field in a gaseous medium that can be ionized, such as air [16]. Following an original ionization event, due to such as ionizing radiation, the positive ion drifts towards the cathode, while the free electron drifts towards the anode of the device. If the electric field is strong enough, the free electron gains sufficient energy to liberate a further electron when it next collides with another molecule. The two free electrons then travel towards the anode and gain sufficient energy from the electric field to cause impact ionization when the next collisions occur; and so on. This is effectively a chain reaction of electron generation, and is dependent on the free electrons gaining sufficient energy between collisions to sustain the avalanche [17]. The total number of electrons reaching the anode is equal to the number of collisions, plus the single initiating free electron. The limit to the multiplication in an electron avalanche is known as the Raether limit.

2.8 Marx generator

Marx generator is circuit to generating very high voltage pulses with a huge current. It was invented in 1924 by Erwin Otto Marx. The circuit generates a high-voltage pulse by charging a number of capacitors in parallel, then suddenly connecting them in series [18].

The figure 2-8 can explain how the Marx Generator works. At first, the *n* capacitors 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 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 *n V*, 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.

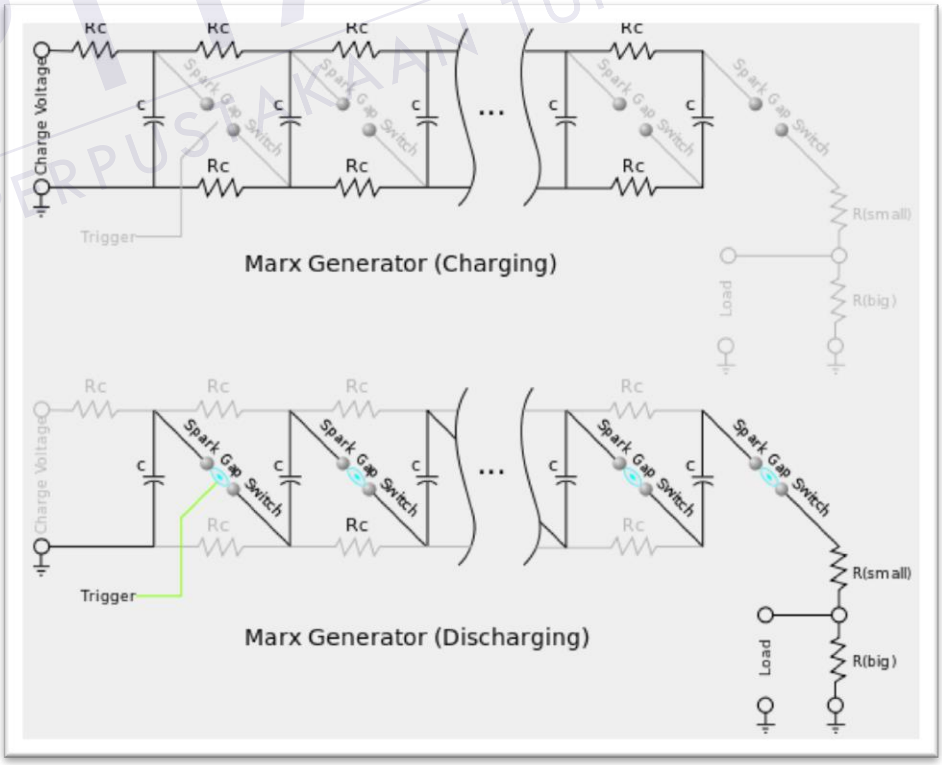

Figure 2.8: Marx generator circuit [18]

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 [19].

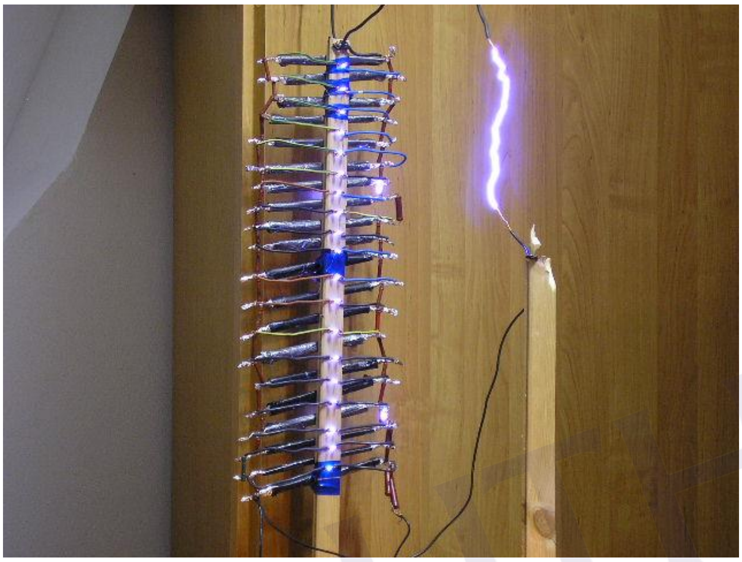

Figure 2.9: Spark over occur in Marx generator circuit [19]

Note that the less resistance there is between the capacitor and the charging power supply, the faster it will charge. Thus, in this design, those closer to the power supply will charge quicker than those farther away. If the generator is allowed to charge long enough, all capacitors will attain the same voltage.

2.9 Lightning Impulse voltage

Schon [20] in his book explain that the electrical strength of high-voltage apparatus against external over voltages that can appear in power supply system due to lightning strokes is tested with lightning impulse voltages. A standard full lightning impulse voltage rises to its peak value û in less than a few microseconds and falls, appreciably slower, ultimately back to zero (Figure 3-9). The rising part of the impulse voltage is referred to as the front, the maximum as the peak and the decreasing part as the tail. The waveform can be represented approximately by superposition of two exponential functions with differing time constants [21].

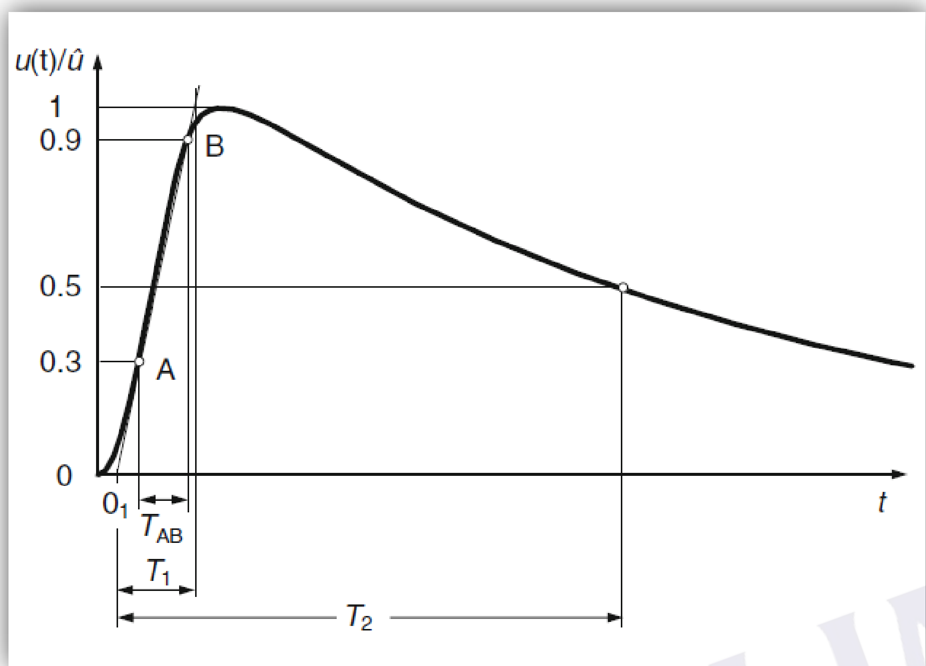

Figure 2.10: Lightning impulse voltage standard waveform [21]

For characterizing a full impulse voltage, numerical values of front times and times to half-value in microseconds are introduced as symbols. The standard 1.2/ 50 lightning impulse voltage has accordingly a front time T1 = 1.2 µs and a time to half-value T2 = 50µs [22]. Figure 2-9shows the impulse parameters for smooth waveforms in which the peak value is equal to the value of the test voltage. In testing practice, however, an overshoot or oscillation could be superposed on the peak of the impulse voltage; depending on its duration or frequency, it can subject the test object to varying degrees of stressing. The impulse parameters are therefore based, as per definition, on a fictitious test voltage curve which is calculated from the recorded data of the lightning impulse voltage applying special evaluation procedures. Making use of appropriate software, it is then possible to adopt a uniform. The front time (T_1) and the time to half-value (T_2) are defined in accordance with the standard.

Standard lightning impulse

Front time T_1 = 1,2µs ± 30%

Time to half-value T_2 = 50 µs ± 20%

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