ANALYSIS RESIDUAL VOLTAGE OF SURGE PROTECTION DEVICE(SPD) BASED ON GROUNDING AND COORDINATION

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A report submitted
in partial fulfillment of the requirements for the degree of
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DECLARATION

I declare that this thesis entitled "ANALYSIS RESIDUAL VOLTAGE OF SURGE PROTECTION DEVICE(SPD) BASED ON GROUNDING AND COORDINATION is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	
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Date	:	28 MAY 2019

APPROVAL

I hereby declare that I have checked this report entitled "ANALYSIS RESIDUAL VOLTAGE OF SURGE PROTECTION DEVICE(SPD) BASED ON GROUNDING AND COORDINATION" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATIONS

To my beloved mother and father

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In the name of Allah SWT, the most Beneficent and Merciful, all praises and glory be upon him. Blessing and greeting upon our beloved prophet Muhammad SAW, his family and companions. In preparing this report, I was in contact with many people, researchers, academicians and practitioners. They have contributed towards my understanding and thought. First and foremost, I wish to express my sincere appreciation to my main project supervisor, Dr. Farhan Bin Hanaffi, for encouragement, guidance critics and friendship. I am extremely indebted to him for his expert, sincere and valuable guidance extended to me. Without his support and interest, this project would not have been the same as presented here.

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ABSTRACT

This project was about impact surge protection device (SPD) based on residual voltage. Nowadays, the global stand with modern technology so that many microprocessors were used in daily life. By using SPD, the overvoltage will limit the overvoltage and reduce from damage the circuit. This project done in the low-voltage system. Every coordination between SPD and grounding resistance has different value of residual voltage. The important characteristic was when residual voltage must be lower than the load voltage withstands. For this reason, the residual voltage was important to make sure the electrical appliance in a good condition. Next, study about value grounding also important to make sure the surge current will flow to the earth. For methodology, simulation SPD circuit modelling was used in PSCAD software. PSCAD was used to analyse the characteristic of SPD and study oscillation phenomena when using different length cable between SPD. For the case study coordination of SPD, difference value of the distance between SPD were determined to get a better residual voltage. For the study on case of grounding method, the suitable value of grounding will be selected to observe analysis result about level protection of SPD. Having this study method, the value of residual voltage (U_{res}), level voltage protection (U_p), and value of withstand voltage (U_w) can be analysed. So, based on the analysis data the level protection SPD can be implemented by the correct SPD installation.

ABSTRAK

Projek ini berkaitan dengan impak alat pelindung kilat (SPD) berdasarkan sisa voltan. Pada zaman sekarang, dunia berdepan dengan teknologi moden jadinya terdapat pelbagai microprosessor digunakan dalam kehidupan seharian. Dengan menggunakan SPD, voltan berlebihan akan dapat dihadkan dan menggurangkan kerosakan pada litar. Projek ini akan dilakukan dalam system voltan rendah. Setiap koordinasi antara SPD dan rintangan pembumian mempunyai perbezaan nilai voltan sisa. Untuk menahan daripada kerosakan,sisa voltan perlulah rendah daripada muatan voltan. Oleh sebab itu, sisa voltan amat penting untuk memastikan barangan elektrik berada dalam keadaan baik. Seterusnya, kajian mengenai nilai peribumi juga sangat penting untuk memastikan aliran kilat dapat dialirkan ke bumi. Untuk methodologi, model litar simulasi SPD akan digunakan didalam perisian PSCAD. PSCAD digunakan untuk menganalisa ciri-ciri SPD dan mengkaji fenomena getaran apabila mengunakan jarak kabel yang berbeza antara SPD. Untuk kajian koordinasi SPD, nilai berbeza antara jarak SPD ditentukan untuk mendapatkan sisa voltan yang berbeza. Untuk kajian kes pembumian, nilai pembumian yang sesuai akan dipilih untuk menilai analisa keputusan mengenai tahap pelindungan SPD. Dengan menggunkan cara ini, nilai sisa voltan, tahap pelindungan voltan dan nilai ketahanan voltan dapat dianalisakan. Berdasarkan analisa data, tahap perlindungan SPD dapat dilaksanakan dengan pemasangan SPD yang betul.

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LIST OF SYMBOLS AND ABBREVIATIONS

SPD	-	Surge Protection Device
U_{res}	-	Residual Voltage
U_w	-	Withstand Voltage
U_p	-	Level Protection Voltage
I_n	-	Nominal Discharge Current
PSCAD	-	Power System Computer-Aided
MOV	-	Metal Oxide Varistor
GDT	-	Gas Disharge Tube
ρ	-	Soil Resistivity
l	-	Rod length
a	-	Area of rod
ε	-	constant 8.5419 x 10^{-12}
μ_0	-	constant 1.25664 x 10^{-6}

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CHAPTER 1

INTRODUCTION

1.1 Background

Lightning is the visible discharge of static electricity, either between clouds or between cloud and earth. Lightning could strike anywhere on earth. High earth resistivity will be increased when a lightning strike occurs[1]. Lightning can cause overvoltage and damage the electrical system. It can directly strike to the system or indirectly by induce to the correlating point. If the lightning strike to the structure in certain areas, its possibility damages the system. If there was no lightning protection system present in the building, it will cause the electrical apparatus damage. Therefore, it necessary to protect electrical system apparatus from lightning current or surge. Thus, surges produce a very high voltage that can damages and disrupts the function of the electrical and electronic component.

Nowadays, the development of electronic technology is growing fast. Due to this, circuit or microprocessor based on electric and electronic devices are widely used in human daily life. Such as a computer system, which has many circuits that are have weak voltage withstand capability. Every type of electrical appliance is design with insulation to isolate the electrical voltage from the earth. The insulation strength depends on the rated voltage and types electrical component. Therefore, by knowing how to limit the overvoltage was the great economic and technical value because it can save the electrical appliance from damage.

Surge protection device (SPD) is using to limit the overvoltage and release the high current through the grounding in the low-voltage power distribution system. Therefore, to limit the overvoltage and achieve the purpose of protecting electronic equipment, SPD is widely used in low-voltage distribution system[1]. Many factors such as protection level SPD, installation mode, and coordination of SPD should be considered for installation of the SPD.

1.2 Motivation

Every house has an electrical route to the earth to protect a building and electrical circuit from any unwanted current and voltage damaged. Even though the building has lightning protection, the surge current still flows to the system. Lightning surge can cause failure of circuit breaker and power transitions between devices or damage equipment. In the case of lightning strikes, the best way to protect the electrical equipment is to disconnect electrical appliances when thunderstorm occurred. Otherwise, people needed to install SPD in order to protect the entire electrical equipment in low voltage from lightning surge. Nowadays, the protection of surges was essential as many microprocessors and electronic equipment is too sensitive to surge overvoltage were used in our daily life. Therefore, proper installation is required to protect the entire house with surge protection. In term of correct installation methods, the SPD are necessary to ensure that the electrical appliance always in good condition.

1.3 Problem Statement

The installation of SPD is a significant role in the surge protection of equipment. The problem could come out if the residual voltage flow at the load is over to load withstand voltage. Firstly, this factor is influence by coordination between SPD and different type grounding. The different loads and coordination between SPD make different surge across the SPD and load. If SPD is installed without consideration proper coordination, the equipment to be protected might be damaged due to overvoltage. This is because there are reflection phenomena on the cable between SPD and the load protected as describe in the IEC 61643-12. The other problem is residual voltage effects on value of grounding resistance. Grounding resistance will make the SPD operation make the SPD operation less efficient because the surge current cannot release to the ground faster. Therefore, the evaluation of coordination and grounding resistance value is needed to investigate the performance of the SPD. The higher value of grounding can make the current will flow to the load than flow to the ground.

Furthermore, the lightning surge in low voltage equipment can be affected by the grounding resistance. Hence, value grounding resistance related to the performance of the SPD.

1.4 Objective

The objective of project is:

i) To analyse different grounding model on SPD residual voltage.

ii) To analyse the effect of length for different grounding configuration.

iii) To analyse SPD residual voltage due to cable length between SPD and protection load with different grounding configuration.

1.5 Scope of Project

In this project, the power system computer-aided design (PSCAD) software has been used to analyze the residual voltage between coordination SPD and grounding configuration. The selected installation of SPD was in the building at low voltage for single phase. Next, this project used MOV type of SPD to analyze the data. Thereby, MOV behavior can show by the non-linear voltage current characteristic. The grounding system TT system connection has been used in this project. Grounding configuration value cover in this project was 10Ω, 50 Ω, 150Ω, 500Ω and 1000Ω. This range of ground resistance value was chosen since Malaysia's soil resistance was not very high. Furthermore, this research focuses on lowland area rather than a sandy area such as the beach. Other than that, length of connecting cable between SPD will vary 3 different lengths which was 1m, 5m, and 10m. The type of load resistance was used in this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Surge Protection Device

SPD is a device to protect electrical equipment from overvoltage transient and SPD will divert the current to the ground caused by lightning or switching action. Generally, the electronic equipment uses were very small in voltage and power level to operates. Which means a small surge current or transient voltage is enough to cause high temperature and breakdown of the voltage to the electronic equipment. Connection SPD must be installed parallel with the load. Thus, once transient overvoltage appears in the system, the impedance of the SPD decreases so the surge current will flow through SPD bypassing the equipment or load.

According to IEC 61643-12[2], the SPD can be divided by two types which is voltage limiting type of SPD and voltage switching type of SPD. The voltage limiting type of SPD that has high impedance when no lightning surge, but it will reduce it continuously by increase the surge current and voltage. Common example component using in the limiting type SPD are varistor and avalanche diodes. The voltage switching SPD has higher impedance when no surge present, but it will drop the impedance in response to voltage surge. Common example component using in the switching type SPD are spark gaps, gas tubes and thyristors. The limiting transient voltage waveform when lightning surge using SPD shown in Figure 2.1 and the response of voltage switching type SPD shown in Figure 2.2.

Figure 2.3 shows that the 8/20 µs waveform for indirect impact lightning strikes. The applied current waveform when the lightning occurs which is the front time or rise time is 8µs. The second number is the half peak value or tail times is 20µs.

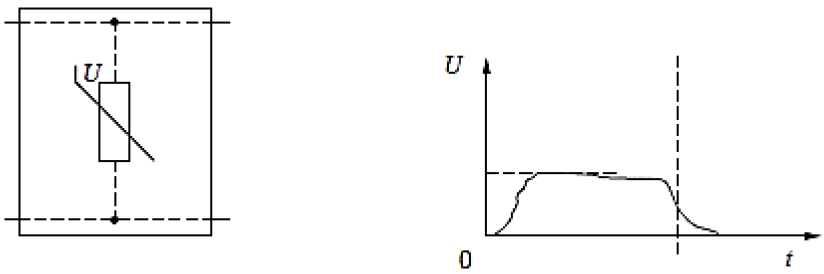


Figure 2.1: Response Of Voltage Limiting Type SPD[2]

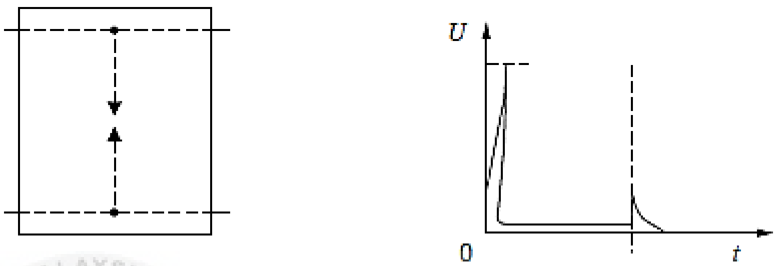


Figure 2.2: Response Of Voltage Switching Type SPD[2]

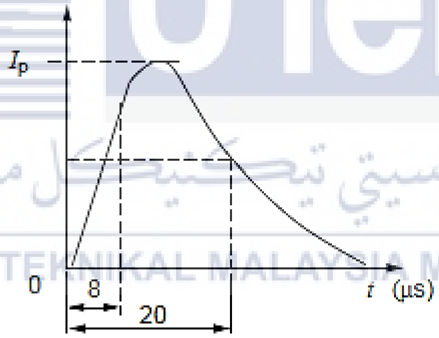


Figure 2.3: 8/20μs Current Waveform[2]

Gas discharge tubes (GDT) and metal-oxide varistor (MOV) are the most common component of SPD. GDT and MOV have their own characteristic to be effective surge protection device.

2.1.1 Gas Discharge Tube (GDT)

GDT usually consist of two or three electrodes in a glass or ceramic, inert gas filled package shown in Figure 2.4[3]. The electrodes are aligned with a small gap between GDT. When the voltage across the electrodes exceeds a certain value, an arc will occur in the tube. Based on the result, it can create a low current path. GDT with three or more electrodes can be constructed with a single volume of gas by providing holes in the internal electrodes. GDT has two regions, which is glow region and normal glow region.

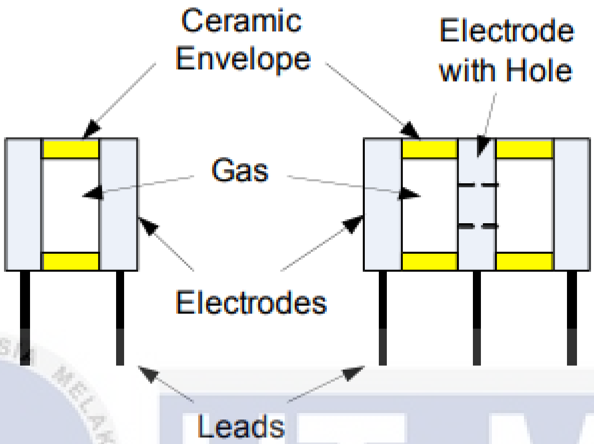


Figure 2.4: Simple Cross Section of Two and Three Lead GDT[3]

A typical V-I curve for GDT shown in Figure 2.5[4]. At point A, GDT turns it conditions from an insulating state to a conducting state. Once a potential reached the transient voltage, the voltage across the GDT will collapse and causing negative incremental resistance. Next, glow region occurs at the segment of the curve between point B and point D. Normal glow region will produce when the voltage across GDT at point B to point C is approximately independent of the current. When the current increase at point D to point E, the GDT voltage drop to the level arc voltage where it remains until the surge passes away. The arrestor remains conductive until its current falls below its level. After the current surge has disappeared, the current is reduced to extinguish the current arc.

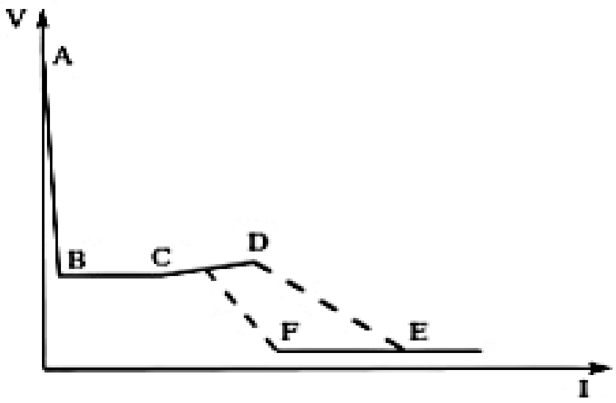


Figure 2.5: Typical V-I Relationship For Gas Discharge Tube[4]

2.1.2 Metal Oxide Varistor (MOV)

MOV is the most commonly used type of varistor. It is made from a mixture of zinc oxide and other metal oxides like cobalt, manganese and so on. MOV will be kept undamaged between two electrodes which are basically metal plates. This structure acts like diodes and connected in series or parallel to ensure a nonlinear performance. MOV is designed to handle a large amount of current for the microsecond surge time frame. MOV is the most commonly used to protect heavy devices from transient voltages. For this reason, MOV was the best choice and widely used for surge arrester. MOV characteristic can be divided by three main regions which is low electric-field region, medium electric-field region and high electric-field region[4].

At the low electric-field regions, which are before a surge, a low voltage is applied at the varistor terminals. The diode does not conduct the current and the varistor will act as an insulator. Next, at the medium electric-field region, the current suddenly increases when the electric field reaches the value over 100 KV/mm. In these regions the current will varies from 1mA to 1kA[4]. Lastly, in the high electric-field region, which is during the lightning surge, MOV changes from very high impedance to a short circuit. The MOV at these regions does two things such as provide short circuit path for the surge current to flow to the ground. Secondly, the MOV will cut off the over transient voltage to the safe level[5].

Figure 2.6 shows the I-V characteristic curve for metal oxide varistor and Zener diode. MOV basically a highly non-linear resistor. It is symmetrical, so it works well AC and DC. In operation, it functions as similar with two Zener diodes placed head to foot. The major difference is that the breakdown has a much softer knee than the Zener combination, so its voltage breakdown limit is not precise.

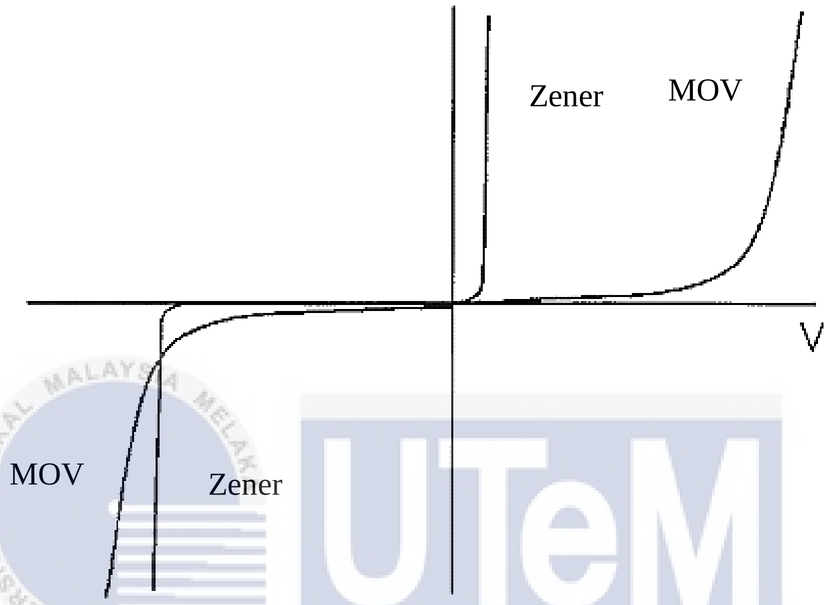


Figure 2.6: Metal Oxide Varistor I-V Characteristic[6]

2.1.3 Class Test of SPD

According to the IEC 61643-12[2], SPD has three types of classes test. The three types of class test are Types 1, 2 and 3 SPDs. The Type 1 SPD usually are installed in the specific sector and industrial building to protect from direct lightning surge. Next, the Type 2 SPD is the main protection for electrical low-voltage systems. Type 2 frequently install at the main electrical switchboard to prevent overvoltage at the electrical appliance. Lastly, Type 3 SPD must install with combination Type 2 SPD to protect the sensitive electrical appliance. Table 2-1 shows the types and classes test of the SPD.

Table 2-1: Type and Class Of The SPD[2]

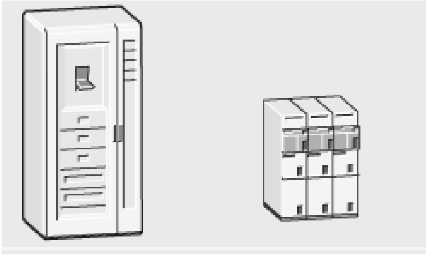
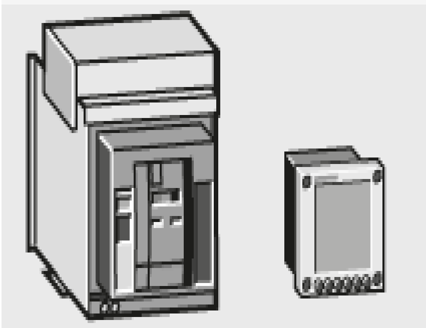
Item	Direct lightning strike	Indirect lightning strike	
Type SPD	Type 1	Type 2	Type 3
Class Test	Class I	Class II	Class III
Current test wave	10/350µs	8/20µs	8/20µs + 1.2/50µs

2.1.4 Category Installation SPD

Choosing the category installation SPD requires to protect the equipment and to match the SPD rated impulse voltage. Category installation SPD are importance because the suitable installation can protect the load and can save the budget installation. This is relating to the category of overvoltage installation. In the standard IEC 60664-1, the installation overvoltage categories are described which is for a 200/400V installation. There have 4 type of installation overvoltage categories. Table 2-2 are shows about installation overvoltage category.

Table 2-2: Installation Category[7]

category	Equipment	Description
Installation category I		• Installation categories 1 is 1.5 kV only suitable for particularly sensitive equipment. • Example for this category is electronic devices like computer, television, etc
Installation category II		• Installation categories 2 is 2.5 kV for normal impulse voltage equipment user. • Example for this category is a household electrical appliance and similar loads.

Installation category III		• Installation category 3 is 4 kV for use in the fixed installation downstream. • Example for this category is distribution boards, circuit breakers and equipment for industrial use.
Installation category IV		• Installation category 4 is 6 kV for equipment installed at or near the origin of main incoming supply mains • Example of this category is electricity meter, primary overcurrent protection devices and ripple control units.

2.2 Residual Voltage

Residual voltage is important parameter to make sure that the load can withstand when the lightning surge occurs in the system. The load will damage if the residual voltage is higher than value the load can withstand. In order to get a better explanation about residual voltage, Figure 2.7 and Figure 2.8 shows a typical example of the coordination between two MOV separated by an inductance. SPD2 has a lower voltage protection device (u_p) value and a lower value nominal discharge current (I_n) through SPD. This is because, the SPD1 will absorb more surge current than SPD2 [2]. For this reason, effect on front of surge most of the current flows through SPD1. The current in SPD2 will steadily increases with a time constant cause by the inductance and characteristic SPD2. Thus, the total of current will flow through SPD2 over time[2].

In addition, Figure 2.7 shows that U_1 as a residual voltage at SPD1, is higher than the residual voltage (U_2) at SPD2. This is because, SPD1 absorbed more surge voltage than SPD2. Residual voltage after passing through SPD1 might be higher and can give a certain impact to the device so that SPD2 is required for limiting a further magnitude of over voltage[8]. Residual voltage higher if the SPD and load are installed further from electrical appliance. So that another SPD must install to reduce the residual voltage at the electrical appliance.

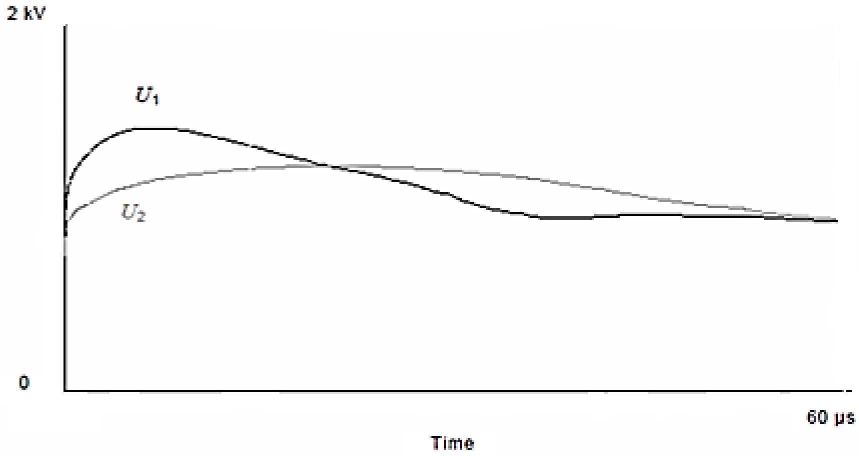


Figure 2.7: Residual Voltage On The SPD1 And SPD2[2]

While, Figure 2.8 below shown the graph current against time to see changes to the current flow through the SPD during the lightning surge. The figure also shows the surge currents waveform (I_T) spike into the system without installation SPD. The surge waveform is lower than waveform (I_T) when SPD are installed to the system. The current through the SPD1(I_1) must higher than the current flow to the SPD2 (I_2) to make sure the load can withstand the current.

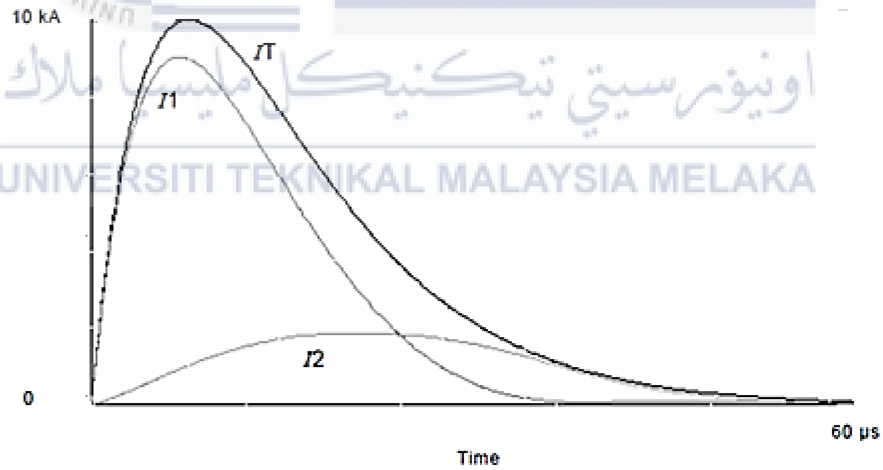


Figure 2.8: The Current Sharing Between SPD1 and SPD2[2]

2.2.1 Residual Voltage Due to Type of Cable

Every size and length cable between SPD and load can influence by the value of the residual voltage. This is because longer the length cable can make the oscillating magnitude larger[8]. The minimum size cable connection for active conductor type 1

SPD is $6\,mm^2$ and for type 2 SPD is $2.5\,mm^2$ [9]. The minimum sizing cable connection cross section of the protection conductor for type 1 SPD is $16\,mm^2$ and for type 2 SPD is $6\,mm^2$. If SPD2 has larger rated voltage, the peak of the residual voltage waveform is higher, and the oscillation phenomenon will occur. When the oscillating magnitude is large, it can make the residual voltage exceed the tolerance of the device, while the high frequency can make the damage to the device[8]. Furthermore, the current ratio of the SPD will be increased with the cable length. Higher the equivalent impedance means the cable length will be large so that SPD branch pass through more current.

2.2.2 Residual Voltage Due to Load

Different type of load lead to different surge across the SPD and load. Frequently, the surge voltage that flows to the load can be very higher than its limited surge withstand voltage[10]. In this regard, it is important to analyze the influence of residual voltage and the property of the load on protective effect. In this paper [8], three different types of loads which is resistance load, inductance load and capacitive load has been compared to get a result about residual voltage. The residual waveform of the inductor load and resistor load are similar. However, when the rated voltage of the SPD is large, the significant oscillation will appear. For capacitor load, the oscillating magnitude is greater than the capacitor load. It has similar conditions when the cable length is longer, the magnitude of the oscillating will be greater.

2.3 Coordination of SPD

SPD with correct coordination installation can make the electrical appliance save from over transient when lightning occurs. Coordination SPD can be separated by two which is coordination between two SPD and coordination SPD with the load. Based on the IEC 61643-12[2], the installation of the SPD must be closest to the load. According to the standard, the coordination length must be below than 10 meters between SPD and the load. If the length is more than 10 meter the level protection SPD will be decreased. This is because the longer the cable length can produce reflection phenomena in the cable.

2.3.1 Coordination of Two SPD

In this paper studies[1], the effectiveness coordination SPD can be determined by analysis energy absorb two stage SPD. When the length cable increase, the energy absorbed by the first SPD becomes greater while the energy absorbed by second SPD decrease[1]. The SPD that can withstand high current must be the first choice if the connection of two SPD is long. Therefore, to achieve better protection effect, SPD which can bypass large current must be installed in the first stage coordination[1]. In this paper [11], Figure 2.9 illustrates basic circuit for energy coordination of two voltage-limiting type SPD by varies the distance between SPD. The total energy fed into the system increases with increasing the impulse current. If the energy dissipated through each of the two SPDs does not exceed their energy withstand capability, energy coordination is achieved.

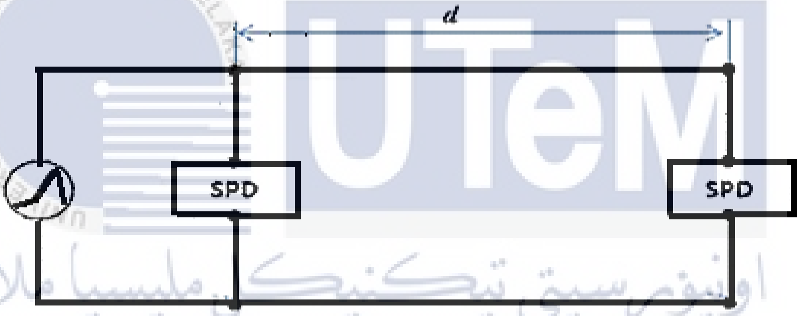


Figure 2.9: Energy Coordination Between Two SPD[11]

Figure 2.10 show energy coordination between two voltage-limiting type SPD. The operation sequence of the SPD is closely related to energy coordination of the cascaded SPDs[2]. If the varistor voltage of the upstream SPD1 is lower than or equal to the downstream SPD2, the upstream SPD1 starts discharging. If the varistor voltage of the upstream SPD1 is higher than that the downstream SPD2, the downstream SPD2 can start discharging first in the case that the distance between two SPDs is short. The energy coordination of two voltage limiting type SPDs without dedicated decoupling elements should be realized by the coordination of their I-V characteristic curves. When the additional decoupling elements are not employed, the decoupling is provided by the natural impedance of the lines connecting two voltage limiting SPD.

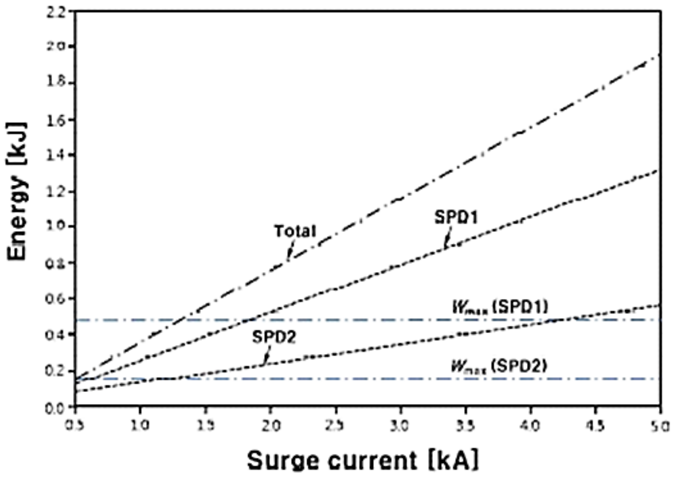


Figure 2.10: Energy Coordination Between Two Voltage-Limiting Type SPD[11]

2.3.2 Coordination Between SPD and Load

Difference loads and cable length lead to different surge across the SPD and load. When the resistive component of the load is less than the cable characteristic impedance, no matter how long the cable is, the overvoltage is always under the limited load resistance[1]. In this paper[10], a simple model single phase low voltage distribution system is used to analyze the reflection and oscillation phenomena occur in the cable with different length and different load as shown in Figure 2.11.

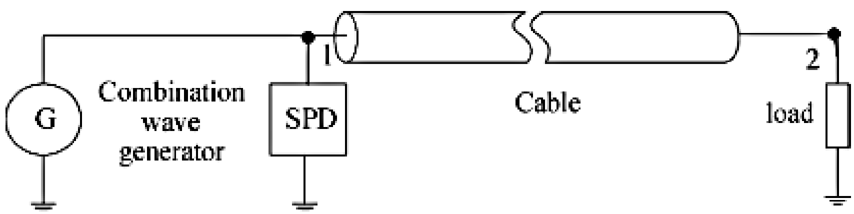


Figure 2.11: Single Model Of Low Voltage Distribution System[10]

For inductive load and capacitive load, the effective protection distance of SPD is limited because of the reflection phenomena on the cable. In this paper [10][9], three different types of load and three different lengths were considered, for the research. For resistive load transient voltage across SPD and the load almost the same. Thus, it is no apparent reflection phenomena at the cable. Difference oscillation phenomena with different type of load will be seen in Figure 2.12, Figure 2.13 and Figure 2.14.

Next, for capacitive loads, the damping voltage wave will occur because energy oscillates back and forth between SPD and load. Moreover, the inductive load influences the high reflection phenomena on the cable. Reflection phenomena will affect the residual voltage at the load. Lastly, when the inductance becomes very large, the surge voltage across the load will oscillate. When the surge lightning occurs, the resistive load will be preferred use than inductive load and capacitive load due to reflection phenomena on the cable.

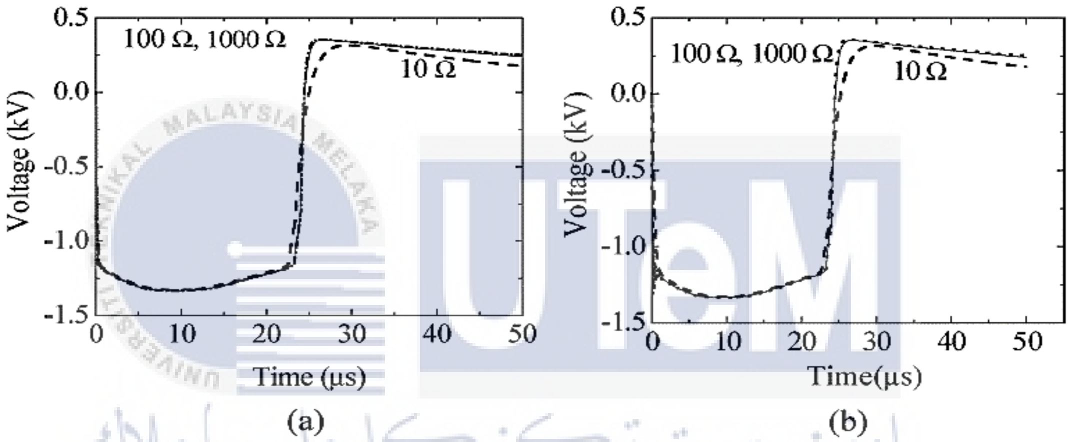


Figure 2.12: Surge Across the (a) SPD and (b) Resistive Load[10]

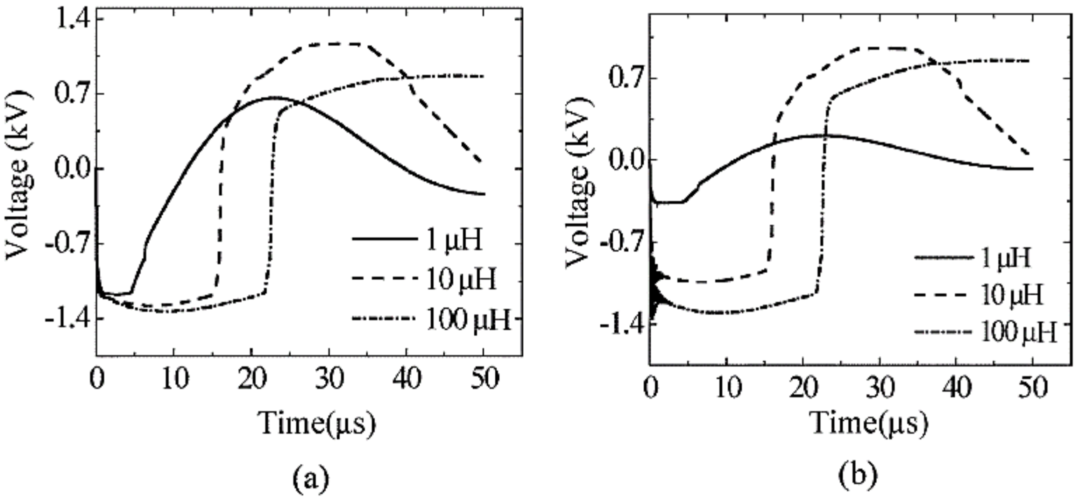


Figure 2.13: Surge Voltage Across the (a) SPD and (b) Inductive Load.[10]

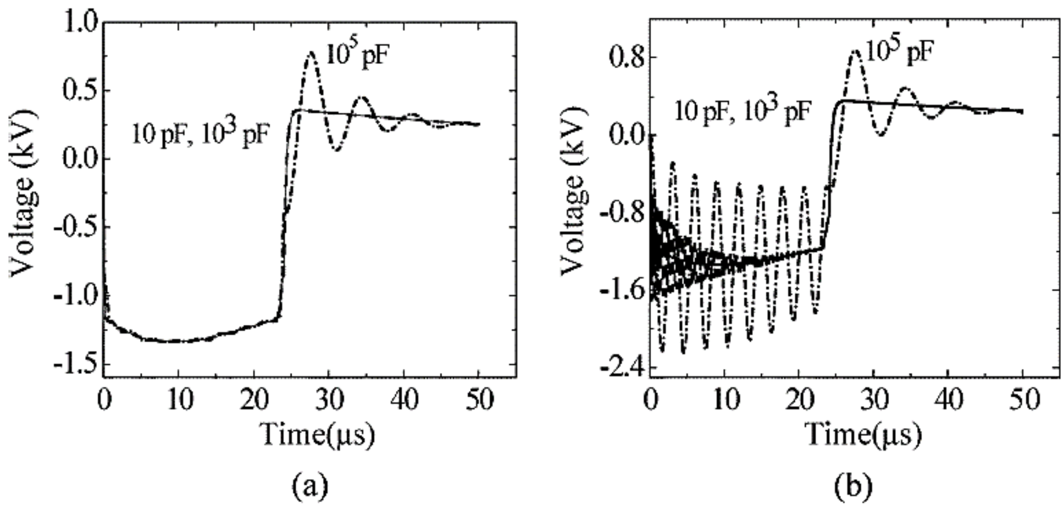


Figure 2.14: Surge Voltage Across (a) the SPD and (b) Capacitive Load.[10]

Since the surge voltage across the load has a relationship with the cable length [10], therefore the cable length should be limit to a few distances to give the good protection effect of SPD. That mean, cable length will affect the residual voltage at the load and the SPD.

2.4 Influence Grounding Resistance

Grounding resistance is important to determine the performance of the SPD in limiting the lightning voltage. When the value of the grounding is higher, the current will flow to the load rather than the ground. As a result, the load will damage because the voltage flow to the load is higher than the voltage that the load can withstand. Therefore, it is important to have low grounding resistance since it will affect the SPD operation effectiveness in limiting the overvoltage. From Figure 2.15 show that the higher earth resistance value can influence the value of overvoltage at load. The performance of the line surge arrester in limiting the overvoltage will decrease to about 5% of every 5 Ω increase.

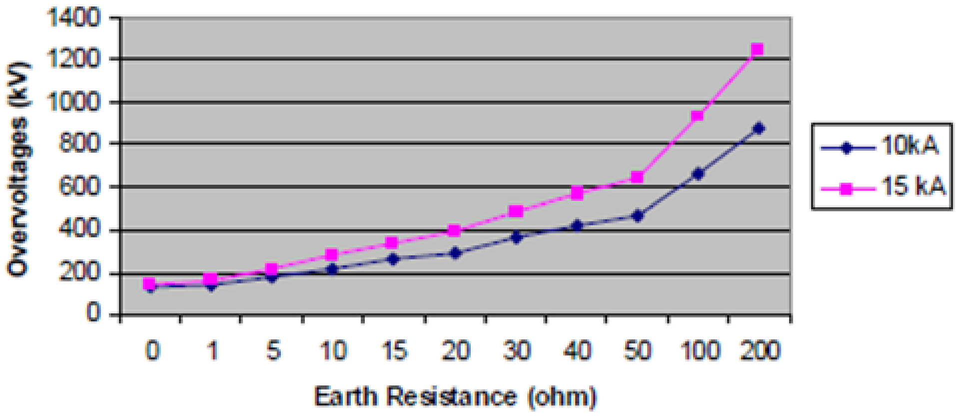


Figure 2.15: Earth Resistance Vs Line Overvoltage[12]

To ensure the best performance of the SPD, the grounding resistance must be lower. The lower the grounding resistance, the higher SPD performance. Thereby, the performance of the SPD depends on its grounding system value[12]. The protection rate of the load will be increased at a low grounding resistance[13]. It is strongly recommended to have a single grounding point leading out of the building, whose grounding resistance should be below 10Ω[14]. In a certain case, such as the military, communication and broadcasting maybe required below this grounding resistance value.

2.5 Grounding Configuration

In electrical engineering, the earth is the reference point in an electrical circuit from which other voltages are measured, or is a common return path for electric current, or a direct physical connection to the Earth. Normally, model grounding just shows by using a single resistor but based on the [15], real situation grounding exactly need to be lumped with an RLC circuit to show the effectiveness of the soil. Vertical ground rods are one of the simplest and most commonly used means for earth termination of electrical and lightning protection[16]. However, related studies on lightning often required modelling in the megahertz frequency range. In the case of lightning, the electrical field on the rod may exceed the electrical strength of the ground and it may cause breakdown and discharge of the sparks.

Based on research [16], there is two types of low-current models of a vertical ground rod which are low-frequency equivalent circuit and high-frequency lumped R-L-C circuit. From figure 2.16 shows low frequency equivalent circuit is using a single resistor while the high frequency circuit is using inductor connect to the capacitor with parallel to the resistor.

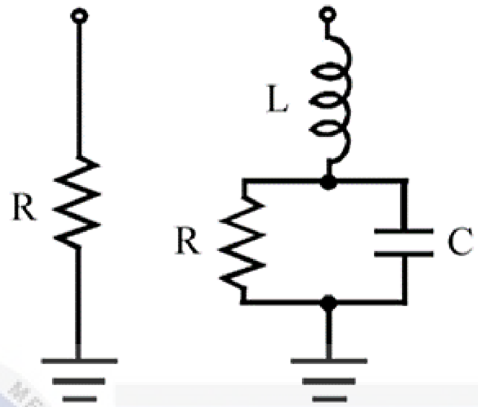


Figure 2.16 : (a) Low Frequency Equivalent Circuit and (b)High-Frequency Lumped R-L-C Circuit[16]

There are one often used of the formula for the parameter of the RLC circuit[16]. From equation 2.1, a resistor of the RLC circuit can be determined. Equation 2.2 is used to determine the capacitor value for the RLC circuit in figure 2.16. From equation 2.3, the value of inductor for RLC circuit show in figure 2.16 can be determined.

$$R = \frac{\rho}{2\pi l}\left[\log\frac{4l}{a} - 1\right](\Omega) \qquad (2.1)$$

$$c = 2\pi\varepsilon l\left[\log\frac{4l}{a} - 1\right](F) \qquad (2.2)$$

$$L = \frac{\mu_0 l}{2\pi}\left[\log\frac{2l}{a} - 1\right](H) \qquad (2.3)$$

Where:

ρ = soil resistivity

l = Rod length

a = Area of rod

ε = constant 8.5419 x 10^{-12}

μ_0= constant 1.25664 x 10^{-6}

2.6 Conclusion

In this literature review, all the information and knowledge about SPD studies are being analyzed. From previous works, the electrical appliance can be protected if the load is installed close to the SPD. By refer to a standard, the value of coordination SPD must be below than 10 meters to the load. If the distance coordination SPD and load is more than 10 meters, another additional SPD must be needed to improve the protection of the SPD. Besides that, the best value of grounding resistance it can flow the current to the ground when lightning surge. Based on the previous study, below 25ohm grounding resistance will make the protection level SPD increase. Based on the previous research, grounding configuration and distance coordination between SPD can determine the effectiveness of SPD. Analyze residual voltage are important to make the electrical appliances protected. Otherwise, the load will damage when the residual voltage value is higher than appliance withstand voltage. For archive the protection level of the SPD a few methods are used to determine the value of the residual voltage SPD due to grounding resistance and coordination. This method will be discussed in the next chapter.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Grounding configuration and coordination of surge protection device (SPD) in low voltage were required to ensure that an electrical appliance or electronic device safe for surge lightning. Furthermore, SPD will be more effective when grounding and coordination has been installed properly. For this project, it was focusing on the performance of SPD that can reduce the residual voltage when surge occurred in the system. Coordination cable length between SPD and grounding resistance can affect the performance of SPD. Next, the effect of different grounding and length of cable must be studied to analyzing the performance of SPD in terms of its characteristics.

This analysis was done by simulation of different cases studies. The first case study was simulation circuit model SPD and loads by using the same connection to the grounding. The second case was model SPD circuit and load with different grounding connection. In order to perform the simulation, double exponential in PSCAD will be used to generate the surge impulse. The research performance characteristic of SPD was applied to the simulation model by applying different grounding value and cable length between SPD and load. The flow chart in Figure 3.1 shows the flow of the step to be done at each stage of the project.

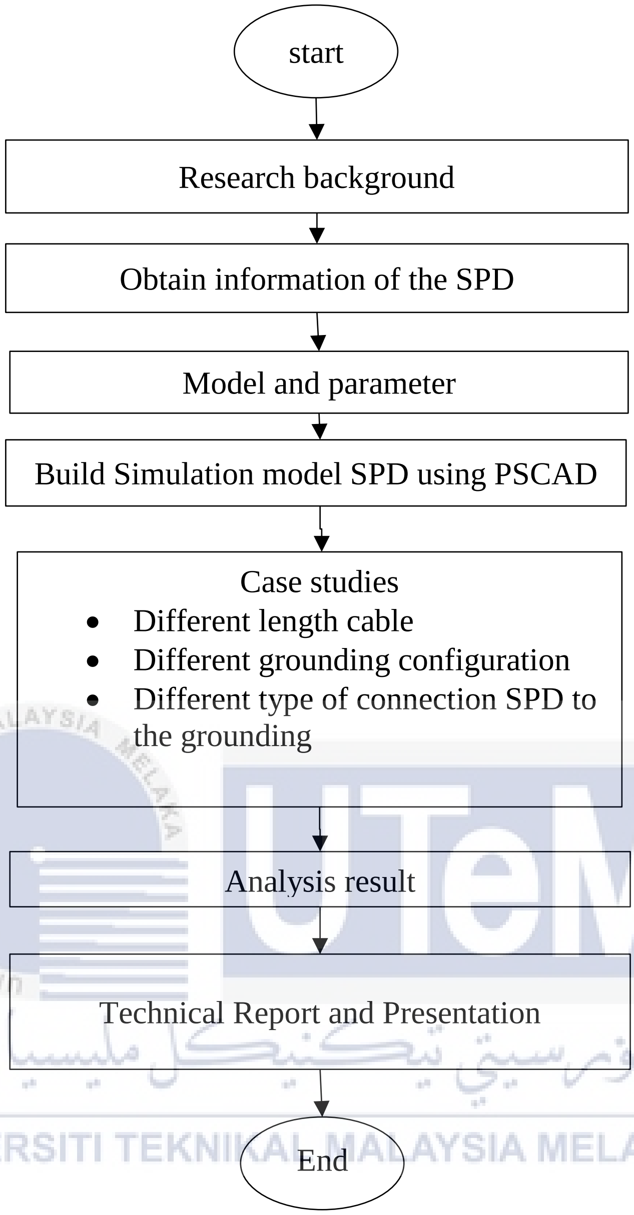


Figure 3.1: Final Year Project Flow

3.2 SPD Research Background

In this section, it will study from the latest researcher and the results of the other experience. Study about coordination and grounding configuration based on residual voltage will be focused on this project. Thus, in order to get a knowledge on this study, many article and journal have been as a reference for this project. The previous article or journal will be a guideline to complete this project. Next, the best method and suitable procedure are selected to complete the studies of this project.

3.3 Obtain Information of SPD

All information about SPD were gathering consist of requirement IEC standard and other sources such as IEEE Standard. Next, data information about SPD also consists of reading and comparing the journals and research papers. The information about SPD was needed to collect the data correctly and to validate the result and follow the standard.

3.4 Model and Parameter

In this project, the experiment was developed by using different model simulation design. Every model consists of three mains part, which was a wave generator, SPD, cables and loads. Cable length between SPD and load can be adjustable. Three different model simulation will be using the same load, which was a 1000Ω resistor. The simulation will be developed in the simple model coordination of SPD in the single-phase low voltage ac circuit. For this project, the SPD will be consider installed in the distribution board at the entrance building. This experiment will evaluate residual voltage U_{res} voltage protection level U_p, voltage load withstands and nominal discharge current I_n. There were two types connection SPD which was SPD and load connect to the same grounding shows in Figure 3.2 and connection different grounding between SPD and load shown in Figure 3.3.

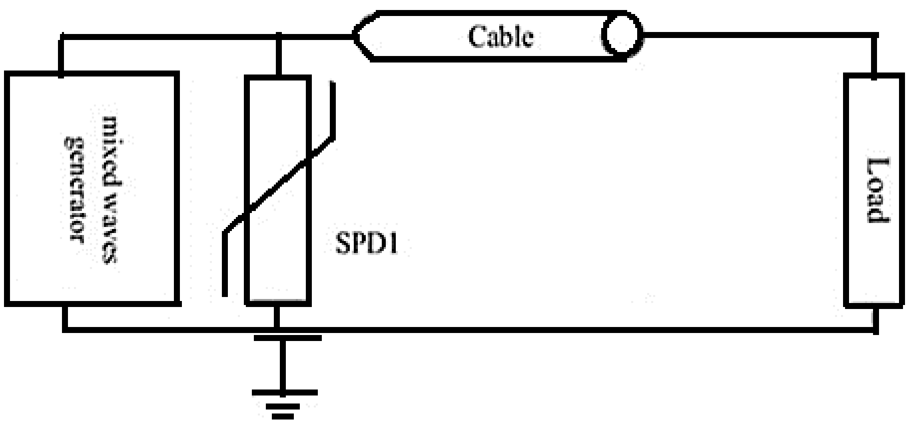


Figure 3.2: SPD and Load Connect With The Same Grounding

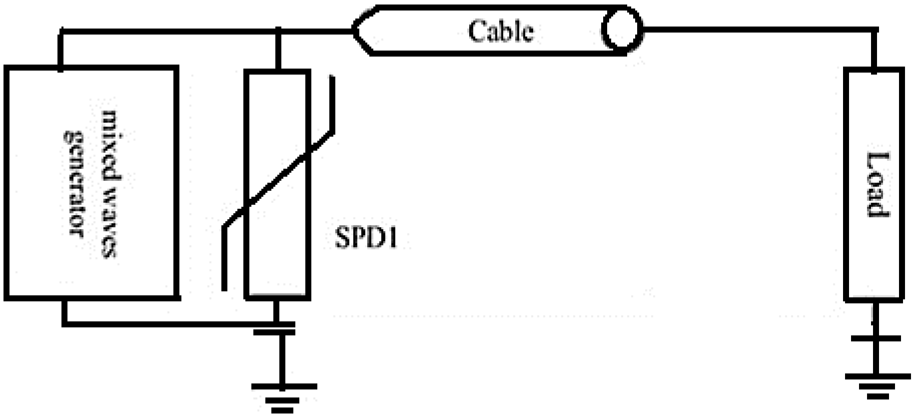


Figure 3.3: SPD and Load Connect With The Different Grounding

3.5 Simulation Design

In this project, Power System Computer Aided Design (PSCAD) software has been used to simulate the SPD design. As the PSCAD software enabled the user to alter the system parameters during a simulation so that it can view the effects while the simulation was in progress[17]. Furthermore, PSCAD also provides a workspace for building custom models.

The analysis was performed base on parameter form IEC 61643-12[2] and previous studies. A suitable component in master library in PSCAD was chosen to design the SPD circuit model. This low-voltage circuit line diagram was designed to assess the effect of the load switching surge.

Mixed wave generator shown in figure 3.5 were selected for simulating lightning impulse because it uses double exponential concept. Furthermore, the type of surge can be varying by setting a certain data parameter in double exponential. The type surge parameter was shown in Table 3.1. In this project, the waveform switching impulse was used in the analysis. Hence, switching impulse can be used to compare the trend of increasing or decreasing voltage and current at load at different cable length.

Table 3.1: Impulse Data [18]

No	Surge type	I	a	b
1	1.2 /50 µs	1.02	1.3 X 10^4	4.4 X 10^6
2	8/20 µs	4.00	8.66 X 10^4	1.37X 10^4
4	8/50 µs	1.23	2.0X 10^4	4.0X 10^5
5	300/1000 µs	1.75	1233	6781.5

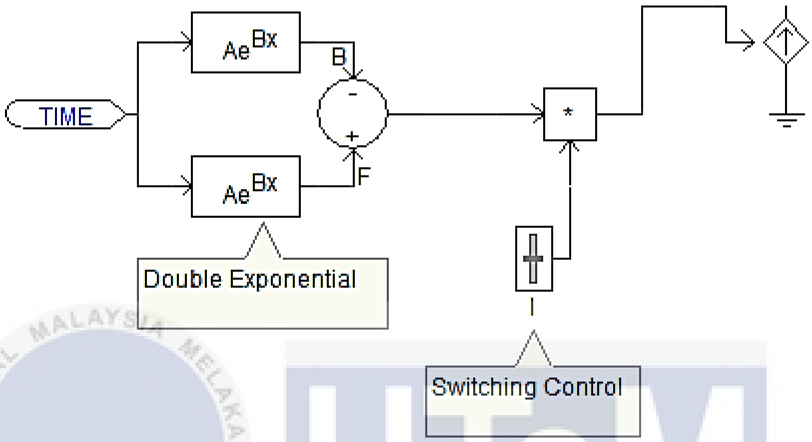


Figure 3.4: Impulse Wave Generator

3.5.1 Coordination SPD and Load

Performance SPD depend on the varies value of the length of cable between the SPD and load. Three value length cable was chosen for this study, which was 1m, 5m, and 10m. According to the IEC 61643-12[2], less than 10m was the best length of cable between SPD and load because it can reduce the oscillation in the cable. The other value was chosen in this project is to see the consequences of the distance that influence the performance of the SPD. After that, by using the SPD model circuit in the PSCAD software, the residual voltage and load withstand voltage can be analyzed. If the value residual voltage was higher than the load voltage, the load will tend to damage. Then, the suitable length of cable between SPD and load compared with the grounding value to get the level protection voltage of the load.

PVC insulated cable with a single core and no shielding sheet were chosen for coordination between SPD. Cable with diameter metal core 1.0 mm and thickness insulation layer 1.0 mm were select as a parameter base on previous research. The relative dielectric constant of metal core is 4.55 and its resistivity is 1.724 X $10^{-8}\Omega$m. All this parameter used in the development of circuit cable figure 3.5. Three length cable which was 1m, 5m, and 10m are used in this simulation.

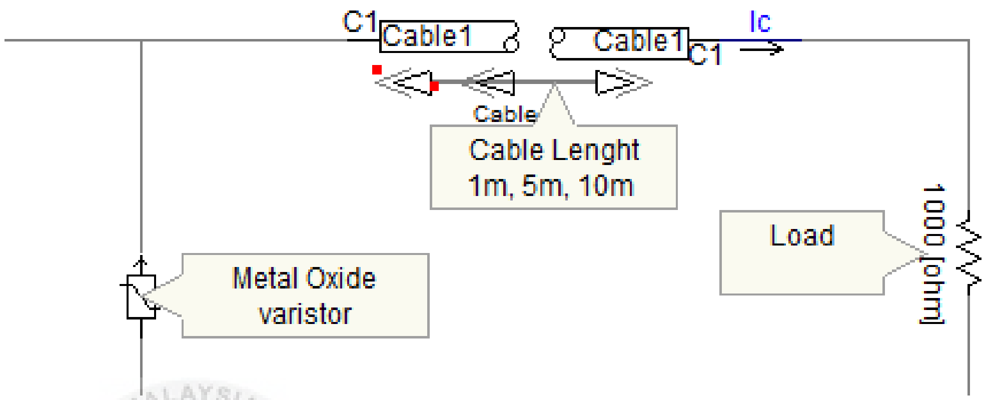


Figure 3.5: Configuration SPD and Load

3.5.2 Grounding Configuration

Different value of grounding, which was 10Ω, 50Ω, 150Ω, 500Ω, and 1000Ω were chosen for this research. Based on previous research these values of grounding were chosen to complete the research[10][19]. An average value of 10Ω was very suitable in practice an acceptable safety level of the SPD[19]. Next, voltage protection level (U_p), load withstand residual voltage (U_{res}) will analyzed by using circuit model SPD in the PSCAD. Then, the value of grounding compared with the value length of the cable between SPD to analysis level protection of the SPD.

This project made in low voltage so that the SPD type 2 have been chosen. The SPD type MOV connected to ground resistance. This was due to the SPD connection in this project is neutral to phase and phase to PE. Usually, at low frequencies, this grounding configuration represented by a single resistor as shown in figure 3.6. While Figure 3.7 shown high frequencies, this grounding configuration represented lumped by RLC circuit.

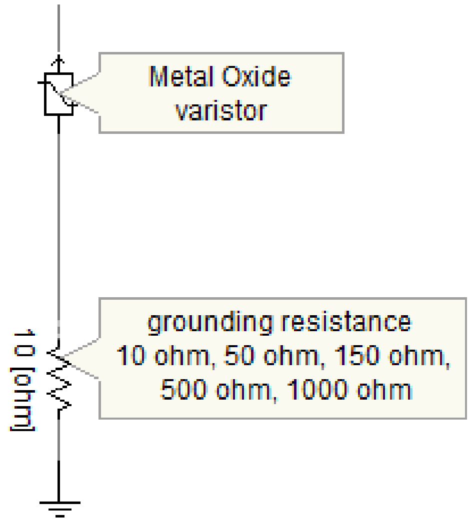


Figure 3.6: SPD Connection With Low Frequency Equivalent Circuit Grounding.

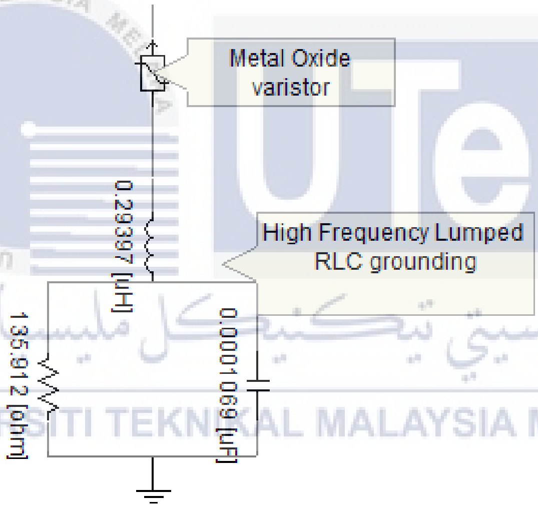


Figure 3.7: SPD Connection With High Frequency Lumped RLC Circuit Grounding

The electric field at the rod may become larger than the electric field at ground strength in the event of lightning. RLC circuit may greatly improve the grounding performance of the rod, especially in the high soil resistivity. The parameter formula of the RLC circuit was discussed in section 2.6. Length of the rod used for this experiment is 1.5m and radius for grounding rod is 5mm. Based on the formula parameter, value inductance L and capacitance C can be determined. The varies value for this configuration was resistance R-value because resistor value varies depending on soil resistivity. Soil resistivity use for this experiment is 10Ω, 50Ω, 150Ω, 500Ω, and 1000Ω.

3.5.3 Grounding Connection SPD and Load

SPD and load connection can be categorized by two types of connection, which were SPD and load, that were connected to the same grounding and SPD and load were connected to the different grounding. Both connections were designed to evaluating the waveform surge and effect of characteristic SPD that was maximum continuous operating voltage Uc and voltage protection level Up. The result compared between these two connections and analyze which one connection more safety to load.

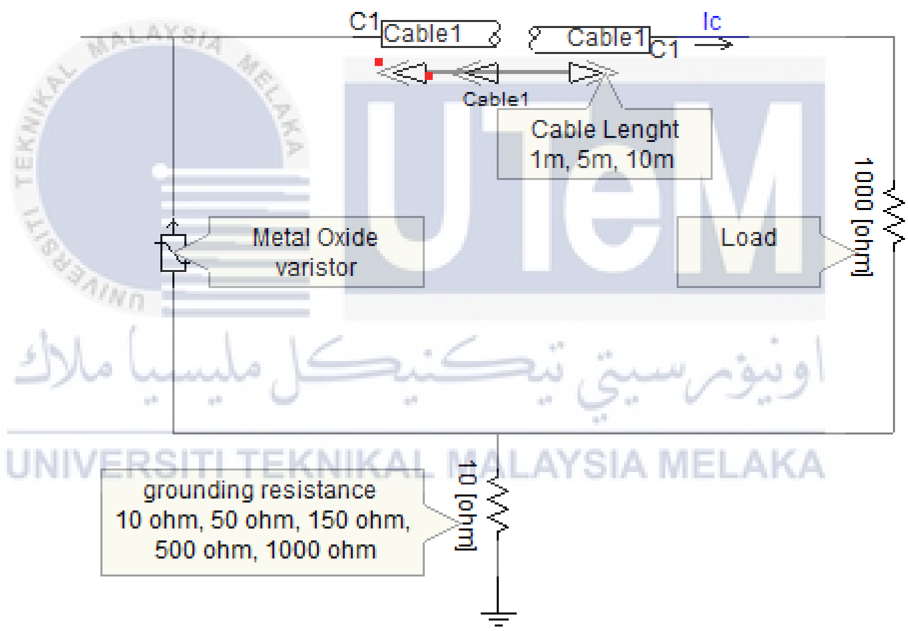


Figure 3.8: SPD and Load Connect With Same Grounding

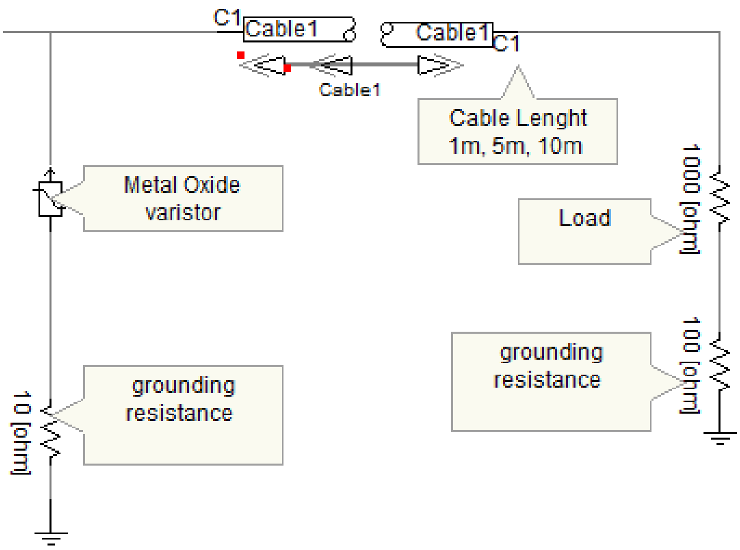


Figure 3.9: SPD and Load are Connected to The Different Grounding

3.6 Analysis Result

For this project, the data-based analysis was described in the appropriate table and graph format. The data for coordination SPD and grounding configuration will be comparing to get the suitable residual voltage for the load can withstand.

3.7 Conclusion

In this chapter, it was briefly explained on how to develop this project from start to finish. PSCAD software was used in this project to monitor the waveform of residual voltage result. Next, the residual voltage due to grounding configuration were analyzed. Voltage at the load were analyzed between two type grounding model. Other than that, the observation and analysis residual voltage done by varies the different of cable length between SPD and load. Comparison data result between a distance between SPD and grounding configuration can be improved the level protection of SPD.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, it will discuss result about performance SPD based on two case studies. The case studies were basically selected based on problem statements and contribution in the review of the research paper. Referring to the methodology in the previous chapter, simulation has been done by using SPD circuit modelling in PSCAD. The discussion will focus on the voltage and current at the load. The comparison data between the case studies were analyzed to evaluate the performance of SPD.

The first case was to evaluate the residual voltage base on the grounding model. Grounding model has two different design, which are single resistor grounding modelling and RLC modelling grounding. The result was analysis for different grounding resistance from 10Ω to 1000Ω and cable length from 1m to 10 m between SPD and load. The second case studies were to evaluate the voltage and current at the load when SPD and load connected with a different coordination grounding.

4.2 Simulation Experiment Achievement

By using the lightning impulse generator model shown in figure 3.5, simulation PSCAD of impulse waveform will be determined. Surge waveform was important to find the residual effect on the SPD coordination and grounding configuration. Since difference surge impulse will affect the value of the residual voltage of SPD. For develop switching impulse, double exponential concept was used in the impulse generator. Parameter for waveform current impulse 8/20 µs were included in the exponential function. Therefore, by using impulse data from table 3.1 the current impulse 8/20 µs are generated shown in Figure 4.1. The range current surge produced by this impulse generator was between $0 < I$ surge < 10 kA. While for the range voltage surge produced was between $0 < V$ surge < 10 kV.

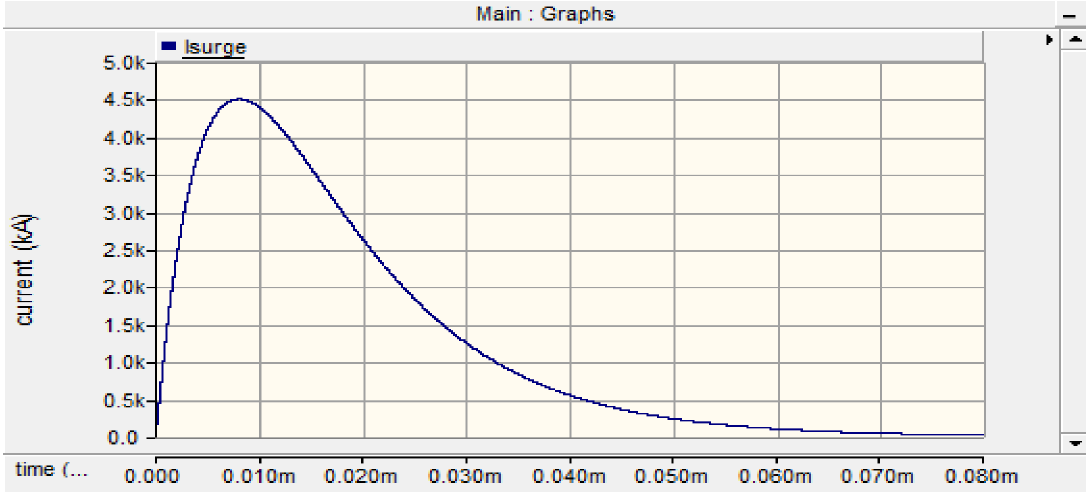


Figure 4.1: The Current Impulse 8/20 µs

Based on observation, a Metal Oxide Varistor (MOV) test was achieved by following the MOV data sheet. The MOV required injecting 4500A maximum peak current to test the clamping voltage of the MOV. Figure 4.2 show the maximum clamping voltage for maximum continuous voltage 250 V MOV could not exceed 650V. If the clamping voltage waveform exceeds the maximum required, it can cause damage to SPD. The performance SPD will drop, and the load will be unprotected.

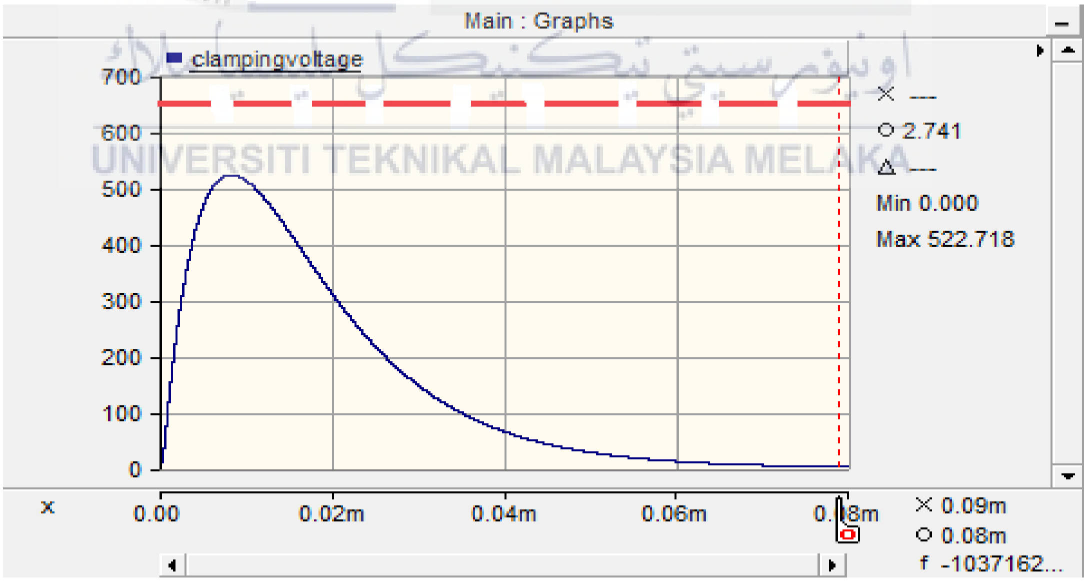


Figure 4.2: Maximum Voltage Clamping

4.3 Case 1: Effect of Length Between SPD and Load Cable for Different Type Grounding Model

There are two grounding modelling design in case 1. The first simulation is the SPD and load connect to same single resistor model grounding. Next simulation is the SPD and load connected to the same RLC model grounding. The simulation is design to evaluate voltage at the load due to cable length between SPD and load.

4.3.1 SPD and Load Connect to Single Resistor Model Grounding.

Figure 4.3 shows the simulation design for the connection SPD and load connected with the same grounding. This simulation was design based on simple and mostly used of grounding configuration for earth termination of the lightning protection system. For this case, a single resistor act like grounding resistance and can vary from 10Ω to 1000Ω values to evaluate the voltage protection for the load.

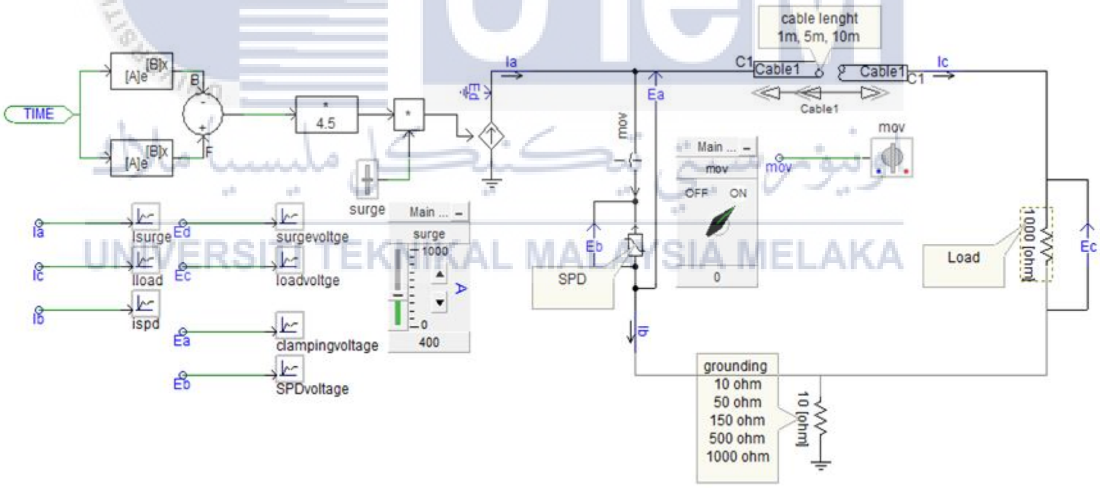


Figure 4.3: Simulation Design SPD Connect to Single Resistor Grounding

The simulation to analyze the voltage at the load for different grounding value and cable length when lightning impulse 8/20 µs was injected to the system. This result was compared between the lowest grounding, 10Ω and the highest grounding value 1000Ω. Figure 4.4 shows the trend voltage surge at the load between grounding and cable length with different value grounding and distance cable length. From the graph, it can be seen for 10Ω resistor the simulation shows the voltage at the load was 523.032V. Meanwhile, for cable length 5m it can increase the voltage at the load 1% from the load voltage at the 1m cable. It produced surge voltage at the load, 528.34V. The load voltage continuously increases by 61.8% when 10m cable was installed to the simulation system. It produces surge voltage at the load, 1001.9V. The different between 1m cable length and 10m were same, 62.8%.

Other than that, if the resistor grounding increase to 1000Ω, the simulation shows the surge voltage at the load was increased to the 544.98V. The load voltage increases by 4.1% than the load voltage at 10Ω grounding. Next, for cable length 5m the surge voltage at the load increases by 78.6%. It produced surge voltage at the load, 1251V. Surge voltage at the load for cable length 10m increases by 64.7% from the load voltage using 5m cable length. It produces surge voltage at the load, 2449.7V.

The graph shows when increasing the grounding resistance, the surge voltage at the load will significantly increase for all connection. It also shows when the cable length was increasing at 1m, 5m, and 10m, the voltage surge at the load also increased. The conclusion from the result the increased of cable can cause increased in the voltage at load, but it becomes worst if the value grounding is high.

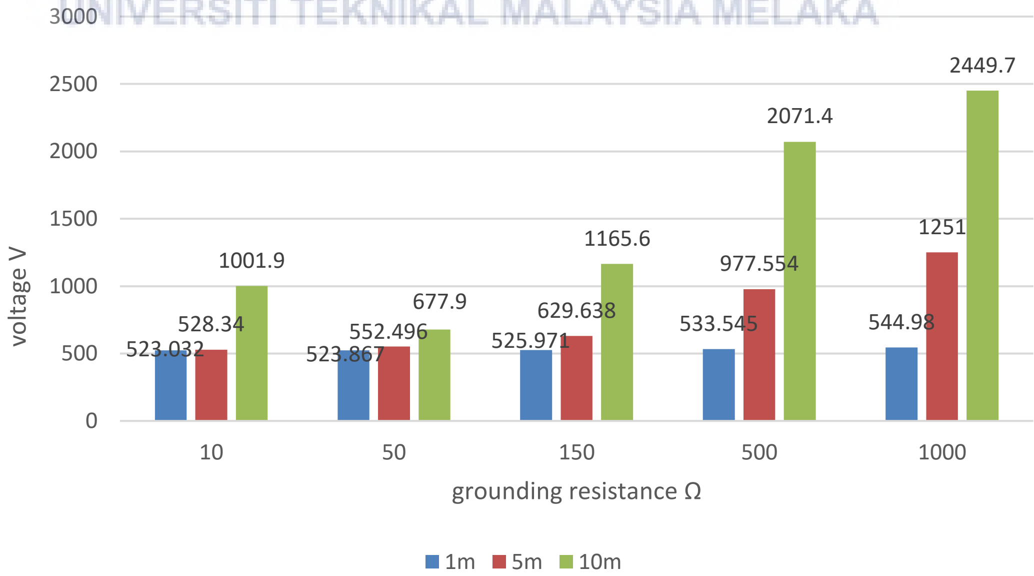


Figure 4.4: Load Voltage for Different Grounding and Cable Length

4.3.2 SPD and Load Connect to RLC Model Grounding

Figure 4.5 shows the simulation design for connection SPD and load connected with the same RLC model grounding. This simulation was designed to improve the grounding performance at the rod, especially in the less grounding resistance. It also designs the study about the consequences of the soil on a high frequency. For this case, inductor and capacitor value will be fixed while the value resistance will vary. This is due to the scope of this case to study the effect of grounding.

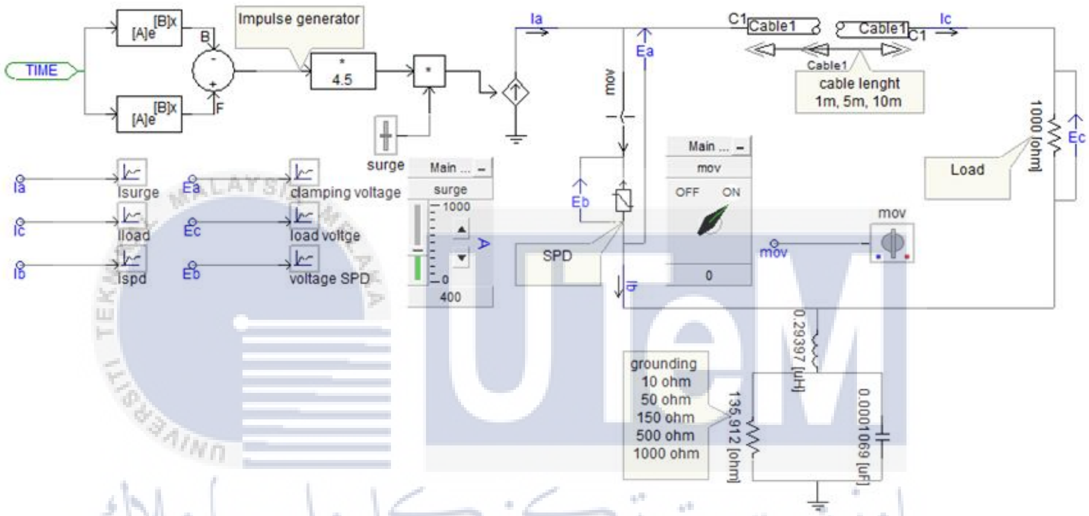


Figure 4.5: Simulation Design SPD Connected to RLC Grounding

Figure 4.6 shows the result of voltage at the load with different grounding and cable length. This result was compared between the lowest grounding, 10Ω and the highest grounding resistance, 1000Ω. Next, the data compared due to cable length. When 10Ω resistor applied for 1m cable length, the voltage at the load will be the lowest, 522.852V. However, the voltage continuously increases by 1% for 5m and 10m cable length. To conclude, the experiment shows if the cable length between the surge protection devices more than 10m, the voltage at the load will be highest.

Next, if the grounding resistance increase to 1000Ω, the voltage at the load also increases to the 525.677V for cable length 1m. It also shows, when the length of the cable increases to 5m the voltage at the load increases by 17.5% to the 617.508V. The experiment shows, the highest the value of grounding, the highest the value of the voltage at the load. The highest load voltage 1128.496 V resulted when configuration resistance 1000Ω and cable length 10m. According to this experiment, the surge voltage at the load can be reduced if the load is installed near to the SPD and using the lowest grounding value.

Figure 4.6 shows the trend voltage surge at the load between the grounding configuration and the length cable. The simulation shows, if the grounding resistance was increase at 10Ω, 50Ω, 100Ω, 500Ω and 1000Ω, the voltage at the load also increased. Furthermore, the length can cause the value of the load increased. Hence, the value surge at the load increased the proportion to grounding configuration and cable length.

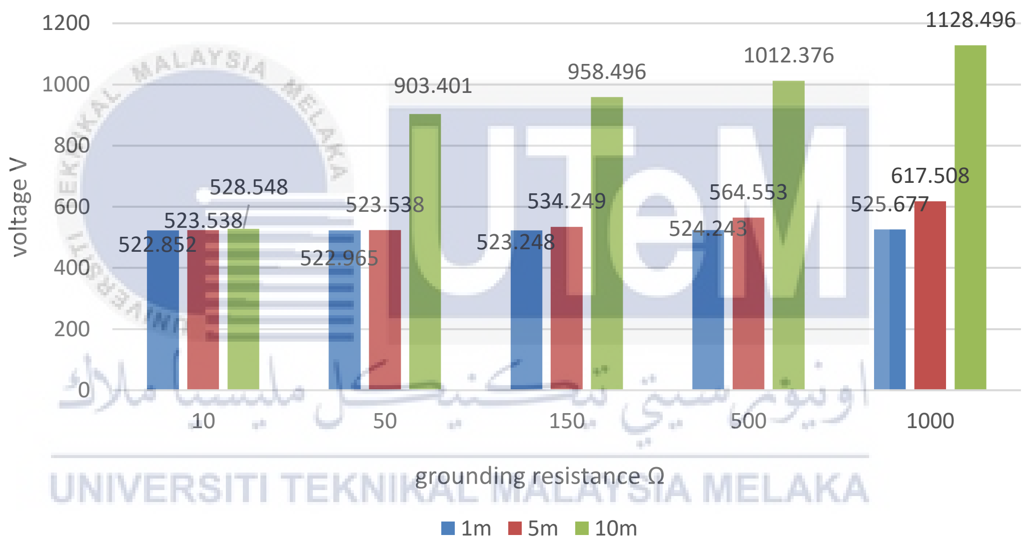


Figure 4.6: Comparison Length and Grounding Value.

4.3.3 Comparison R & RLC Model Grounding Based On Load Voltage

Table 4.1 shows the percentage different between resistor model and RLC model grounding. The 1m cable length was chosen to evaluate the grounding model comparison. The 1m cable length was chosen based on the standard that required below 10m cable length between SPD. Both simulation between single resistor model and RLC model grounding shows that the surge voltage at the load was increased when the grounding resistance increase. That means the surge protection device depends on the value of the grounding. The investigations show voltage at the load for the RLC grounding model lower than the single resistor model. When the grounding increase from 10Ω to grounding resistance 1000Ω the voltage at the load between the resistor model and RLC model grounding will have more gap. The highest percentage different between resistor model and RLC grounding model was 3.6%. The different percentage between both models at 10Ω grounding resistance was very close which is 0.03%. The result shows that the RLC model is more efficient to deliver the surge lightning to the earth.

Table 4.1: Percentage Different Voltage at Load Between R Model and RLC Model

Grounding resistance Ω	Voltage at the load V		Percentage different %
	Resistor model	RLC model	
10Ω	523.032V	522.852V	0.03
50Ω	523.867V	522.965V	0.17
150Ω	525.971V	523.248V	0.52
500Ω	533.545V	524.243V	1.76
1000Ω	544.98V	525.677V	3.6

Figure 4.7 shows the comparison voltage at the load between resistor model grounding and RLC model grounding with different grounding. Both experiments show when applied 10Ω grounding resistance to the system, the voltage at the load was the lowest than others grounding. It also shows when grounding was increased at 10Ω, 50Ω, 150Ω, 500Ω, and 1000Ω the different voltage at the load between the resistor model and RLC model become higher. The graph trend for the resistor model grounding dramatically increases when increasing the resistor value. The trend graph for the RLC model grounding slightly increase when the grounding resistance increase. That means RLC model grounding was more effective to increase the performance SPD.

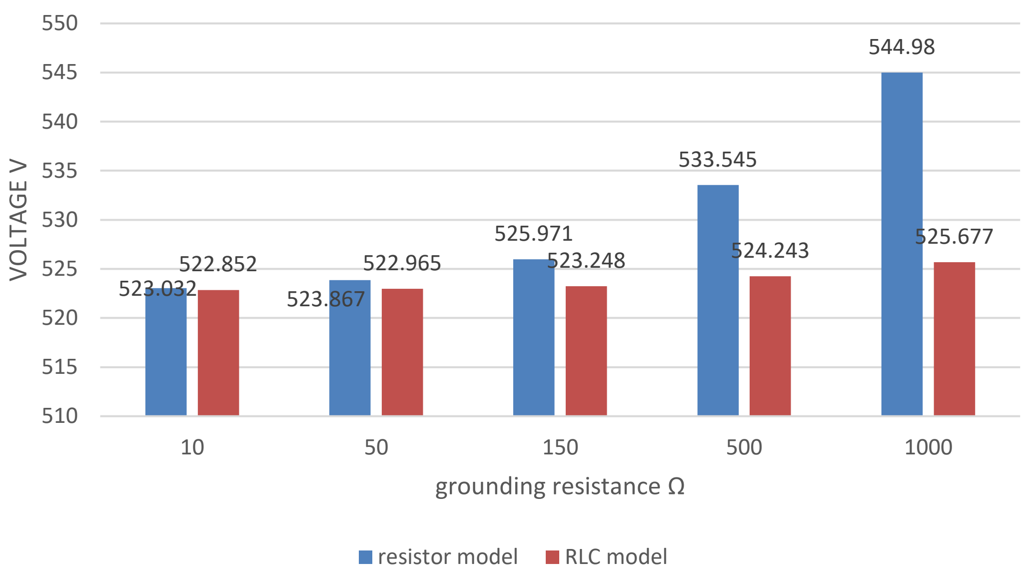


Figure 4.7: Comparison Voltage at Load Between Resistor Model and RLC Model Grounding

In a conclusion, situations show the voltage surge at the load increase when value grounding resistance was increased. The resistance of the SPD will conduct from high resistance to the lower resistance to bypass the surge current. Thus, a performance surge protection device depended on the grounding resistance. The grounding model that can discharge how much current to the grounding can affect the voltage drop at the SPD. Simulations show that the RLC model grounding was more delivered the surge current to the earth compare to the single resistor grounding. Therefore, the RLC model grounding was suitable for the high values grounding. To be conclude, the performance of SPD to limit the surge voltage can increase if the grounding RLC model implemented to the system.

4.4 Effect On Different Length

Both modelling grounding shows the voltage surge at load increase when the connection cable between SPD and load increase. It was due to the oscillation phenomena occur in the cable. During the surge occurred, the fast transient was travelling along the cable between SPD and load. Therefore, if the cable is too long to the SPD, the surge voltage at the load can be increased. Basically, the effective voltage protection distance of the load was according to the installing of SPD that less than 10 meters. Otherwise, if the load was very sensitive equipment it was recommended to install another SPD to protect the load.

4.5 Case2: Residual Voltage Based on different Grounding Configuration

Figure 4.8 shows the simulation design for surge protection device and load connected with the different grounding configuration. The purpose of this simulation design was to evaluate the residual voltage based on different grounding value. For this case, the SPD and the load connected with 10Ω and 100Ω grounding resistance. There were four conditions to conduct this experiment. The first condition, the SPD and load were connected to the 10Ω (R1 and R2) grounding resistance. Second, the SPD was connected to the 10Ω (R1) grounding resistance while the load was connected to the 100Ω (R2). Next, the load connected to the 100Ω (R2) while the SPD connect to the 10Ω (R1). Lastly, the SPD and the load were connected to the 100Ω (R1 and R2). The purpose of this condition was to show that every soil has a different value of resistance.

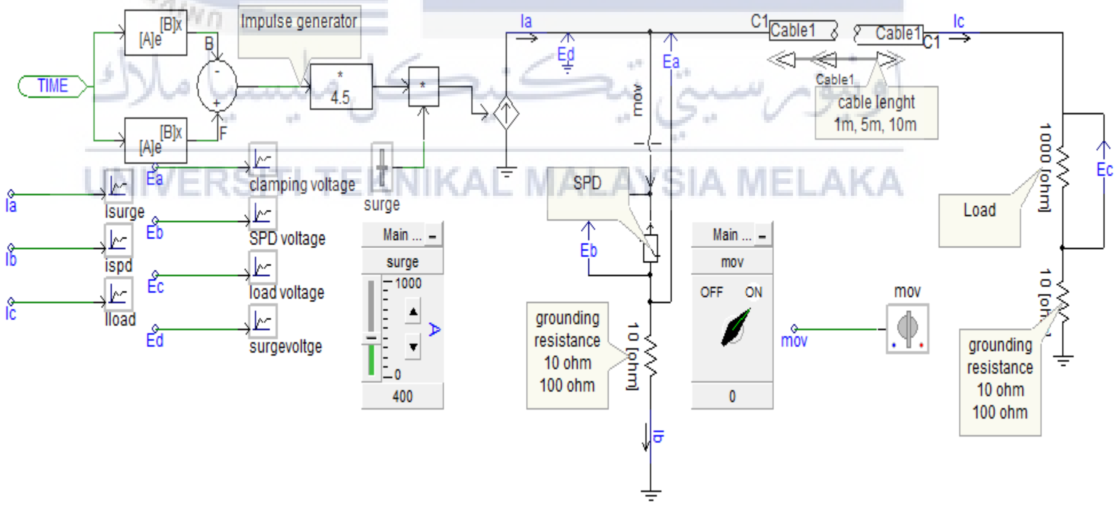


Figure 4.8: SPD and Load Connect to Different Grounding

4.5.1 Voltage at The Load

Figure 4.9 shows the trend voltage surge at the load with different conditions of grounding configuration. The lowest voltage surge at the load occurs when grounding resistance SPD were connected to the 10Ω (R1) while the load grounding resistance connected to the 100Ω (R2). When the value grounding at the SPD lower than grounding at the load, the performance SPD will increase to limit the overvoltage at the load. Thus, the surge voltage will flow to the SPD than flow to the load. The highest load voltage occurs when the grounding SPD 100Ω (R1) while the load was connected to the grounding resistance 10Ω (R2). When the value of the grounding was higher the current will flow to the load rather than to the ground. As a result, the load will tend to damage since the voltage flow to the load was higher than the voltage that the load can withstand. To be conclude, ground resistance at SPD need to lowest than grounding resistance at load to avoid the load damage.

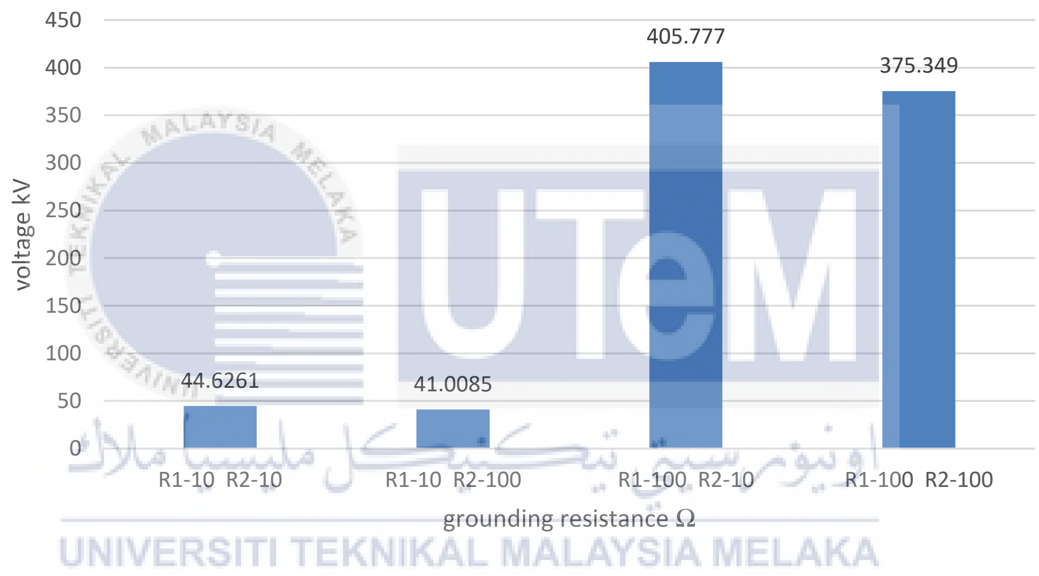


Figure 4.9: Surge Voltage at The Load

4.5.2 Voltage at Surge Protection Device

Figure 4.10 shows the voltage at the SPD for different condition grounding configuration. The simulation shows when applied 10Ω (R1) grounding resistance, the voltage at SPD was higher than others condition grounding configuration. The lowest voltage surge at SPD occurs when 100Ω (R1) were installed to the SPD configuration while the load applied 10Ω (R2) grounding resistance. When surges event occurs in the system, the surge characteristic resistance SPD will drop from higher resistance to the lower resistance state for flow the surge to the earth. Therefore, SPD required to connect to the lowest grounding to increase the performance of the SPD. Furthermore, SPD required the lowest grounding resistance to clamping the voltage surge from flow to the load. In case of that, SPD did not bypass the surge to the ground if the value grounding very high from the requirement. The performance SPD will increase if the lowest connection configuration was installed to the system. That means the voltage drops at SPD depend on how much current will flow to the grounding.

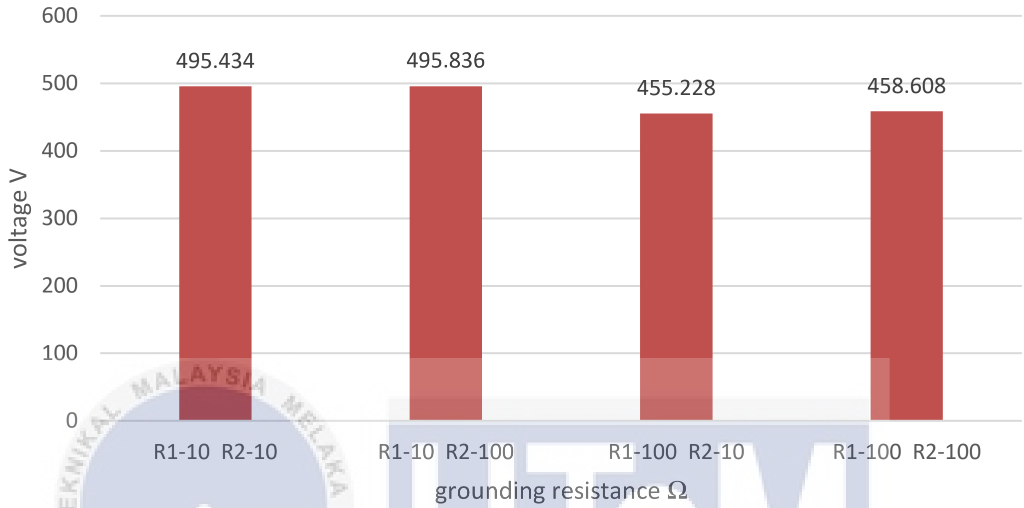


Figure 4.10: Voltage SPD Based On Different Grounding

4.5.3 Current at Load

Figure 4.11 show trend current at the load for different grounding configuration. The result shows the performance SPD to reduce the current surge occurred to the load. When the 10Ω (R1) grounding resistance connects to the SPD while the 100Ω (R2) connect to load, the current at the load will be lowest. This is because, when a lower value grounding resistance applied to the system means the best performance for SPD to limit the surge current happed at the load were increased. Other than that, if the SPD connect to 100Ω (R1) and the load connected to the 10Ω (R2) the current at the load will be 405.6A which was the highest current at the load. That means when increasing the value grounding resistance at SPD, it can reduce the performance of SPD to limit the surge current occurred at load. Therefore, load will damage if surge current flow to the load higher.

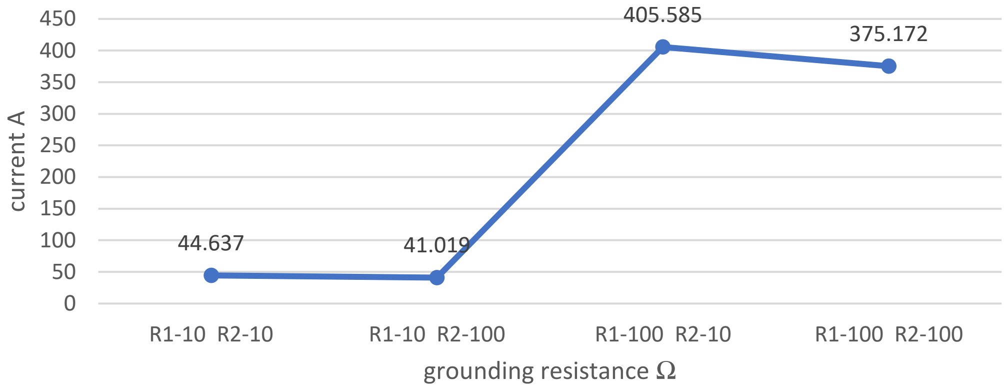


Figure 4.11: Current at The Load for Different Grounding Configuration

4.5.4 Current at Surge Protection Device

Figure 4.12 shows the trend current at the surge protection device for different grounding configuration. When the grounding 10Ω (R1) were connected to the SPD while the load was connected to the 100Ω (R2) the value of current at the SPD will be highest. Due to this, when the grounding at the SPD lower than the load, surge current will flow to the SPD then flow to the load. The performance surge protection device to bypass the current surge need the lower grounding value. The lower value grounding resistance applied to the system, the best performance for SPD to bypass the surge current to the ground. The lowers current at the SPD have resulted when grounding resistance 100Ω (R1) were connected to the SPD while 10Ω (R2) is connected to the load. Increasing the grounding resistance can reduce the performance for SPD to bypass the surge current to the ground. That means the value current surge at SPD decreased corresponding to the increase the value grounding resistance.

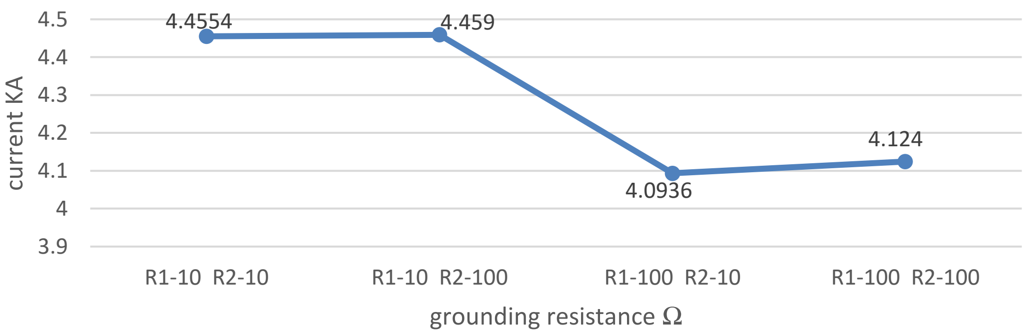


Figure 4.12: Current at SPD for Different Grounding Configuration

In summary, both simulations show current at load was increased and current at SPD was decreased when value grounding resistance was increased. Surge protection device cannot operate properly to bypass the current surge to the ground if the value of the grounding resistance high. Therefore, the current surge will flow to the load and make the current at the load increase. Current flow through the SPD must be higher to cut off the current surge to flow to the load. To bring out this situation, the grounding at the SPD must be lower than the grounding resistance at the load.

4.6 Comparison Connection Grounding of SPD

Figure 4.13 show the comparison voltage at the load for different grounding connection to SPD. The result show voltage at the load for isolated grounding higher than same connection grounding SPD. This is because, isolated ground uses one or two electrodes, is much higher than the common ground. The touch potential of the electronic equipment enclosures in the event of an earth fault within the equipment may therefore exceed safe limits. Voltage at the load for same grounding are lower because with multiple grounding points with different types of electrodes bonded together to form a low impedance ground path which ties together all forms of grounding within the building. It prevents the grounding system from attaining dangerous potential rise with reference to the general earth mass and avoids differential voltages to the equipment. Therefore, the grounding connection SPD and load need to bond together to increase the protection of the load.

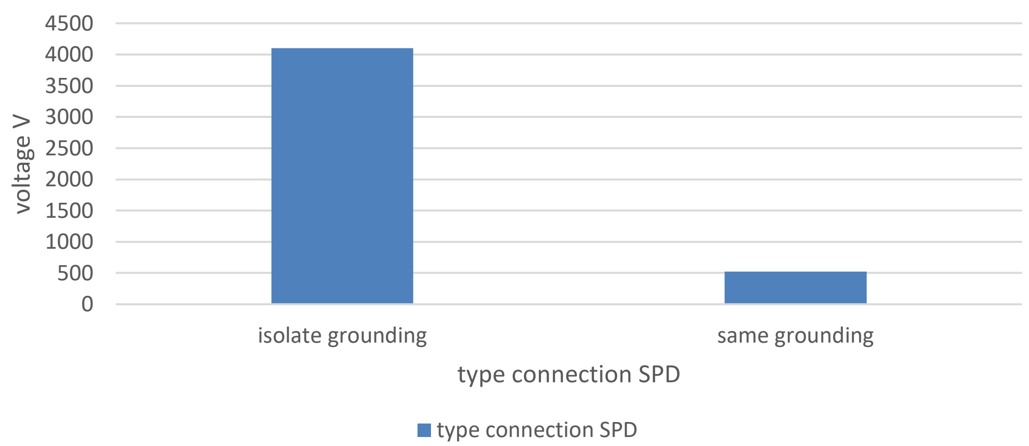


Figure 4.13: Voltage at the Load for Different Type Connection SPD

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This project describes residual voltage when different resistance grounding and cable length implemented to the system. If the residual voltage SPD was higher than voltage load can withstand the load will damage. This project also evaluates the performance SPD based on the grounding model. The high value grounding resistance effect the performance SPD to bypass the current to flow to the earth. Based on a case study in this project, the performance SPD depend on applied surge waveform, grounding configuration and coordination of SPD.

In order to analyze the SPD residual voltage, this project uses the PSCAD software to interpret the data and result. There are two different model grounding which is single resistor grounding and RLC model grounding. The simulation model grounding will be used as different grounding system. This experiment conducted with 3 different cable length and the same value of the load. A few characteristic SPD will be analyzing such as the voltage at the load, voltage surge SPD, current at load and current at SPD.

Simulation show that the RLC model grounding was more delivered surge current to earth compared single resistor grounding. Furthermore, the RLC model grounding was suitable to be installed for the high values grounding. Performance of the SPD to limit the surge voltage increases, if the grounding RLC model implemented to the system. The RLC model grounding to SPD will protect the electrical appliance by limiting the over transient and divert it to the ground. Despite RLC modelling was better than the single grounding model, it has a small percentage different for voltage at the load and voltage at SPD. Therefore, the single resistor grounding modelling most commonly used for earth termination of electrical and lightning protection.

Furthermore, different coordination SPD and load can affect the residual voltage of the SPD. During the surge occurred, the fast transient was travelling along the cable between SPD and the load. Installation coordination of SPD and load must be shortest below 10 meters to avoid reflection and oscillation phenomena in the cable. If SPD was installed in this length, the residual voltage will be lower than the voltage that load can withstand. Otherwise, if length cable SPD and load more than 10 meters it needs another surge protection device install to the system to make sure the load was safe.

Based on the result, the voltage at the load and current at the load were affected by the value of grounding and cable length. For grounding configuration, the lower the grounding resistance will affect the level voltage protection of the SPD. The value voltage at the load and current at the load will increase when the value grounding resistance increase. In case that value of the voltage at SPD decreases, it causes by value of grounding resistance increase. The best value of grounding resistance was below 25 Ω. It is difficult to get grounding value above the 10Ω because every soil has a different value of resistance. It was important to get the lower grounding resistance to increase the performance SPD to bypass the surge to the earth. If the value grounding resistance were higher, the performance SPD to bypass the current will be lower. So that, the voltage flow at the load will higher than the withstand load voltage.

SPD and load need connected to same grounding to ensure that no unsafe conditions develop during lighting strikes or ground faults. Bonding of the different grounding systems is thus the first step towards protection of sensitive equipment against surges. In fact, it is not only the electrical reference points which need to be bonded, but also all kinds of metallic surfaces which can give rise to a differential potential. Based on result, SPD and load connected the same grounding have lower voltage at the load then SPD and load connected to the different grounding.

5.2 Future Works

In the surge protection device system, the design RLC modelling grounding will be implemented in the different grounding connection SPD and load to evaluate the performance SPD. Other than that, further studies and analysis about sustainability of surge protection device when multiple surge occurs to the system. Therefore, the lightning was unexpected phenomenon that give the damage to the system, especially to the electrical appliance. Next, for further studies, it was recommended to test a different type of load to evaluate performance the SPD.

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APPENDICES

APPENDIX A : KEY MILESTONE

Project progress	Duration
Collect all of journal and literature review	September 2018
Research background	October 2018
Develop SPD design simulation	October 2018
Write report draft	October 2018
First seminar	December 2018
Submit report	December 2018
Develop simulation using PSCAD	January 2019
Analysis the result	April 2019
Write a report	April 2019
Final seminar	May 2019
Submit report	May 2019
Hard cover and CD	June 2019

APPENDIX B : GANT CHART

	September				October				November				December				March				April				May				June			
Tasks	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Title Project Registration																																
Search and Read Article Related to the SPD																																
The Study About Coordination Between SPD And Load.																																
The Study About SPD Residual Voltage Due to Grounding Configuration.																																
The Study About Grounding Modelling																																
Develop SPD Model Simulation																																
Write FYP 1 Report																																
Seminar/Presentation 1																																
Analysis by Using PSCAD Simulation																																
Determine Relation Coordination SPD And Grounding Configuration																																
Determine Comparison Grounding Modelling																																
Fulfil the Report of Final Year Project																																
Submission Report of Final Year Project																																
Seminar/ Presentation 2																																
Send Hardcover Report And CD																																

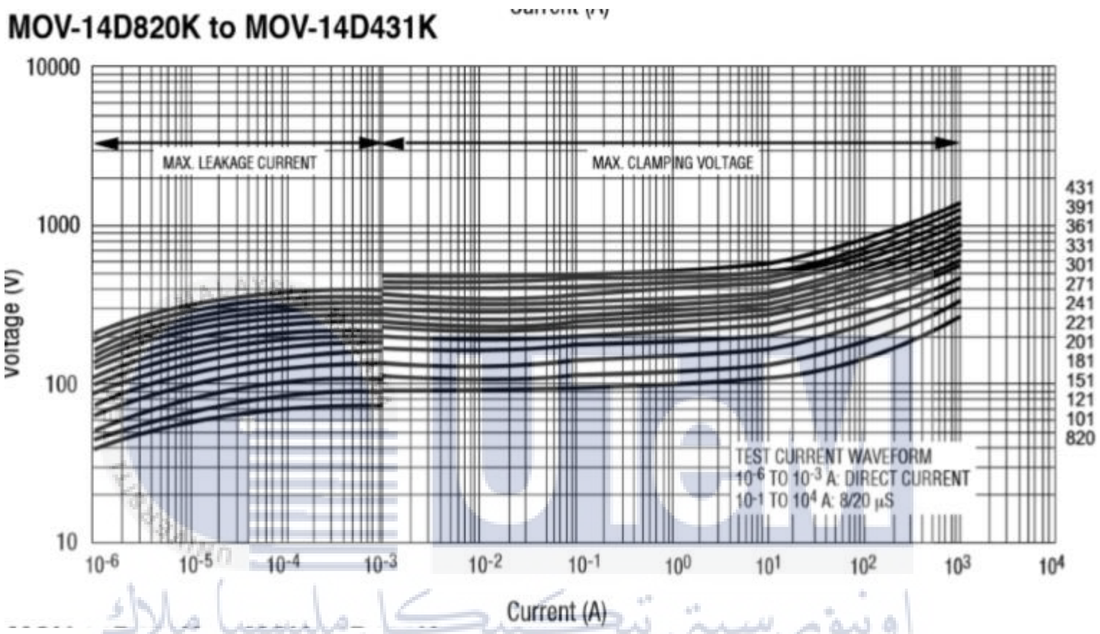
APPENDIX C: SIMULATION SETTING

i. From data sheet metal oxide varistor (i--v characteristic)

Size disk = 14mm

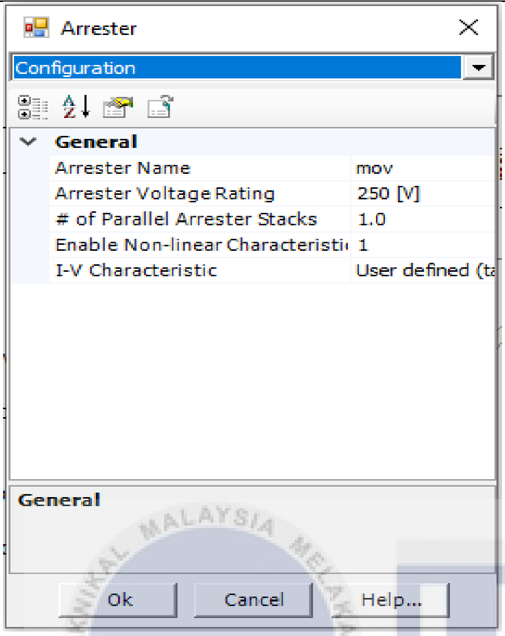
Uc = 250 VAC

Maximum voltage clamping = 650 VAC

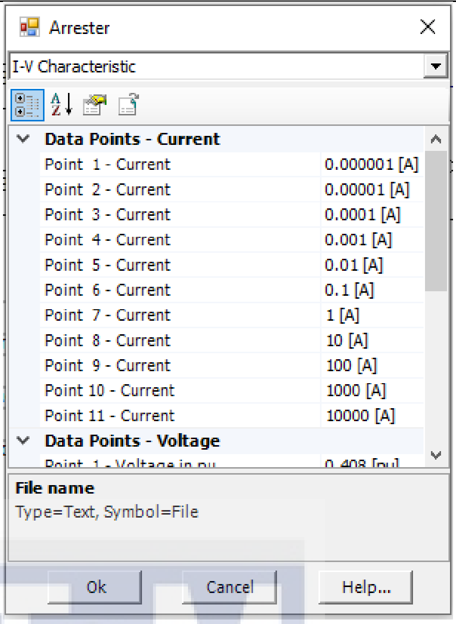


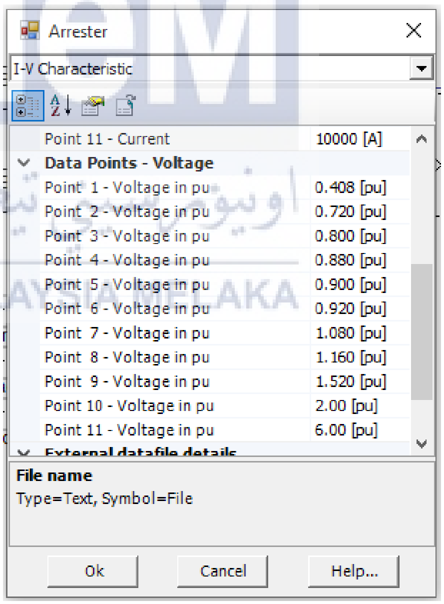
ii. Setting MOV at SPD

Uc



i-v characteristic





iii. Setting lenght of cable

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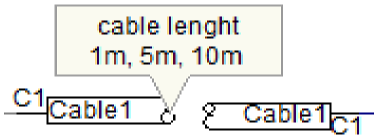
<tr><td>1</td><td>
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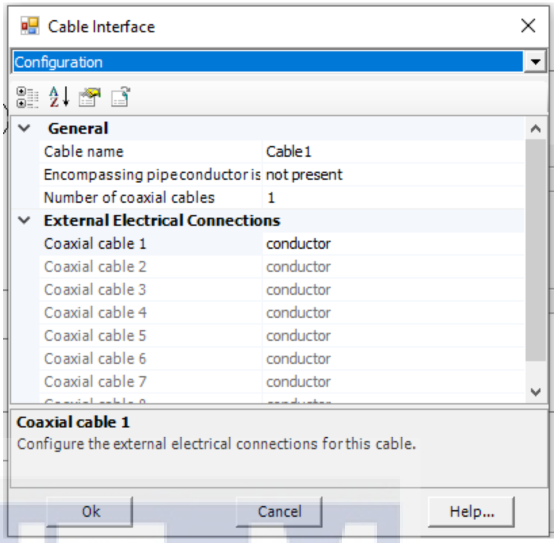
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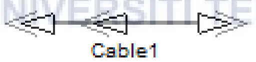
<tr><td>2.</td><td>
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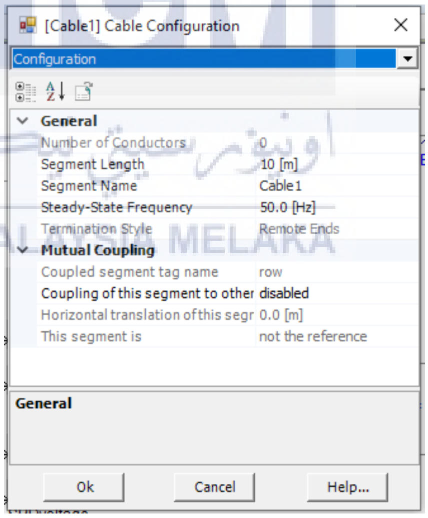
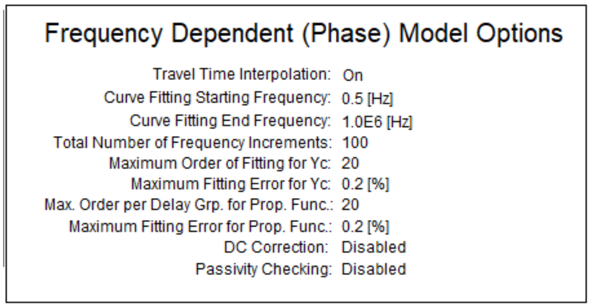


Frequency dependent (phase) model option

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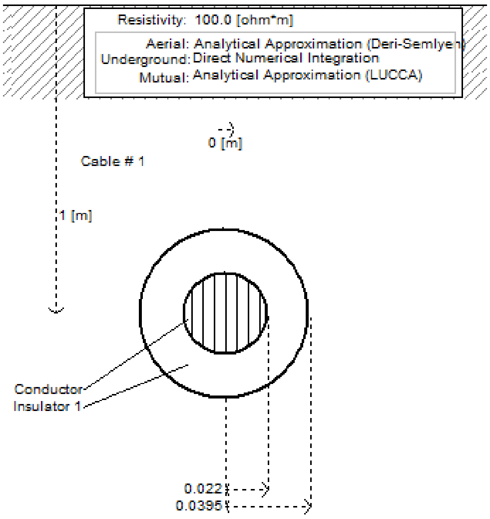

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APPENDIX D : RESULT SIMULATION

i. voltage at the load for single resistor model configuration

Cable length (m)	1m	5m	10m
Grounding resistance Ω	Voltage at the load V	Voltage at load V	Voltage at load V
10Ω	523.032 V	528.34 V	1001.9 V
50Ω	523.867V	552.496 V	677.9 V
150Ω	525.971 V	629.638 V	1165.6 V
500Ω	533.545 V	977.554 V	2071.4 V
1000Ω	544.98 V	1251 V	2449.7 V

ii. Voltage At The Load For RLC Model Configuration.

Cable length (m)	1m	5m	10m
Grounding resistance Ω	Voltage at the load V	Voltage at load V	Voltage at load V
10Ω	522.852 V	523.538 V	528.548 V
50Ω	522.965 V	523.538 V	903.401 V
150Ω	523.248 V	534.249 V	958.496 V
500Ω	524.243 V	564.553 V	1012.376 V
1000Ω	525.677 V	617.508 V	1098.7 V

iii. Case2: Result for different connection grounding

Grounding value	Ispd kA	Iload A	Vspd V	vload kV	Clamping voltage
R1-10 R2-10	4.4554	44.626	495.434	44.6261	517.711
R1-10 R2-100	4.459	41.008	495.836	41.0085	518.131
R1-100 R2-10	4.0936	405.778	455.228	405.777	475.696
R1-100 R2-100	4.124	375.45	458.608	375.349	479.227

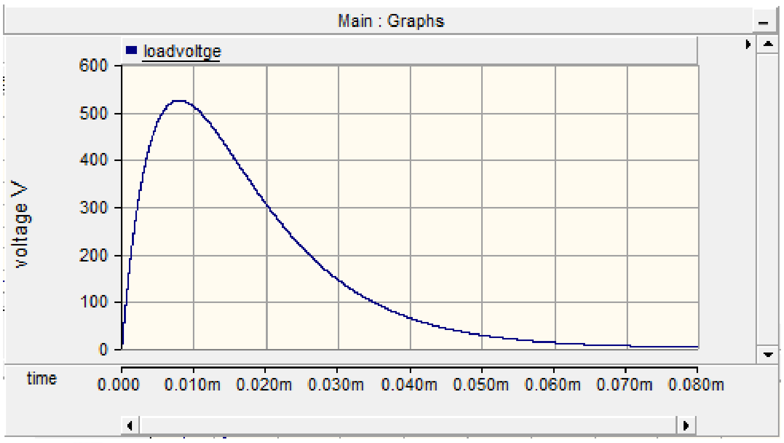
Where :

RI = grounding connected to the SPD
R2 = grounding connected to the load

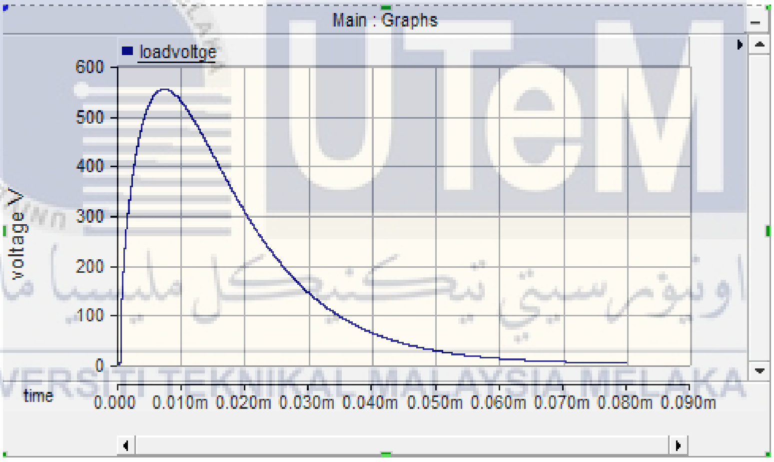
iv. Surge waveform for single resistor grounding model

Voltage at the load
Grounding resistance = 50 Ω

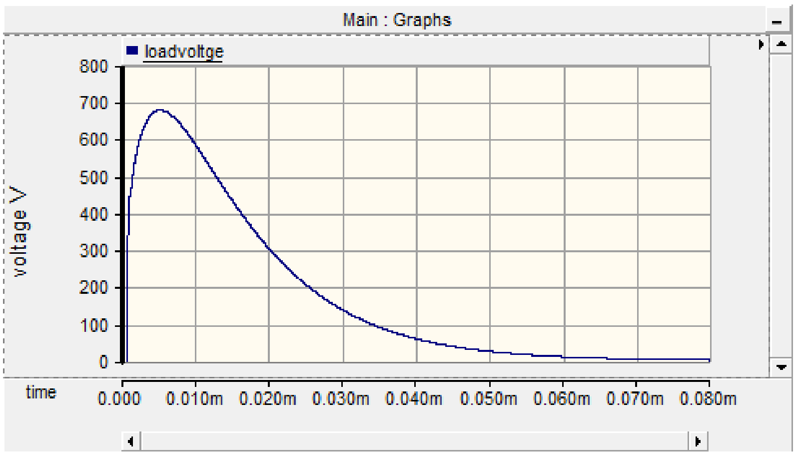
Cable lenght = 1m



Cable lenght = 5m



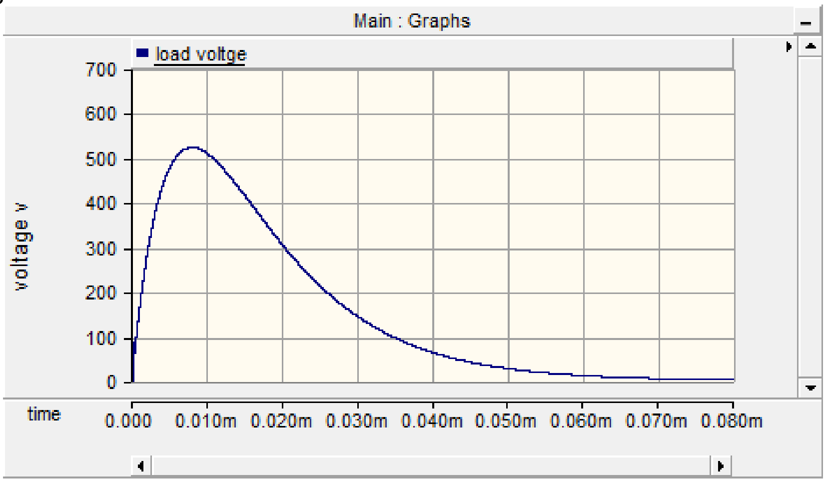
Cable lenght = 10m



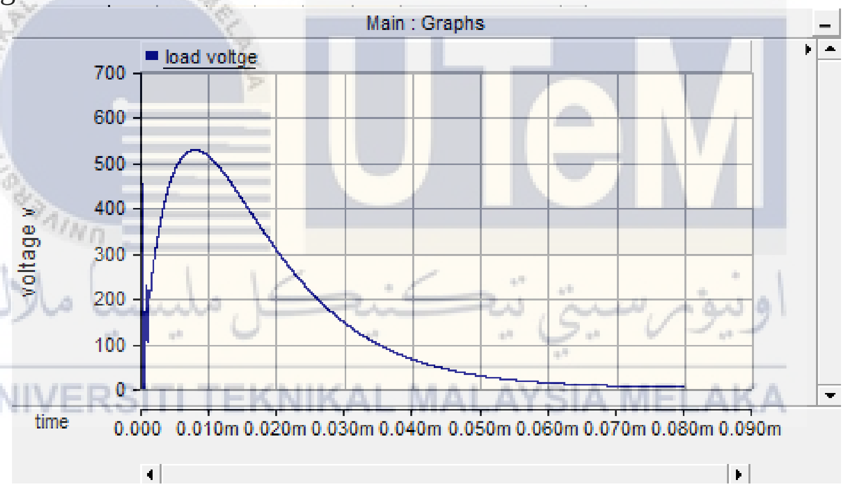
v. Surge waveform Voltage at the load for RLC grounding model

Grounding resistance = 50 Ω

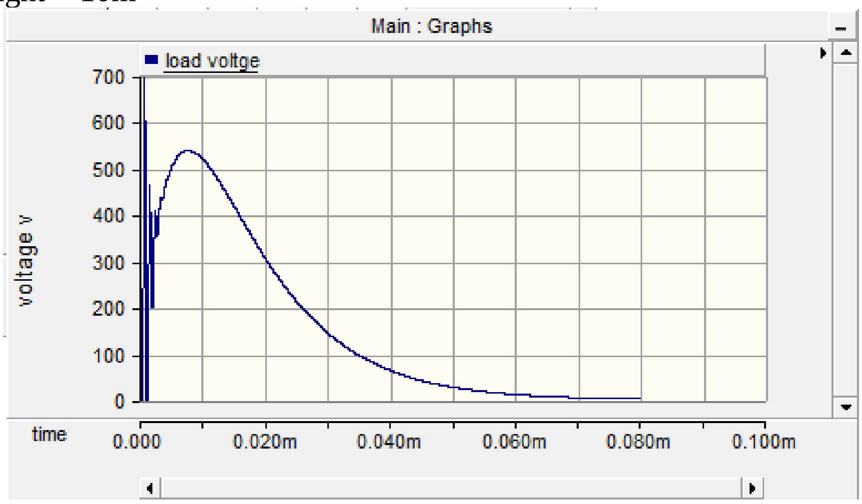
Cable lenght = 1m



Cable lenght = 5m

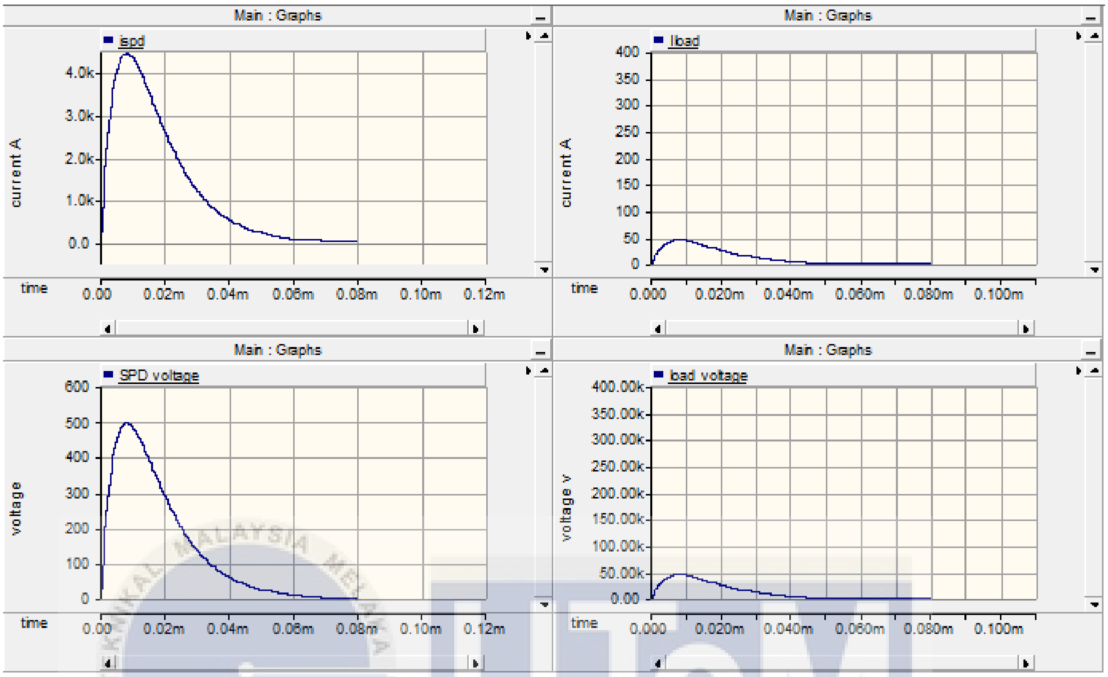


Cable lenght = 10m

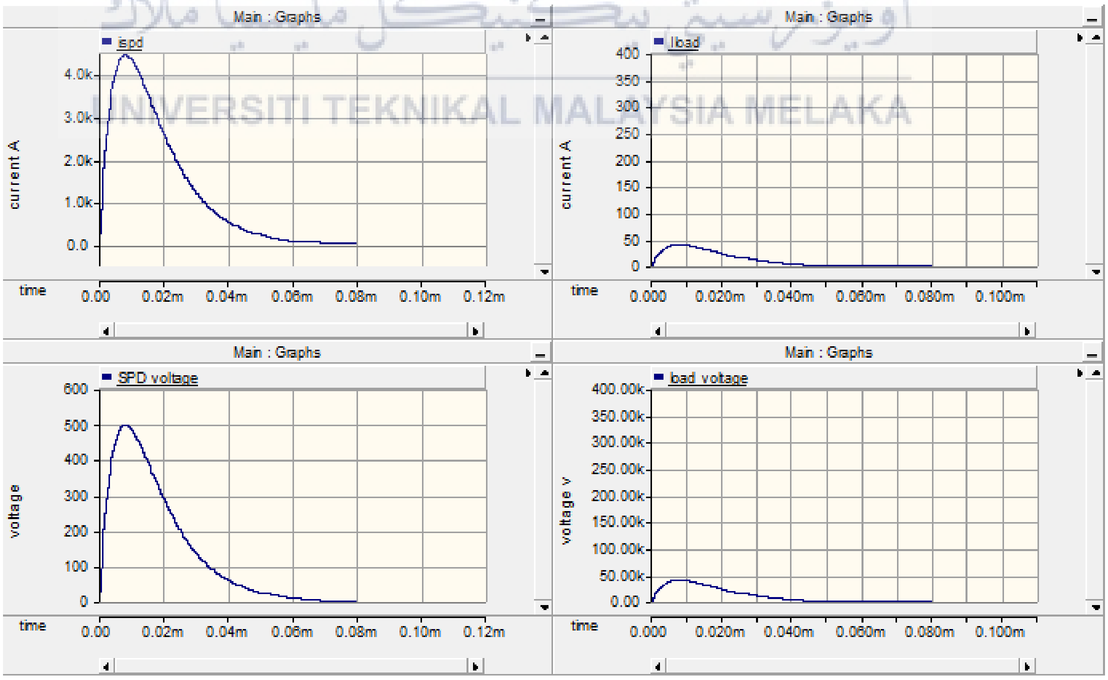


vi. Case 2 : Result surge waveform for diffrent grounding configuration

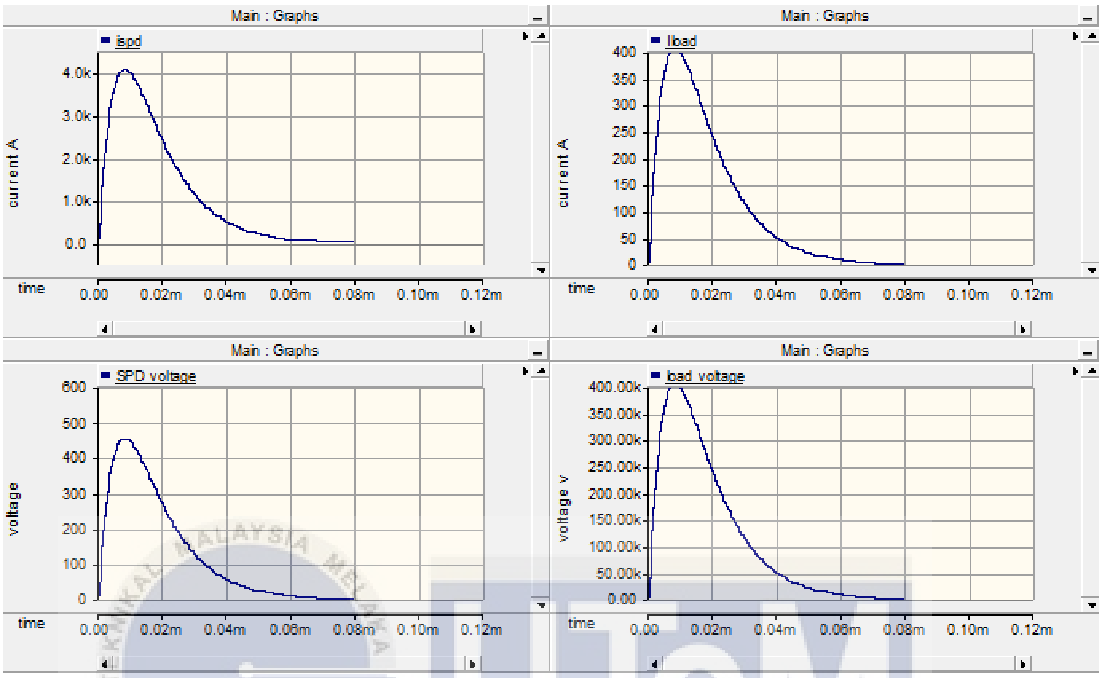
Grounding at SPD (R1)=10Ω Grounding at load(R2) = 10Ω



Grounding at SPD (R1)=10Ω Grounding at load(R2) = 100Ω



Grounding at SPD (R1)=100Ω   Grounding at load(R2) = 10Ω



Grounding at SPD (R1)=100Ω   Grounding at load(R2) = 100Ω