

AIR BREAKDOWN CHARACTERISTICS IN PLANE-PLANE AND SPHERE
GAP ELECTRODE CONFIGURATION UNDER LIGHTNING IMPULSE

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Dedicated and thankful appreciation for the love, pray and encouragement.

To my beloved father and mother
wonderful siblings - brothers



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ABSTRACT

This report describes the air breakdown characteristics in plane-plane and sphere gap electrode configuration under lightning impulse. The breakdown in air (spark breakdown) is the transition of a non-sustaining discharge into a self-sustaining discharge. In electrical power system, high voltage power equipments are mainly subjected with spark over voltage. This over voltage which may causes by the lightning strokes, switching action and so on. In this project, two different electrodes (plane-plane and sphere gap) are used to study the air breakdown characteristics. This two electrodes are tested by using different gap start with 0.5 cm, 1.0 cm until 2.5 cm. Refer to British Standard BS EN 60060 that explained detail about the general definitions and test requirements for high voltage test techniques to construct in this project. In addition, TERCO lightning impulse circuit are use to obtain the lightning impulse waveform. To estimate U_{50} during the experimental, up and down method are used with the value of $n \geq 20$. Finite element method magnetic software (FEMM) is use to shows the potential higher electric field occurs around the electrodes. Vector and contour around the electrodes also can be viewed. From this project can conclude that electric field distribution between two conductors (or electrodes) depends on applied voltage (U_{50}), gap between electrodes, types and surface of electrodes. In the end of this project, the relationship between voltage (U_{50}) and gap, electric field ($|E_{\max}|$) and gap, field utilization factor (η) and gap, U_{50} and field utilization factor (η) and electric field ($|E_{\max}|$) and field utilization factor (η) have been constructed with help of graph.

ABSTRAK

Laporan ini menerangkan ciri-ciri pecahan udara (air breakdown) dalam konfigurasi elektrod rata-rata (plane-plane) dan sfera dibawah denyutan kilat. Pecahan didalam udara (spark breakdown) adalah peralihan pelepasan tidak kekal ke dalam pelepasan kekal. Di dalam sistem kuasa elektrik, kebanyakan peralatan kuasa voltan tinggi sering dikaitkan dengan percikan lebihan voltan. Lebihan voltan ini disebabkan oleh panahan kilat, tindak balas suis dan sebagainya. Dalam projek ini, dua elektrod yang berbeza (elektrod rata-rata dan sfera) digunakan untuk mengkaji ciri-ciri pecah tebat udara. Kedua-dua elektrod ini diuji dengan jarak yang berbeza iaitu 0.5 cm, 1.0 cm sehingga 2.5 cm. Merujuk kepada piawai British BS EN 60060 yang menjelaskan secara terperinci mengenai definisi umum dan keperluan ujian untuk teknik ujian voltan tinggi dalam menjalankan projek ini. Di samping itu, litar denyut kilat TERCO yang digunakan untuk mendapatkan bentuk gelombang denyut kilat. Untuk menganggarkan U_{50} semasa eksperimen dijalankan, kaedah naik dan turun digunakan dengan nilai $n \geq 20$. Perisian magnet kaedah elemen terhingga (FEMM software) digunakan untuk menunjukkan medan elektrik yang lebih tinggi yang berpotensi berlaku di sekeliling elektrod. Vektor dan kontur di sekitar elektrod juga boleh dilihat. Daripada projek ini boleh disimpulkan bahawa taburan medan elektrik di antara dua konduktor (atau elektrod) bergantung kepada voltan yang dimasukkan (U_{50}), jarak antara elektrod, jenis dan juga permukaan elektrod. Di akhir projek ini, hubungan antara voltan (U_{50}) dan jarak, medan elektrik ($|E_{max}|$) dan jarak, faktor penggunaan medan (η) dan jarak, U_{50} dan faktor penggunaan medan (η), dan juga medan elektrik ($|E_{max}|$) dan faktor penggunaan medan (η) telah dibina dengan bantuan graf.

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LIST OF SYMBOLS AND ABBREVIATIONS

E_{max}	-	Maximum electric field
U_{50}	-	50% probability voltage to breakdown
η	-	Field utilisation factor
AC	-	Alternative current
DC	-	Direct current
<i>FEMM</i>	-	Finite element method magnetic
<i>HV</i>	-	High voltage
<i>UTHM</i>	-	Universiti Tun Hussein Onn Malaysia



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CHAPTER 1

INTRODUCTION

1.1 Project background

In the wide of engineering's world, built a perfect and safe condition system to the consumer always be the main important aspect for an engineer. Every analysis result is highly important to achieve the mission and goal. For example, to design of overhead line, substation equipment and various air insulated high voltage equipment, the fundamental characteristics of the electrical breakdown have to understand. All the aspect for the electrical breakdown must be examined. British standard are use in this project as guidance for the high voltage test technique. This British Standard is the UK implementation of EN 60060-1:2010 [1]. It is identical to IEC 60060-1:2010. BS EN 60060-1:2010 explained detail about the general definitions and test requirements for high-voltage test techniques.

This project is study about the air breakdown characteristics in plane-plane and sphere gap electrode configuration under lightning impulse. Use two different electrodes which are sphere gap and plane to plane as the testing objects. The main aim for this project is to find the air breakdown voltage experimentally for different electrodes (plane-plane and sphere gap) by using lightning impulse test. From the theory, lightning impulse waveform has front time and tail time. The front time is 1.2 μs with the 93% from maximum voltage while tail time is 50 μs with the 50% from maximum voltage.

In addition, this project consists of experimental setup and software simulation. For the experimental setup, TERCO lightning impulse circuit is used to obtain the lightning impulse waveform. The lightning impulse waveform could be observed by using oscilloscope which is connected to the circuit. The most important thing before conducting the experiment is to make sure the experiment is to produce lightning impulse. Besides, during conducting the experiment, the safety aspects always come first.

In addition, this project also use up and down method. This method is use to determine the U_{50} during the experiment. U_{50} is 50% probability breakdown voltage. The data for voltage are taken until $n \geq 20$ to estimate $U_{50} \pm 3\%$ of voltage also consider in decrease or increase the voltage value during the experimental with the interval time for voltage is 60 second.

Furthermore, these projects use FEMM software to simulate electric field in electrostatic problem. The estimation of U_{50} from the experimental results are applied into the FEMM software. The actual dimensions for the electrodes are drawn in this software. The estimation value of U_{50} will be applied in this software to define the voltage for the electrodes. Means, the maximum or minimum electric field that occurs surrounding the electrodes could be seen. Electric field intensity shows the electric field strength in order to evaluate the electrical stress and breakdown characteristics between two different types of electrodes. In addition, vector and contour around the electrodes also can be viewed. From this project can conclude that electric field distribution between two conductors (or electrodes) depends on applied voltage (U_{50}), gap between electrodes, types and also the surface of electrodes.

In real life, sphere gaps are commonly used to measure the peak values of high voltage. IEC and IEEE also adopt the sphere gap as a calibration device. Besides, the standard sphere gaps are widely used for protective device in electrical power equipments. In Malaysia, the largest electricity utility is Tenaga Nasional Berhad (TNB). The gap overhead transmission lines in TNB are applied to reduce or restrain sag of an overhead transmission line. Higher gap is applied give less probability to breakdown and this will give more safety condition on the overhead transmission line. Another application that required use the suitable gap is in switch on burner. In power plant, to heat the boiler in order to generate electric, sparkover is

needed. This thesis is also important in application such as in power transformer, switch gear, overvoltage arrester, insulator, power cable and transformer.

1.2 Problem statement

Sparkover voltage is the mainly cause damage to high voltage power equipment in electrical power system. Usually, lightning strokes cause the overvoltage [2]. In order to avoid the overvoltage in high voltage power equipment, the study of air breakdown voltage with difference electrode configuration plane-plane and sphere gaps. This air breakdown will generated by using lightning impulse test. From this air breakdown, the different electrodes may determine which configuration of electrodes will more easily to breakdown.

1.3 Objective

The main aim in this project is to find the air breakdown voltage experimentally for different electrodes (plane-plane and sphere gap) by using lightning impulse test.

Objective for this project is:

- i. To find the electric field for different electrodes (plane-plane and sphere gap) for a given voltage by using FEMM software.
- ii. To construct relationship between voltage (U_{50}) versus gap, electric field ($|E|$) versus gap, field utilization factor (η) versus gap, U_{50} versus field utilization factor (η), and electric field ($|E|$) versus field utilization factor (η).

1.4 Project scope

In order to achieve the objectives of the project, several scopes have been outline. The following are the scopes of the project:

- i. By using difference electrode plane-plane and sphere gaps in study of the air breakdown characteristic.

- ii. Generate the air breakdown voltage by using lightning impulse setup by refer to TERCO manual guide in UTHM High Voltage Laboratory.
- iii. The simulation of electric field between the electrodes will be simulating by using Finite Element Method Magnetic (FEMM) software.
- iv. The TERCO's single stage voltage impulse generator capable to produced lightning impulse at maximum 140 kV.
- v. Gap between electrodes start with 0.5 cm, 1.0 cm, 1.5 cm, 2.0 cm until 2.5 cm are used for measurement of air breakdown voltages and electric field of the high voltage equipments.
- vi. Use air = gas @ atmosphere $P = 1$ bar.
- vii. Temperature and humidity effect are not considered.

1.5 Organization of the project

This project divided into five chapters which are including the introduction, lightning and air breakdown: a review, lightning impulse test procedures and simulation models, breakdown properties of air under lightning impulse: effects of electrode geometry and gap lengths and lastly, general conclusion and future works. This thesis focused on the air breakdown characteristics in plane-plane and sphere gap electrode configuration under lightning impulse.

Firstly, chapter 1 describes on the project background and problem statement to explain in detail for this project. This project also elaborates the project objectives and several scopes or the limitation that had been outlined to achieve the objectives. Besides, the organization of the thesis also included as the outlines for this project.

Next, in chapter 2, it discussed more on theory and literature reviews that related to this project. In this chapter, the general knowledge about the lightning, air breakdown, and lightning impulse will be covered. Previous related works in this chapter helps a lot to guide and as references in this project.

In chapter 3, methodology discussed about the method and technical strategies to apply for this project. In addition, this project deals with the experiment set up for air breakdown characteristic in plane-plane and sphere gap electrodes configuration by using TERCO lightning impulse circuit. From FEMM software, the different result electric field are simulated for electrodes, plane-plane and sphere gap.

Then, chapter 4 described the result for the air breakdown characteristics in plane-plane and sphere gap electrodes configuration from the experimental and also in FEMM simulation. The main content of chapter 4 is the results from the simulations followed by comprehensive discussions on the findings. From the experiment, the reading of U_{50} obtained from up and down method. The data is used to view the electric field surrounding the electrodes configuration by using FEMM software. Comparison between two electrodes are shown with the helped of graph.

Finally, in Chapter 5 discussed for the overall accomplishments of the project and some recommendations for future improvement to this project.



CHAPTER 2

LIGHTNING AND AIR BREAKDOWN: A REVIEW

2.1 Introduction

Literature review is a process of collecting and analyzes data and information that are related to this study. By refer from variable source such journals, books, websites and articles, the data and information can be collected.

2.2 Lightning

Lightning can be defined as an electrical discharge between cloud and earth, of atmospheric origin, comprising one or more impulses of many kilo amps [3]. It can also be defined as a transient, high current discharge whose path length is measured in kilometers [3]. 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 [4]. Lightning is natural phenomena that are always happened in our country, Malaysia.

Typical Isokeraunic Level in Malaysia is approximately 200 Thunder Days per Year [5]. 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 [6, 7]. Figure 2.1 shows the lightning occurred. Figure 2.2 shows the top cities in Malaysia with highest lightning days per annum [5]. In Malaysia, the monthly trends for lightning are:

- High during inter-monsoon (April to May)
- Moderate during Southwest monsoon (May to Sept)
- Low during Northeast monsoon (Dec to March)



Figure 2.1 : Lightning [8]



Figure 2.2 : Top cities in Malaysia with highest lightning days per annum [5]

2.3 Sparkover

Sparkover defined as disruptive discharge that occurs in a gaseous or liquid dielectric [1]. Figure 2.3 shows the illustrated for spark over while for figure 2.4 shows the sparkover occurred in air.

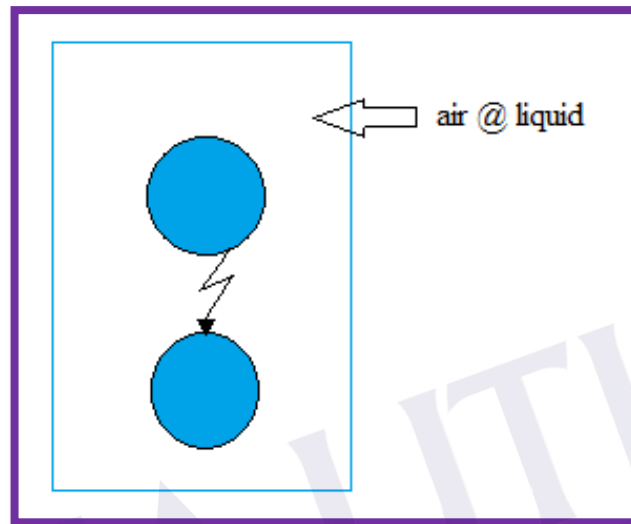


Figure 2.3 : Illustrate for sparkover (reproduced from [1])

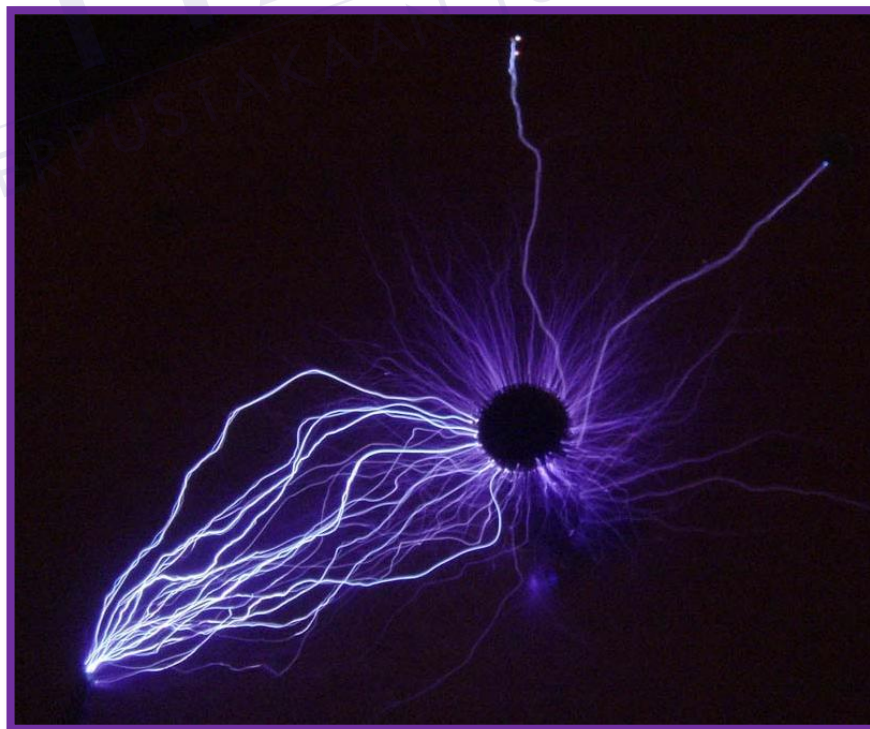


Figure 2.4: Sparkover occur in air [9]

2.4 Flashover

Flashover defined as disruptive discharge that occurs over the surface of a dielectric in a gaseous or liquid dielectric [1]. Figure 2.5 shows the illustrate for flashover while figure 2.6 shows the flashover occurred on surface of insulator .

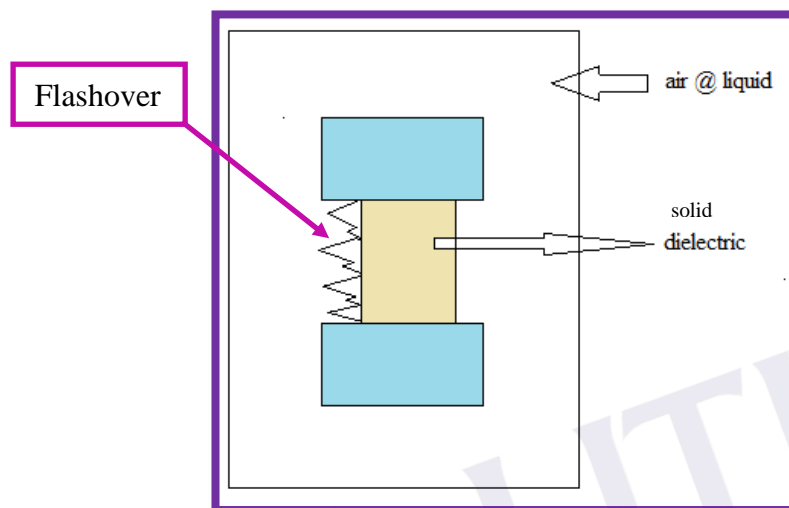


Figure 2.5 : Illustrate for flashover (reproduced from [1])



Figure 2.6 : Flashover occurred on surface of insulator [10]

2.5 Puncture

Puncture can be defined as disruptive discharge that occurs through a solid dielectric [1]. Figure 2.7 shows the illustration of puncture.

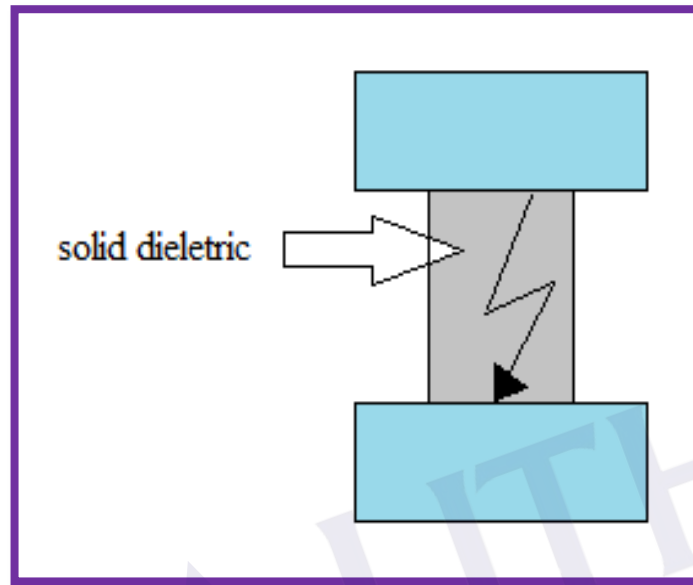


Figure 2.7 : Illustrate of puncture (reproduced from [1])

2.6 Lightning Impulse

Lightning impulse voltages are overvoltages due to lightning and are considered as an external overvoltage and are dependent on the system voltages. Also known as fast-front overvoltages or FFO. This is due to a very fast rise-time occurring on the waveform shape. The standard waveform used for testing is 1.2/50 μ s. 1.2 μ s represents the rise time T_1 while 50 μ s is a decay-time T_2 [2].

In the standard lightning waveform, T_1 is determined at about 93% level (0.93) just about to reach the peak voltage/current magnitude and T_2 is measured at 50% off the peak magnitude [2]. Figure 2.8 shows the standard lightning impulse voltage waveform.

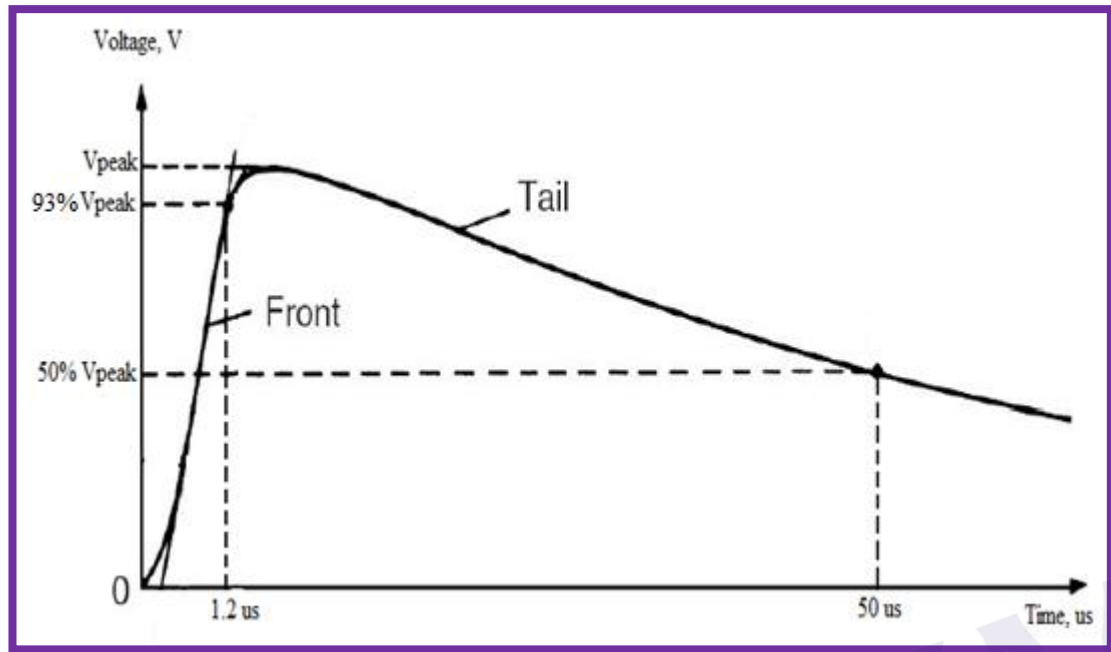


Figure 2.8 : The standard lightning impulse voltage waveform [11]

Due to many reasons such as equipments accuracy / aging, weather condition, humidity and extra, it may be difficult to generate an accurate impulse waveforms in the laboratory that can follow exactly the specific standard 1.2/50 μ s of FFO. Table 2.1 shows the tolerance for lightning impulse.

Table 2.1 : The tolerance for lightning impulse

Lightning Impulse	Front Time (T1)	Tail Time (T2)
Tolerances	$\pm 30\%$	$\pm 20\%$
Standard time, us	1.2	50
Voltage	$0.93V_{peak}$	$0.5V_{peak}$

Lightning impulse waveform will chopped when air breakdown occurred which a disruptive discharge causes a rapid collapse of the voltage, practically to zero value. The standard impulse chopped by an external gap with a time to chopping value between 2 μ s to 5 μ s [1]. There are two time chopping occur:

- Lightning impulse voltage chopped on the front between 0.5 μ s to 2 μ s [1].
- Lightning impulse voltage chopped on the tail between 2 μ s to 5 μ s [1].

Figure 2.9 shows the lightning impulse voltage chopped on the front while figure 2.10 shows lightning impulse voltage chopped on the tail. The difference between this waveform is the time chopping that occurs whether on the front time or tail time.



Figure 2.9 : Lightning impulse voltage chopped on the front [11]

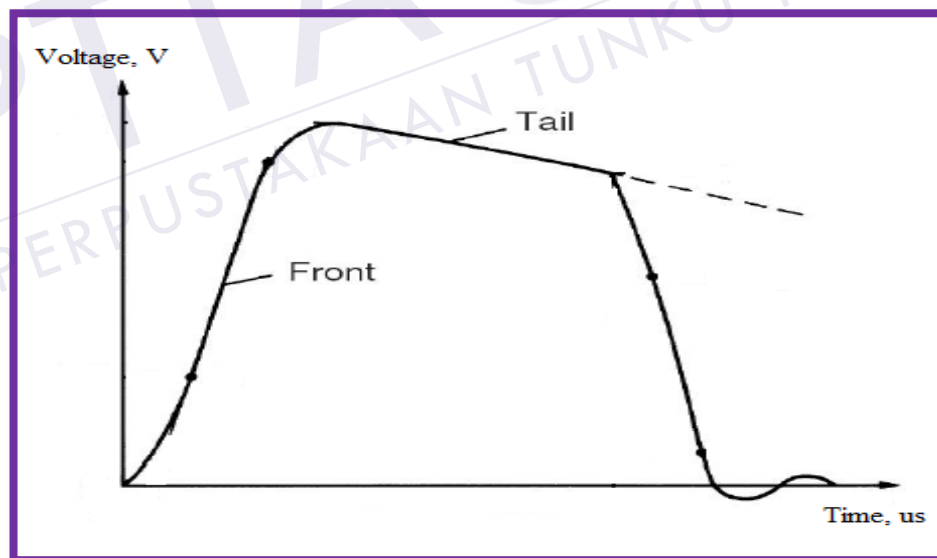


Figure 2.10 : Lightning impulse voltage chopped on the tail [11]

2.7 Air Breakdown

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

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