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LAPORAN PROJEK SARJANA MUDA

SURGE PROTECTION DEVICE (SPD): EFFECT OF DIFFERENT DESIGN OF GROUNDING SYSTEM

By

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“I hereby declare that I have read through this report entitle “Surge Protection Device (SPD): Effect of Different Design of Grounding System” and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)”

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SURGE PROTECTION DEVICE (SPD): EFFECT OF DIFFERENT DESIGN OF GROUNDING SYSTEM

SHAFRI BIN SAAD

A report submitted in partial fulfilment of the requirements for the degree of Bachelor of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

I declare that this report entitle "Surge Protection Device (SPD): Effect of Different Design of Grounding System" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : ....

Date : ....

To my beloved mother and father

ACKNOWLEDGEMENT

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.

First and foremost, I would like to express my deepest appreciation to my supervisor and lecturer Dr. Farhan Bin Hanaffi, who has encouraged and helped me to complete this project and preparing the report. I am extremely indebted to him for his expert, sincere and valuable guidance extended to me.

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ABSTRACT

This study is about the impact of the difference value of grounding impedance for surge protection device (SPD) in the low voltage system. High grounding impedance will reduce effectiveness of the surge current to flow through earth which increase possibility users and equipment exposed to surge current. The important characteristics when to choose SPD is the SPD voltage protection level (*Up*) must be less or equal to equipment withstand voltage (*Uw*). This study also considered the important criteria for SPD coordination such as the length of cable to the equipment. This study was conducted by software simulation and real equipment experiment. Simulation was use circuit modelling software known as PSCAD. It used to analyze the characteristics of SPD and investigate the oscillation phenomenon. In order to prove it is a reliable simulation it requires validation using experiment. Therefore, experiments using actual equipment was be carried out at the High Voltage Laboratory, University of Technical Malaysia Melaka (UTeM). Results of the data from the two experiments are compared and analysed. The analysis shows that the effect of the increment of impedance grounding was affected the discharge surge current from SPD to earth.

ABSTRAK

Kajian ini adalah mengenai kesan perbezaan nilai impedan pembumian untuk peranti perlindungan lonjakan (SPD) pada sistem voltage rendah. Nilai impedan pembumian yang tinggi akan mengurangkan keberkesanan arus lonjakan untuk mengalir ke bumi malah meningkatkan kemungkinan pengguna dan peralatan terdedah pada arus lonjakan. Antara ciri-ciri penting semasa pemilihan SPD adalah tahap perlindungan voltan SPD (*Up*) mesti kurang atau sama nila dengan voltan menahan peralatan (*Uw*). Kajian ini juga mengambil kira kriteria penting semasa kordinasi pemasangan SPD seperti panjang kabel dari SPD kepada peralatan. Kajian ini telah dijalankan mengunakan perisian simulasi dan juga ekperimen mengunakan peralatan sebenar. Ekperimen simulasi telah mengunakan perisian model litar simulasi PSCAD. Ia digunakan untuk menganalisa ciri-ciri SPD serta menyiasat fenomena ayunan. Walaubagaimanapun untuk mencapai simulasi dipercayai ia memerlukan pengesahan daripada ekperimen. Oleh itu ekperiment mengunakan peralatan sebenar akan dijalankan di Makmal Voltage Tinggi, Universiti Teknikal Malaysia Melaka (UTeM). Keputusan data dari kedua-dua ekperimen telah dibandingkan dan dianalisa. Hasil analisa menunjukan bahawa kesan dari kenaikan nilai impedan pembumian telah memberi kesan kepada pelepasan arus lonjakan dari SPD ke bumi.

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CHAPTER 1

1.1 Project Background

Surge phenomenon can cause occurrence over-voltage and over-current at low-voltage power system. This phenomenon can cause damage or functions failure to the electrical and electronic equipment [1]. Engineers usually recognizes two sources of voltage surges. This is classified as a source of internal and external causes.

According to the white paper presented by Phoenix Contact, an estimated 63 percent of the surge comes from within a facility. However, the remaining 37 percent of surges originate from outside of the affected facility [2]. Figure 1.1 shows the percentage source of surge from internal and external causes. Surges are caused by internal events such as motors starting and stopping, load dynamic changes on larger production machines, light load panels switching on and off, etc. Beside that, surges are caused by external events such as lightning strikes, utility grid switching, switching of capacitor banks, electrical accidents, etc.

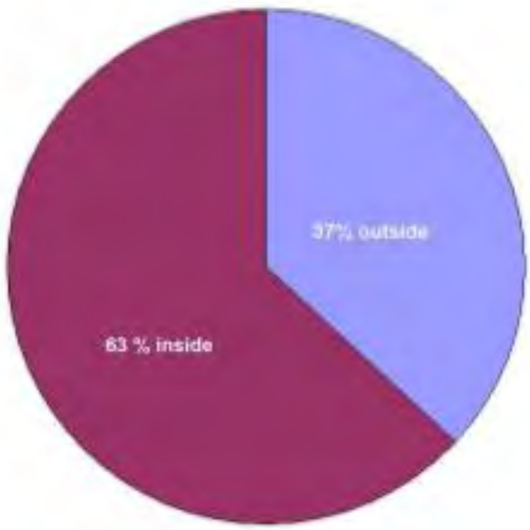

Figure 1.1: Percentage Source of Internal and External Causes Surge [2].

Therefore, the perfect surge protection system must be applied in every building that might be exposed to the risk of surge. The perfect surge protection system including the grounding arrangement, bonding arrangement, and coordination surge protection device (SPD) for protect at any surge coming [3]. Besides that, the installation air termination and down conductor as an addition protection surge especially for protect from lightning surge. Coordination SPD in building can limit the surges voltage on electrical equipment by absorbs and divert or limit high surge current to ground. It also can bypass the surge without through that equipment. It also able to repeat these functions as described depend on the manufacturer.

1.2 Problem Statement

Electrical and electronic equipment sometimes can be damaged during the occurrence of surge coming even protected by SPD. The issue of the value impedance circuit protective conductor (CPC) and value impedance in the grounding system correlates to the performance of the SPD. This is because the current surge bypass by SPD to the earth depends on the system grounding arrangement. Besides that, the oscillation phenomenon also causes the over-voltage will increase again in the terminal equipment. These oscillation phenomena depend on the characteristics of the SPD, the properties of the protected loads, the length of the connecting cable and system grounding arrangement. It also needs to be taken into consideration because the SPD potentially may are not working in supposed condition. The damage to the equipment still can occurs when be ignored this consideration.

1.3 Objective

Objective studies on Surge Protection Device (SPD): Effects of different design of grounding are:

- To evaluate SPDs protection level (*Up*) in order to limit surge voltage across the load.
- To analyse the performance of surge protection device (SPD) by referring the variation of impedance grounding.

- To investigation oscillation phenomena when different impedance grounding applying.

1.4 Project Scope

This project limit will cover simulation and hardware only for installation one SPD in the building at low-voltage system for single phase. The protection SPD only cover from surges are caused by internal events. The system grounding arrangement will consider use TT system. The type 2 SPD will be choosing because is the main protection system for low-voltage installation. Other than that, one load is used on fixed value impedance. Length of the connecting cable from SPD to the load will consider fixed at 5 meter and 10 meter. The value surge current flow to the load and bypass surge current flow to the grounding will be taken for analyse the performance SPD.

1.5 Expected Project Outcome

After the project is done, hopefully it can help to understand clearly the impact of surge for SPD and load. The efficient SPD, it design to limit the surges current on electrical equipment by absorb and will divide again and again until it finally reached the grounding electrode system where it will eventually travel into the grounding and disappearing. In order to do so, the characteristic performance SPD with different impedance value grounding should be analysing successfully.

In summary, the project should be:-

- Successful analyse the surge current flow of the SPD designed by using simulation PSCAD software.
- Successful understand the impact of surge current for SPD and load.
- Successful analyse the characteristic performance SPD with different impedance value grounding.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter will explain detail about the theory and basic principle in the developing project. Moreover, there will be a review and results discussion of the previous studies in the same area for this project. All the findings obtained in the previous study that are related with project could help in enhance the knowledge and understanding.

2.2 Surge

According to Curtis McCombs [4], a surge or transient is a voltage spike that only lasts a few millionths of a second. It can contain thousands of volts and thousands amps. The surge can come from two type of source that is from internal and external event. The surge from internal events such as from air conditioners, compressors, elevators, blower motor and office copiers. This surge known as oscillatory surge. It can produce a smaller surge and lower energy during start and off that equipment. Another surge is from external events such as from lightning, electrical accidents, switching capacitor banks and utility grid switching. This surge known as impulse surge. It more danger that can cause a large over voltage and over current at higher energy. Figure 2.1 shows the voltage waveform between normal voltage and during surge events. The peak voltage during the surge event higher than peak voltage at normal. This situation is more danger for the equipment especially for sensitive equipment.

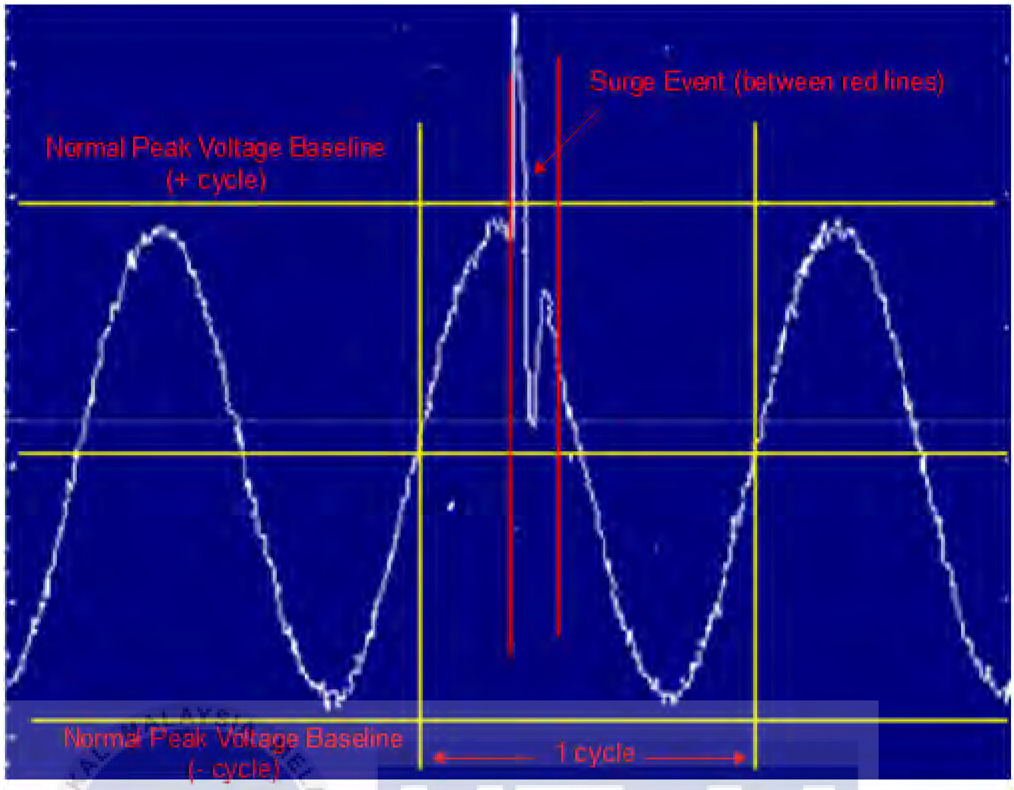

Figure 2.1: Voltage Waveform between Normal Voltage and Surge [4].

2.3 Surge Protection System

According to Curtis McCombs [4], the best surge protection system is only as good when its location and installation is suitable. This matter should consider the source surge it can come from especially from external event surge. According to T. Kisielewicz [5], electrical and electronic appliances modern structure is sensitive to surges. Surge protection system is used to reduce the impact of damage during lightning strikes to a structure. It protects the building and structures from fire or material damage, failure of electrical and electronic equipment, and persons from injury or event death. According to IEC Standard [6], a lightning protection system consists of external and internal lightning protection. External lightning protection system is needed to protect the direct impact of the lightning stroke on the building. While the internal lightning protection system is used for protect from indirect impact of the lightning stroke on the building. As shown in Table 2.1, the possible of the external and the internal lightning protection is as follows.

Table 2.1: The External and Internal Lightning Protection System [7].

No	External	Internal
1.	Air-termination system • is to capture the lightning strike to a selection point.	Equipotential Bonding (EB) • to minimizing potential differences.
2.	Down-conductor system • discharge current can be directed through the down conductor to the earth-termination system.	Grounding Cable • to distribution of the lightning current into the earth-termination system.
3.	Earth-termination system • to distribution of the lightning current into the earth.	Surge Protection Device (SPD) • to protection of internal systems against lightning surges (voltage and current).

2.4 Surge Characteristics

According to Sreten Skuletic and Vladan Radulovic [8], characteristics lightning surge voltage and current depends to the location and selection SPD. According to Y. Du, Binghao and Mingli Chen [9], evaluate and analyse characterize the surge environment in buildings is important for protection sensitive equipment. The specified waveform and amplitude of surges in different locations must considered. The characteristics surge current and voltage related to the direct and indirect impact of the lightning strikes on the building.

2.4.1 Characteristics Lightning Surge

The IEC Standard [6,7] specify two current impulse waveform for the testing of surge protective devices. The two specified waveforms are referred as 10/350 µs waveform for direct impact lightning strikes. Other waveforms referred as 8/20 µs waveform for indirect impact lightning strikes. The first number refers to the rise time in micro seconds. The second number refers to the half peak width in micro seconds. These two types waveform are used to specify tests on SPD immunity to lightning currents. The intensity of lightning stroke can determined base on the peak value of the current wave. The value intensity requirement is a at 10kA, 3kA, 0.5kA and 0.2kA. Figure 2.1 and figure 2.2 shows the characteristics waveform from direct and indirect lightning stroke.

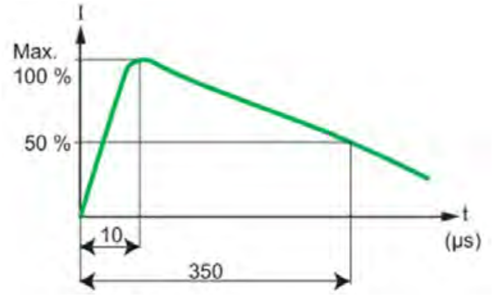

Figure 2.2: 10/350 μs current wave direct impact [6].

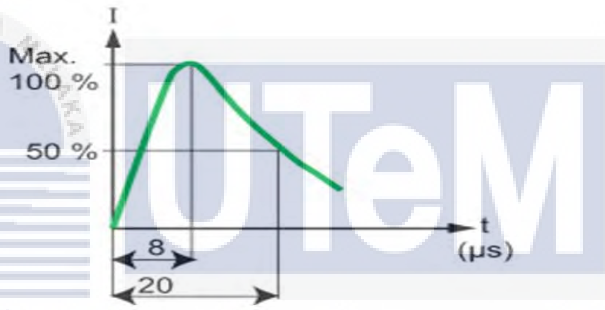

Figure 2.3: 8/20 μs current wave indirect impact [6].

According to IEC Standard [6,10] the voltage impulse waveform created by lightning strokes are characterized by a 1.2/50 μs voltage wave. This waveform is used to verify equipment's withstand to over-voltage of lightning stroke. The requirement over-voltage is at 10kV and 6kV. Figure 2.4 shows the characteristics voltage pulse or wave form from lightning stroke.

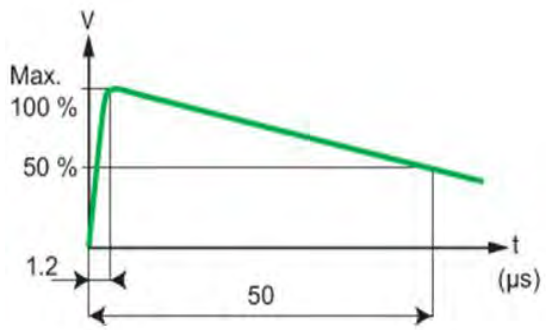

Figure 2.4: 1.2/50 μs voltage wave [6].

2.4.2 Characteristics Switching Surges

Another type of characteristics surge is a switching surge. According to IEC Standard [6,10] the voltage impulse waveform created by switching surge are characterized by a 250/2500 µs voltage wave. This waveform is used to verify equipment's withstand to over-voltage of switching. The requirement over-voltage is at 6kV to 10kV. Figure 2.5 shows the characteristics voltage switching surge wave form.

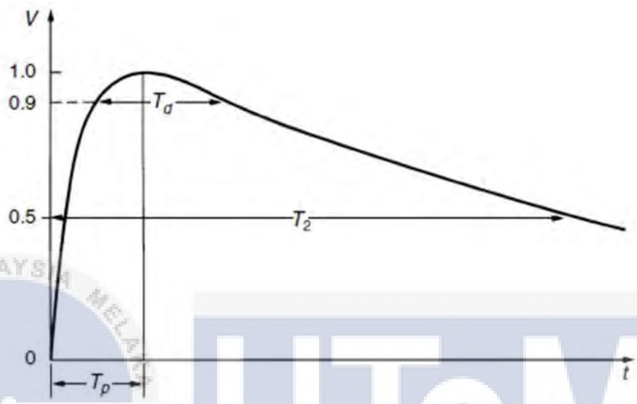

Figure 2.5: 250/2500 µs voltage wave [10].

2.5 Surge Protection Device (SPD)

Another research [11] stated that the surge protective devices (SPD) can reduce the probability of electrical equipment damage. The SPD has high impedance before the transient over-voltage appears in the system. The impedance of the SPD will decrease when the transient overvoltage appears in the system. The surge current is driven through the SPD, bypassing the sensitive equipment. It can also be used at all levels of the power supply network. Figure 2.6 shows the principle of protection system in parallel from lightning stroke and switching surge.

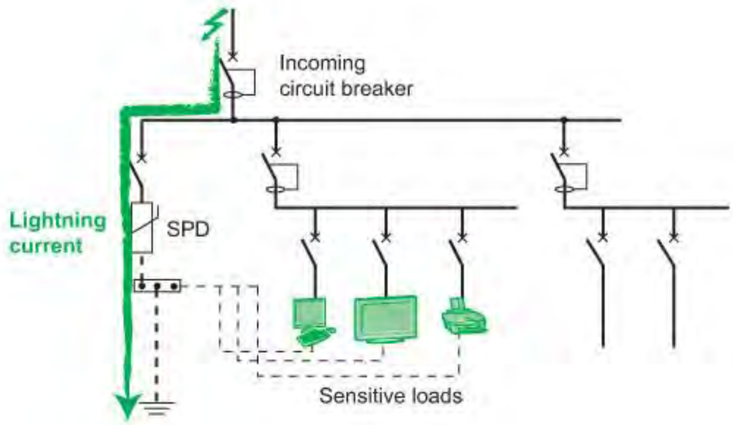

Figure 2.6: Principle of protection system in parallel [10].

2.5.1 Types and Classes Test of SPD

Base on IEC Standard [10], three types and three classes test are requirement for SPD. The three types SPD are namely Types 1, 2 and 3 SPDs. Type 1 SPD is for protect against direct lightning strikes. Type 2 SPD is for protection the low-voltage electrical installation. It installs at each electrical switchboard. While the Type 3 SPD for protect the sensitive equipment. It must install with combination Type 2 SPD. The three classes test is a Class I test for SPD Type 1, Class II test for SPD Type 2 and Class III test for SPD Type 3. Table 2.2 show the types and classes test of SPD.

Table 2.2: Types and Class Test of SPD [10].

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

2.5.2 Performance Characteristics SPD

According to [11], two main categorise of SPD are used for the protection against lightning surges. These categories depend on the characteristics construction component inside in the SPD. The two categories are namely switching type SPD (spark gap) and limiting type SPD (varistors). Another research [12] stated that to reduce the probability of damage to electrical and electronic equipment it is rationale for evaluating the characteristics of SPD system. Their characteristics are mainly determined by the maximum continuous operating voltage *Uc* and the voltage protection level *Up*.

Requirements from IEC Standard [10] defines the common characteristics is a maximum continuous operating voltage *Uc*, voltage protection level *Up*, nominal discharge current *In*, and maximum discharge current *Imax*. Table 2.3 shows the common characteristics for performance overall of SPD.

Table 2.3: Characteristics Performance of SPD [10].

No.	Characteristics	Function	Notes
1.	Maximum continuous operating voltage (*Uc*)	This is voltage which the SPD becomes active. The value is selected based on the rated voltage and the system grounding arrangement	All Type SPD
2.	Voltage protection level (*Up*)	Maximum voltage drop across the SPD. This voltage is reached when the I_{SPD} is equal to *In*. The *Up* must be below the overvoltage withstand capability of the loads.	All Type SPD
3.	Nominal discharge current (*In*)	The peak value of a current of 8/20 µs waveform that the SPD is capable can withstand at least 20 times. The higher value of *In* means a longer life for the SPD.	All Type SPD
4.	Impulse current (*Iimp*)	*Iimp* is the peak value of a current of 10/350 µs waveform that the SPD is capable of discharging 5 times	Type 1 SPD

No.	Characteristics	Function	Notes
5.	Maximum discharge current (*Imax*)	*Imax* is the peak value of a current of 8/20 μs waveform that the SPD is capable of discharging once	Type 2 SPD
6.	Open-circuit voltage (*Uoc*)	*Uoc* applied during class III (Type 3) tests	Type 3 SPD

2.6 Coordinated Surge Protection Device (SPD)

According to [13], the efficiency of a coordinated SPD depends not only on the proper selection SPD, but also on their proper installation. The proper installation SPD by requirement standard [6,14], also considering the lightning protection zone (LPZ) concept. The proper analysis LPZ can provide sufficient protection for the electrical and electronic equipment installed inside the structure.

2.6.1 Lightning Protection Zone (LPZ)

Another research [15], stated the principle of lightning protection zone (LPZ) requires forming in stages zones for reduce values of the electromagnetic environment. Different types of SPDs are applied at the different LPZs. Base on IEC Standard [6,14], the lightning protection zone (LPZ) at the structure is divided from external and internal LPZ. LPZ from external to internal will decrease lightning protection levels. In the external zones only resistant equipment can be used. However, in internal zones, sensitive equipment (SPD) can also be use. Table 2.4 shows the individual zones are characterized and named.

Table 2.4: Lightning Protection Zone (LPZ) [6].

No.	Lightning Protection Zone (LPZ)	Notes
1.	LPZ 0_A	This is unprotected area outside a building from direct lightning strikes.
2.	LPZ 0_B	This is protected area outside a building from direct lightning strikes using an air-terminal.
3.	LPZ 1	This is area inside the building which may experience to high surge voltages or surge currents and strong electromagnetic fields
4.	LPZ 2	This is area inside a building which may experience to surge voltages or surge currents and electromagnetic field that have already been weakened
5.	LPZ 3	This is area inside the building which may only be exposed to very low or almost no surge voltages or surge currents. It also protect for very weak or non-existent electromagnetic fields

Figure 2.7 shows all lines that cross between zones must use coordinated surge protective devices. The requirement basis for selecting SPD will assume 50% of the lightning current will be discharged to ground. The other 50% of the lightning current is directed to the electrical installation must has installation SPD system. Figure 2.8 shows the balanced surge current traveling in structures.

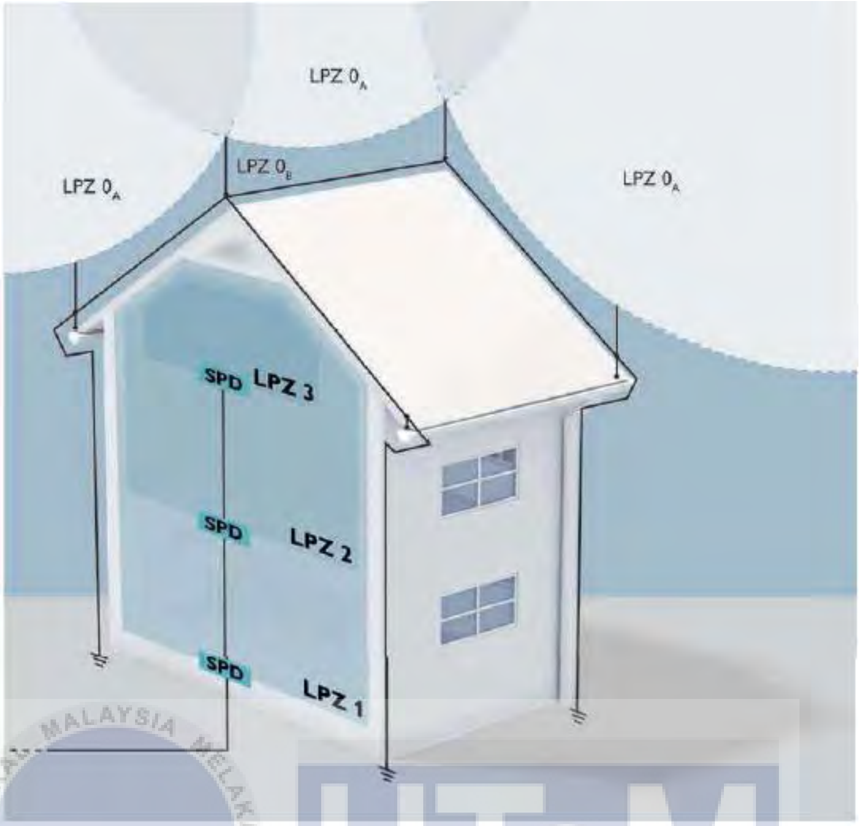

Figure 2.7: Lightning Protection Zone (LPZ) Concept [6,14].

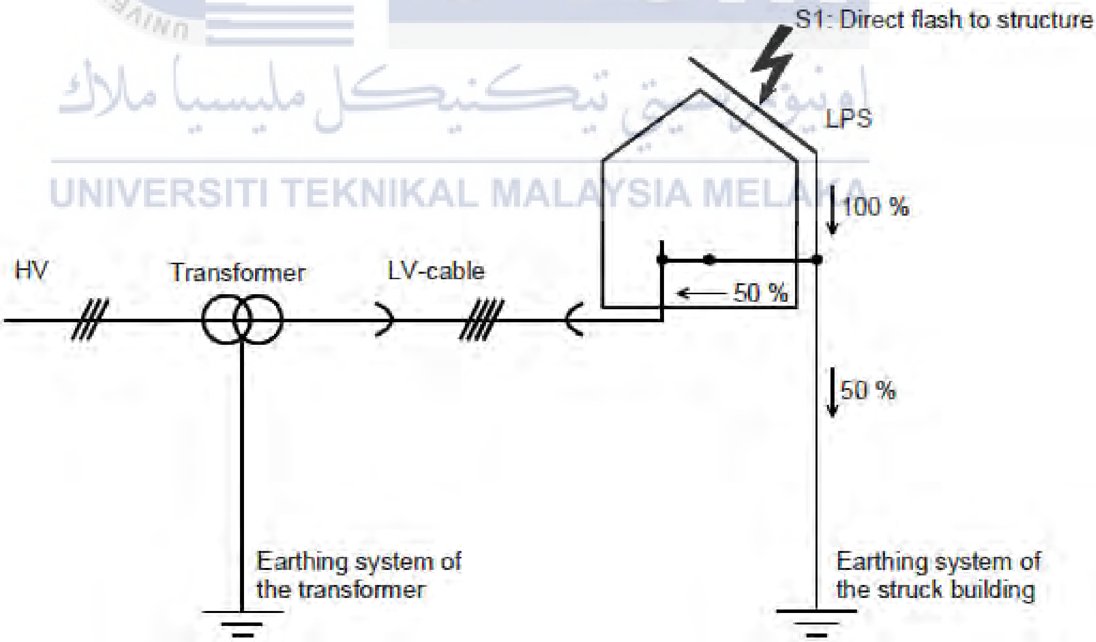

Figure 2.8: Balanced Surge Current Traveling In Structures [14].

2.6.2 Location of Type SPD

Base on standard [6,14,16], a Type 1 SPD must always be installed at the service entrance. It also can install at anywhere with combination with Type 2 SPD. The Type 2 SPD must install for load side only connection. The Type 3 SPD only for sensitive equipment. The number of additional SPDs to be installed is determined by the size of the site and the distance separating sensitive loads. Figure 2.9 show the requirement location installation type of SPD.

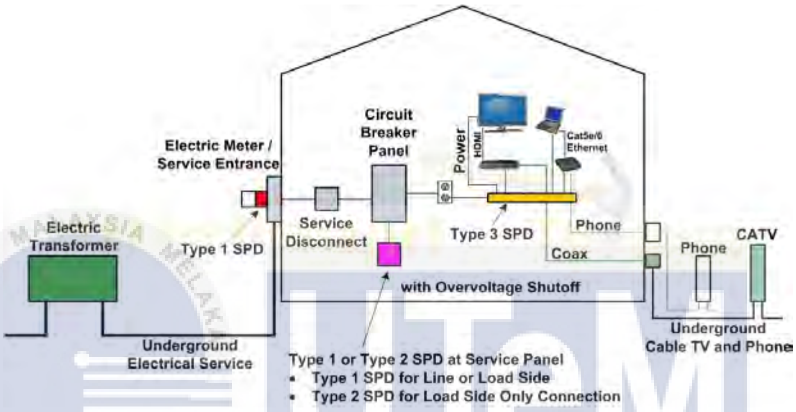

Figure 2.9: The Requirement Installation Type of SPD [6,14,16].

2.6.3 Connection SPD

Another requirement standard [14,17] stated the connection SPD must consider the effect of surge voltage as common-mode (CM) over-voltage and normal-mode (NM) over-voltage. CM over-voltages occur between phase to earth or neutral to earth. It are hazardous especially for apparatus whose frame is connected to earth due to risks of surge. NM over-voltages occur between phase to phase or phase to neutral. It are mostly hazardous for electronic equipment and sensitive apparatus such as computer systems. Figure 2.10 shows the effect of surge voltage as normal-mode over-voltage and common-mode over-voltage.

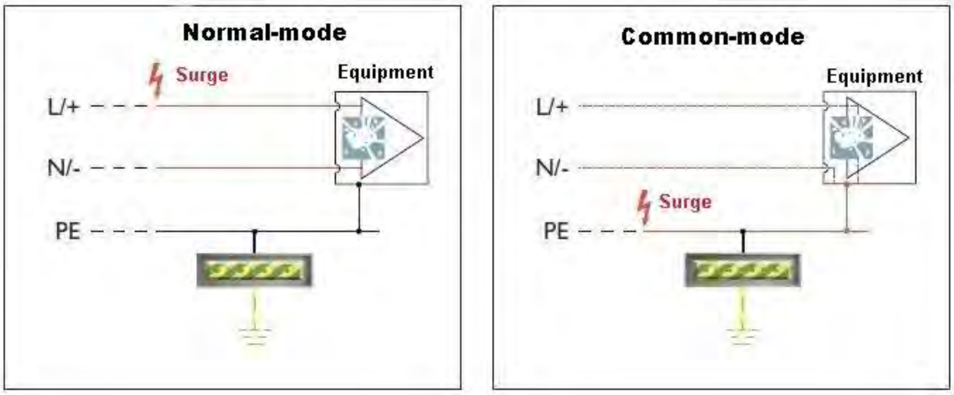

Figure 2.10: Effect of a Surge Voltage as NM and CM Over-voltage [14,17].

Figure 2.11 shows the requirement connection SPD for protection the effect of a surge voltage as normal-mode over-voltage and common-mode over-voltage. The connection SPD for normal-mode must between phase to phase, phase to neutral or both connections. Beside that the connection SPD for common-mode must between phase to earth, neutral to earth or both connections.

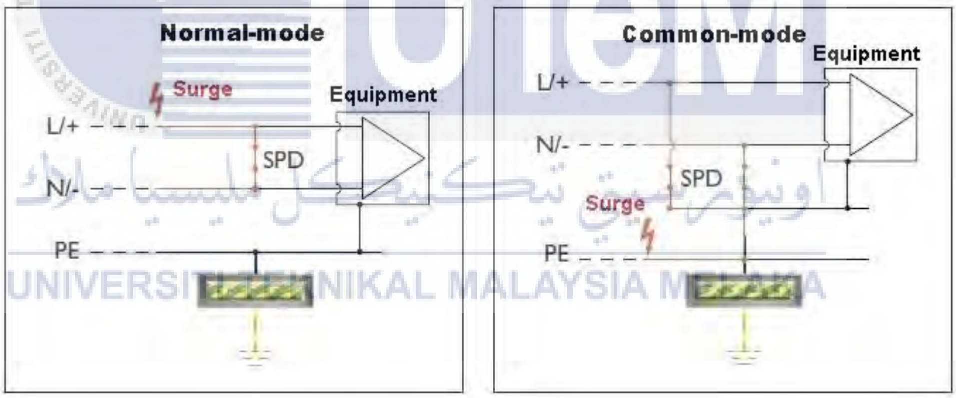

Figure 2.11: Connection SPD for Protection from NM and CM Over-voltage [14,17].

2.6.4 Distance Requirement

Base on standard [17] the distance of a SPD to the loads must be as short as possible. This is important to reduce the voltage protection level on the terminals at the protected equipment. The total length wiring to the active conductor and the earth terminal block should not exceed 50 cm. The length wiring if more than 10 meter between SPD and load should install another SPD close to the load. Figure 2.12 shows the requirement length for connection between SPD and load.

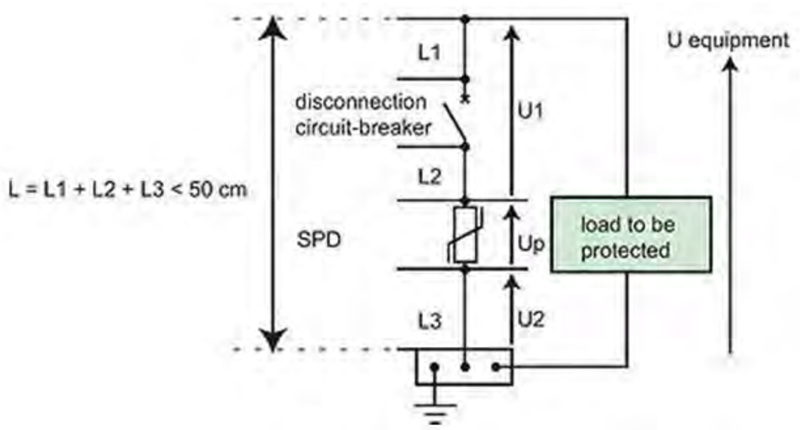

Figure 2.12: Connections of a SPD L < 50 cm [17].

2.6.5 Cable Requirement

Requirements from IEC Standard [17] defines the connecting cable need for short circuit withstand capability. The minimum sizing cable connection cross section of the active conductor for type 1 SPDs is a 6 mm^2 and type 2 SPDs is a 2.5 mm^2. The minimum sizing cable connection cross section of the main grounding busbar or the protective conductor for type 1 SPDs is a 16 mm^2 and type 2 SPDs is a 6 mm^2.

2.6.6 System Grounding Arrangement

The requirement standard [17] stated the operating voltage *Uc* rely on the system grounding arrangement. The maximum continuous operating voltage *Uc* of SPD must be equal to or higher than the values shown in the table 2.5. The most common values of *Uc* chosen according to the system grounding arrangement are a 260, 320, 340 and 350V for TT and TNS grounding arrangement. The value impedance grounding is 5 to 10 ohms are desirable. However the value impedance grounding sometime must no more than 25 ohms is required. Table 2.5 shows the minimum value of *Uc* depending on the system grounding arrangement.

Table 2.5: Minimum Value of *Uc* [17].

No.	SPDs Connected	System Grounding Arragement
1.	Line conductor and neutral conductor	1.1 *Uo*
2.	Each line conductor and PE conductor	1.1 *Uo*
3.	Neutral conductor and PE conductor	*Uo*
NOTE 1: *Uo* is the line-to-neutral voltage of the low voltage system (rated voltage).		

2.7 Effect of Different Impedance Grounding

In this section, it will explain more details about the concept of performance SPD effect of different impedance grounding in the structure that can be referred in the reference of the previous case study related. All the information gets from books, journal and articles in order to develop the ideas and help this research. Continual research and development still produces the incremental performance of SPD, however with the techniques and algorithms becoming more mature.

According to T. Kisielewicz and G.B. Lo Piparo tell that the current I_{SPD} and the Q_{SPD} are affected by the structure conventional grounding impedance Z [18]. The increases values I_{SPD} and Q_{SPD} are related to the lowest values of Z. Another present paper [19], the I_{SPD} and voltage drop U_{SPD} on the SPD increase with the ratio earth impedance and impedance of the equipment to be protected. For this reason, the performance SPD can effected by the grounding impedance value. However, this researcher only focuses on direct and indirect flashes to overhead low voltage power lines.

Based on [20], the type of surge current flowing into the substations earth rely on the earth resistance of the utility earth and the substation earth. It also depends on the wire length to the substation from the utility. Hence, if earth resistance of utility earth is high and the substation is located closely to the utility will cause surge current may flow the neighbouring building. It also will cause a potential rise (over-voltage) in their power neutral. The potential rise will cause damage to the equipment in the neighbouring building. Therefore, this researcher only uses earth resistance value below than 10Ω. So, for this study the different value impedance grounding will be implemented for analyze the performance of SPD.

Another research [21], this researcher analyse the performance connection SPD related to lowering the inductance of PE can reduce the equipment damage. The lowering value inductance of PE related to the highest current I_{SPD} flowing to the earth terminal. They use the concept the effect of surge voltage as common-mode over-voltage between Main Distribution Board and Secondary Distribution Board (SB). This analysis performed by simulation using the transient software EMTP-RV. However, this researcher only focuses on the direct strike with three standardized lightning current like as 100 kA wave shape 10/350 µs for first positive stroke, 100 kA wave shape 1/200 µs for first negative stroke and 50 kA wave shape 0.25/100 µs for subsequent stroke of negative flashes. So, for this project simulation the analysis performed by using software PSCAD and focus on the switching impulse from internal events.

According to Dominik Krasowski [22], the performance SPD for overvoltage depends on the earth resistant, the different length of wires between SPD and resistance protected device. When the resistance value is higher, the over-voltage on the equipment terminals increases and the additional SPD is needed. This researcher stated the length wire above 10 meters is a critical value to increase overvoltage higher at the protected device. This contribution is to perform the concept of lightning protection zone (LPZ). However, this research only in computer simulation design using software PSpice and the value earth resistant is constant at 10 Ω.

Another research is clearly related [23], the performance SPD protected is related to the length cables, different impedance values of neutral and phase conductors and the conventional earth impedance of utility. This analysis use the neutral point grounding impedance is 100 Ω and the grounding impedance of the customer is 10 Ω. This research analyse the voltage protection level U_P and I_{SPD} of SPD at different location, different type connection and protection distance. The voltage drop on each connecting conductor of 1 kV/ µs may be reasonable assuming a value of inductance per unit length of 1 µH/ m. This contribution research performs by computer simulation using PSpice software and Power Systems Simulink of MATLAB software.

The next paper studied the method to testing the performance coordination between two SPDs with different length of wire and different value resistant load at phase and neutral connection (LN) [24]. This hardware experiment used two size cable length sizing is an 8 m and 20 m between two SPD. It also considers the cable enclosure and used 2 Ω and 55.2 Ω resistors for different type of load. This research analyse the voltage protection level U_P, current surge I_{surge} and I_{SPD} of two SPD at different location. However, this method did not include the grounding impedance in their experiment.

Base on [25], four important things must consider when setting cable for simulation using PSCAD. It is a diameter of conductive cores, thickness of insulation layers, relative dielectric constant and distance between adjacent wires. This simulation used diameter of conductive cores is 1.6mm, thickness of insulation layers is 0.66mm, relative dielectric constant is 4.55 and distance between adjacent wires is 3mm. However, this research only in computer simulation design using software PSCAD and the value earth resistant is constant at 10 Ω.

According to Jinliang He [26], the PVC insulated cable with single core and no shielding sheath is selected for setting cable using PSCAD simulation. The diameter of conductive cores is 1.6mm, the thickness of insulation layer is 0.6mm, relative dielectric constant of the conductive cores is 4.55, and the resistivity conductive cores is 1.724×10^{-8} Ω.m. It also considers the cable is 50mm above the wall surface. This research analyse the voltage surge at load and SPD with applied the different type of load. So, for this project simulation focus on the size of cable at $2.5mm^2$ with diameter of conductive cores is 1.78mm.

2.8 Conclusions

In reviewing the literature, all the knowledge and information about the surge protection device (SPD) studies are being analysed. The theoretical findings from the journal, papers and books are compared in order to provide strong understanding that related to the study. The theory or previous works that can be used in this project are based on the SPD by determining the performance common characteristics SPD by effected with different value impedance grounding.

Generally, determining the performance common characteristics SPD by locating at different lightning protection zone (LPZ) depend on selected of type SPD requirement. Each of the LPZ will guide the user to choose the different lighting protection system (LPS) for protect lightning strike in the structure. Many of researchers stated the location and distance between SPD with the apparatus protected also can affect the performance characteristics SPD. The good performance SPD must installation closely to the load. Overall, right selected type SPD and distance between loads with LPZ requirement the important part in order to help this study achieve the objectives.

Beside that the perfect grounding arrangement is the most important to bypass the surge current into the earth. The value grounding impedance of the consumer and grounding terminal impedance must lowest by refer to the standard requirement. The performance SPD related to the grounding impedance value. The incorrect arrangement and connection SPD to the grounding makes the SPD function not according to the ordinance. This is because the value surge transmitted to the grounding terminal and apparatus depends on the grounding impedance value. Thus, to avoid this problem, the proper selection SPD by requirement, installation closely SPD at the equipment and coordinated cascaded SPDs can be applied to limit and by pass surge to earth. As a result, the effect of different impedance grounding became the issues to this study as it can improve the performance SPD and provide solution the problem. Lastly, table 2.3 below shows an overview for this chapter.

Table 2.6: Summary of Previous Research

Authors/ Years	Field Of Study	Contribution	Lack of
T. Kisielewicz, G.B. Lo Piparo, F. Napolitano, C. Mazzetti and C.A. Nucci [18].(2015)	SPD Dimensioning In Front of Direct Flashes to Overhead Low Voltage Power Lines	The current I_{SPD} and the Q_{SPD} are affected by the structure conventional grounding impedance Z.	Focuses on direct and indirect flashes to overhead low voltage power lines.
T. Kisielewicz, G.B. Lo Piparo, C. Mazzetti and F. Fiamingo [19].(2015)	Stress to Surge Protective Devices System Due to Direct Flashes to Low Voltage Lines	The I_{SPD} and voltage drop U_{SPD} on the SPD increase with the ratio earth impedance and impedance of the equipment to be protected.	Focuses on direct and indirect flashes to overhead low voltage power lines
Chandima Gomes [20].(2011)	On The Selection And Installation of Surge Protection Devices in a TT Wiring System for Equipment and Human Safety	The type of surge current flowing into the substations earth rely on the earth resistance of the utility earth and the substation earth.	Only uses earth resistance value below than 10Ω
G.B. Lo Piparo, T. Kisielewicz, C. Mazzetti and F. Fiamingo [21].(2016)	Protection of Apparatus against Lightning Surge in an Extended Grounding Arrangement	The performance connection SPD related to lowering the inductance of PE can reduce the equipment damage.	Focuses on the direct strike
Domink Krasowski [22].(2013)	Computer Simulations of Protection Devices for Proper Overvoltage Protection Creation	The performance SPD for overvoltage depends on the earth resistant, the different length of wires between SPD and resistance protected device.	Research only in computer simulation design using software PSpice and the value earth resistant is constant at 10 Ω
F. Fiamingo, M. Marziotto, C. Mazzetti, Z. Flisowski, G. B. Lo Piparo and G L. Amicucci [23].(2007)	Evaluation of SPD Protection Distance in Low-Voltage Systems	The performance SPD protected is related to the length cables, different impedance values of neutral and phase conductors and the conventional earth impedance of utility.	Only perform research by computer simulation and did include hardware experiment.
Qibin Zhou, Alain Rousseau, Yang Zhao, Feifan Liu and Xiaoyan Bian [24]. (2016)	Experimental Investigation of The Coorninaton Between SPDs and SPD and The Protected Equipment	The method to testing the performance coordination between two SPDs with different length of wire and different value resistant load at phase and neutral connection (LN).	This method did not include the grounding impedance in their experiment.
Ziyu He and Y. Du [25]. (2016)	Influence of Different Factors on Coordination of Two Cascaded SPDs	Four important thing for setting the cable using PSCAD that is diameter conductive cores, thickness insulation cable, relative dielectric constant and adjacent wires.	Another factor setting cable not include such as resistivity conductive cores.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Coordination surge protective device (SPD) in low-voltage it is necessary to ensure the survival of electric or electronic devices from impact of any surge. Better coordination can make SPD will perform and function properly. For this project, it categorizes and focussing on the performance of SPD when the surge coming from within a facility. It also known a small switching impulse happen from the situation of ON and OFF the equipment. The effect of grounding has different impedance value and length of cable can reduce the performance of SPD.

Actually, the idea choosing surge protection device (SPD) topic comes from the problem situation that peoples always know and saying the surge only happen from lightning. However, a small portion only know most of, much of disturbances of surge come from within of facility. Besides that, the effect of different impedance value grounding and length of cable must to investigate for analyse the performance of SPD in terms of its characteristics.

This analysis was done by two concept experiments. The two concept experiments is a by construct the model by simulation and hardware design. In order to do the simulation, an analysis of performance SPD should be done by construct the impulse voltage generator model in PSCADE Software. This experiment, SPD was being assumed installed in the distribution panel at the entrance of building.

The investigation performance characteristics SPD by applying any different impedance value grounding and length of cable at the simulation model. While for construct the hardware design, was followed the schematic simulation design. This hardware analysis also use a same value impedance grounding and cable length using at simulation experiment. Before that, a relevant data or existing data for construct the simulation and hardware design should be done first in order to get the accurate analysis. All data for the experiments are based on the IEC Standard and the other requirement related to the concept of this project. Data gathering also consists of reading and comparing the research papers and journals. The information of data analysis setup is as in Appendix C, D, E, F, G, H, I, and J.

3.2 Methodology Chart

The flow chart shown in Figure 3.1 illustrates all the tasks to be done at each stage of the project. It is important to make sure the project complete at the on time.

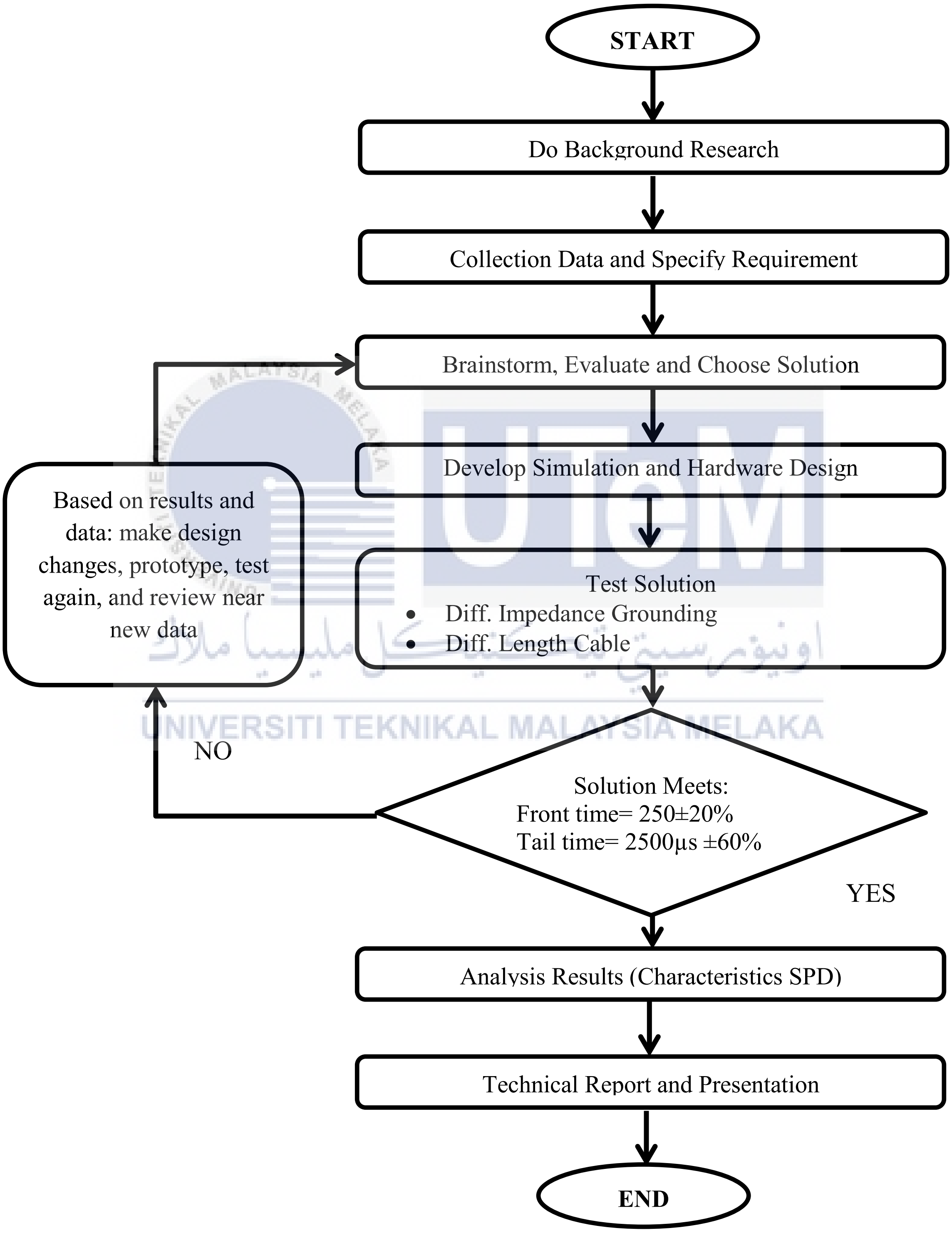

Figure 3.1: Flow Chart Methodology

3.3 Do Background Research

This part is review and learns from the experiences of others. This review from previous researches can be a guideline in this project. The best procedure or the most suitable way can be analysed in order to accomplish the best result. Besides that many references had been done in order to get information about this project. In this part, the focus is about performance SPD when giving different value impedance grounding.

3.4 Data Collection and Specify Requirement

All data gathering consists from requirement IEC Standard and others requirement like as IEEE Standard. Besides that, data gathering also consists of reading and comparing the research papers and journals. The information of data and test requirement is as in Appendix C, D, E, F, H, I, J and K. This is important for collect the data correctly to show the validity of the result and follow the standard.

3.5 Develop Simulation and Hardware Design

In this project, the experiment was developed in simulation and hardware design. The simulation and hardware design was constructed in the simple model coordination of SPD in the single phase low voltage AC circuits. The SPD was assumed installed in the distribution panel at the entrance of building. Both design was use concept one line diagram modelling is constructed which consists of impulse generator, varistor (SPD), cable, impedance grounding and load. Type 2 SPD choose for the hardware experiment. Both experiment is design for evaluate the waveform surge and effect of the characteristics SPD that is a maximum continuous operating voltage *Uc*, voltage protection level *Up*, nominal discharge current *In*, and maximum discharge current *Imax.*

3.5.1 Develop and Test Simulation Design

Power Systems Computer Aided Design (PSCAD) software is widely used for various types of simulation studies AC and DC power, including the power electronics, sub-synchronous resonance, and lightning over voltage [27]. This software use to evaluate the waveform surge flows after giving the impulse input at the simulation design.

Before sketching the desired circuit in PSCAD, analysis the compatibility component must conducted. The analysis is performed based on the proposed parameters by standard and previous researcher. This circuit also can be use for setup the hardware experiment.

This simulation circuit single line diagram low-voltage was design for evaluate the effect switching surge at the load. A single line diagram low-voltage modelling is constructed which consists of impulse generator, metal oxide varistor (SPD), cable, impedance grounding and load. This circuit construct by referring the circuit given from the requirement standard and overview the previous researcher.

The constructed impulse generator was use the concept double exponential. This concept chosen because it can test at any type of surge by entering the data from the requirement or previous research. In this experiment, the switching impulse waveforms are adopted in the analysis. The switching impulse was use for comparison the trend of increasing or decreasing voltage and current at load when different length of cable given. Figure 3.2 show the development of impulse generator concept.

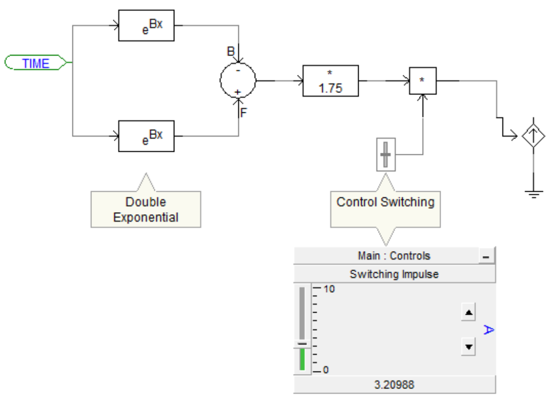

Figure 3.2: Development of Impulse Generator

The selection SPD is a Type 2 Class that suitable for protection at low voltage system. Connection SPD in this project is a phase to neutral and phase to PE. The grounding terminal of SPD will have connected to the grounding impedance. Figure 3.3 show the development of circuit SPD.

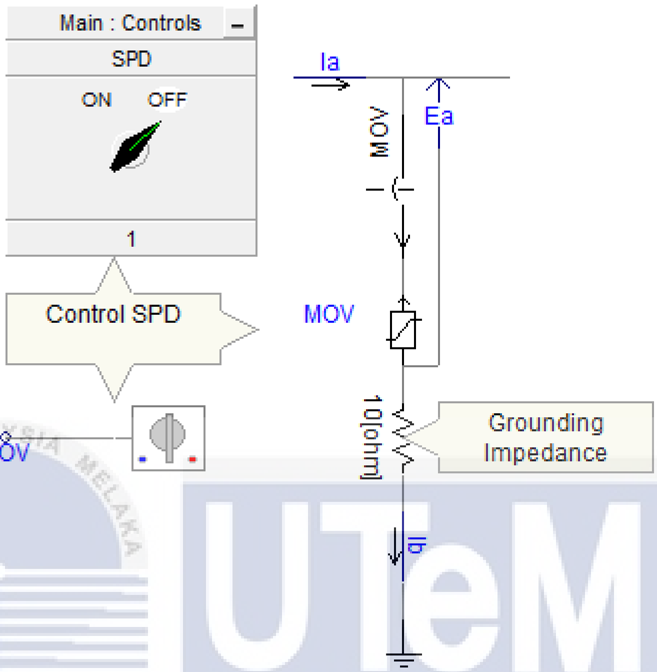

Figure 3.3: Development of SPD (MOV)

Besides that, another circuit development is a development of cable from SPD to the load. The PVC insulated cable with single core and no shielding sheath is selected. The diameter of the metal core is 1.78 mm. The thickness of the insulation layer is 0.6 mm. The relative dielectric constant of metal core is 4.55 with resistivity is 1.724 X 10^{-8} Ωm. In the simulation, the cable is modelled as transmission cable, instead of lumped characteristic impedance. The transmission cable model in PSCAD is handled as frequency variant model. The frequency spectrum of the surge is considered in the analysis. Figure 3.4 show the development of circuit cable.

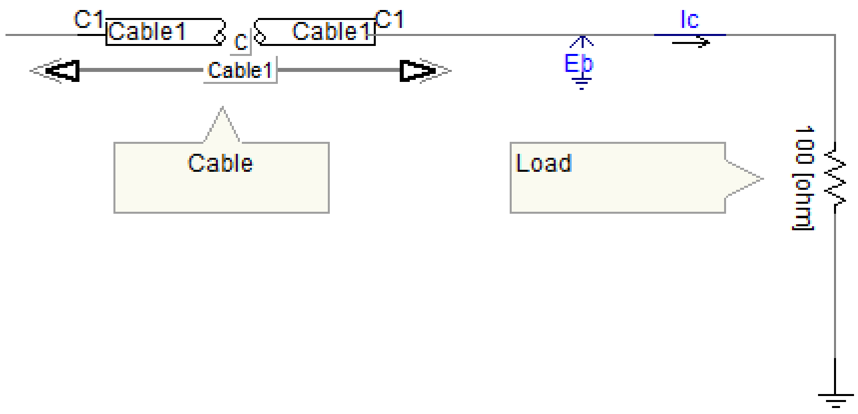

Figure 3.4: Development of Cable

The value impedance load in this experiment is set at constant value. The variable value component that use in this experiment is an impedance grounding and length of cable. Impedance grounding value that will be used in this experiment is 10Ω, 22Ω, 25Ω, 56Ω, 100 Ω and 1000Ω. Three size length of cable is a less than 1 meter, less than 5 meter and above 10 meter. Figure 3.5 show the schematic diagram design for simulation will be use in this project.

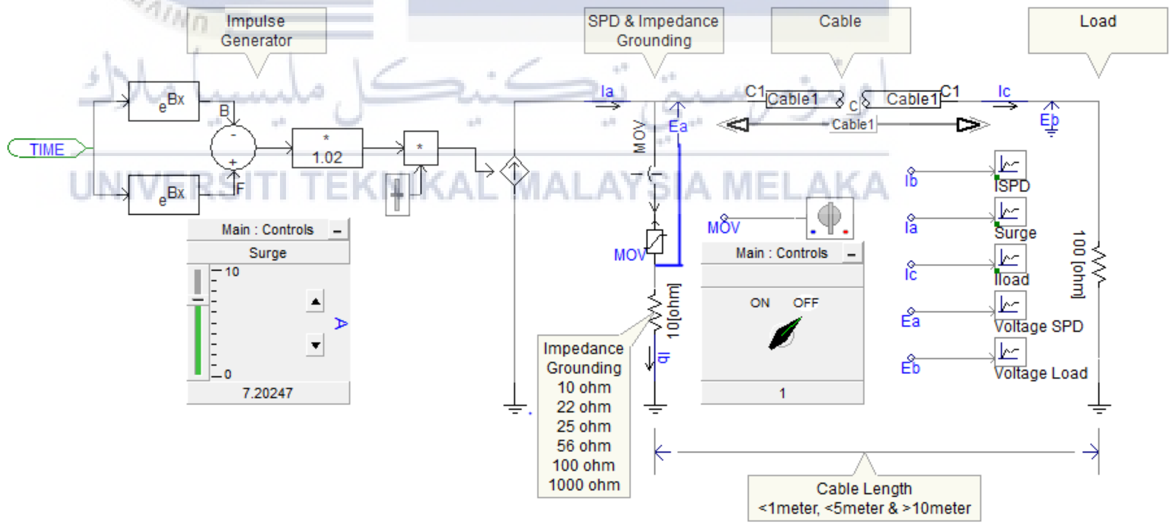

Figure 3.5: Schematic Diagram Simulation Design

Before run the simulation design, this experiment must set the analysis setup for impulse generator, cable, and SPD. Some of analysis data setup refer to the requirement, previous research and manufacture data. The information of data analysis setup is as in Appendix C, D, E, H, I, and K. The testing was conducted with different value the grounding resistors and different length. Record the waveform of surge for voltage SPD U_{SPD} , current SPD I_{SPD}, voltage load V_{LOAD} and current I_{LOAD}.

3.5.2 Develop and Test Hardware Design

This hardware experiment setup for low-voltage distribution system for protects one load such as light bulb. The concept circuit use for setup the hardware experiment is same like as the simulation design. A single line diagram low-voltage design is constructed which consists of connection with the impulse generator, Type 2 SPD, cable, impedance grounding and load. The impulse generator was injected the impulse to the phase incoming SPD. The information of data analysis setup is as in Appendix F, H, I, J, and K.

The concept design for produce surge is use the phenomena surge are caused by internal events. Small power transformer with output power 96VA is selected. When supply 240 AC given into the system, the one way switch will ON and OFF manually. The surge or voltage spike produce by the effect of ON and OFF tansformer was investigated.

In order to test the coordination between SPDs and this load, the value load selected is a 100Ω resistor (light bulb). The load was connected in parallel directly with SPD with length of cable at less 1 meter, less 5 meter and above 10meter. The selection SPD is a Type 2 Class that suitable for protection at low voltage system. Connection SPD in this project is a phase to neutral and phase to PE. The different value grounding resistance is connected in series at the terminal grounding SPD to grounding system. Resistors value was used in this experiment is 10Ω, 22Ω, 25Ω, 56Ω, 100 Ω and 1000Ω. These resistors were choosing at 10 watt above.

Measurement hardware experiment was used digital oscilloscope, high voltage oscilloscope probe with ratio 1000V : 1V, clamp meter and digital multimeters. The oscilloscope will be adjusted the setting at single trace because it easy to catch the surge. The peak value of current and residual voltage at SPD and load for different impedance grounding and length of cable were measured. Besides that, the investigation oscillation phenomena when different length of cable applying was record. Figure 3.6 show the schematic diagram design for hardware experiment was used in this project.

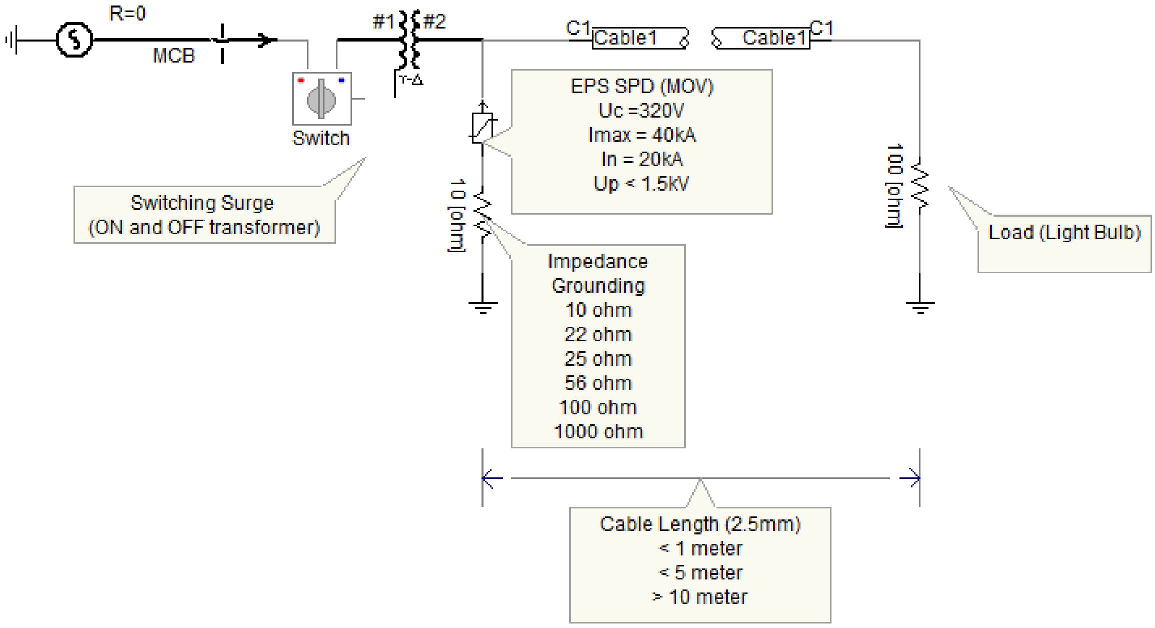

Figure 3.6: Schematic Diagram Hardware Design

3.6 Solution Meets Requirement Partially or Not at All

This part was focusing at the result getting from the experiment part. The data result getting must at range the requirement. The standard test for switching impulse is 250/2500us. The front time is a 250µs±20% and the tail time is a 2500µs±60%. The range standard requirement that is 200 < t1 < 300 µs for front time and 1000 < t2 < 4000 µs at tail time. Besides that, if the data result getting so far away from the range requirement. The design and prototype experiment was changed and the test will do again, and review near new data for analysis.

3.7 Analysis Result

This analysis is based on data was described in the form of tables and graphs appropriate. Correlation and comparison of the graph was the basis of discussion for this project. The information of data use for analysis is as in Appendix G.

3.8 Conclusion

This part was briefly review the development of the project from beginning until the end. This study conducted to analyse and investigate the performance SPD when has different impedance grounding. PSCAD software is used to observe the waveform characteristics between two SPD. Then, the observing and analysing of current and voltage can be done by implement the different value impedance grounding. The hardware experiment is more at the real situation coordination SPDs. By applying different impedance value at ground cable, the observation peak value of current and residual voltage at SPDs can be analyse. Comparison data result between software and hardware can be strong information for this project discussion.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter was discussed the result between simulation and hardware experiment during surge happen. The discussion will focus on the voltage and current at load and surge protection device. The comparison between two wave forms from hardware and simulation will analysed. Furthermore, there are several cases of study is selected that need to be analysed. Basically, the case studies are choosing based on problem statement situation and contribution in research paper review.

4.2 Experiment Achievement

4.2.1 Simulation Experiment Achievement

Figure 4.1 shows the simulation design done for the coordination SPD using PSCAD software. This simulation was done with design the simulation impulse generator by using concept double exponential for develop switching impulse. The input surge that need for experiment can be control with using control panel box. The range current surge produced by this impulse generator is between 0 < Isurge < 10kA while for the range voltage surge produced is a between 0 < Vsurge < 10kV.

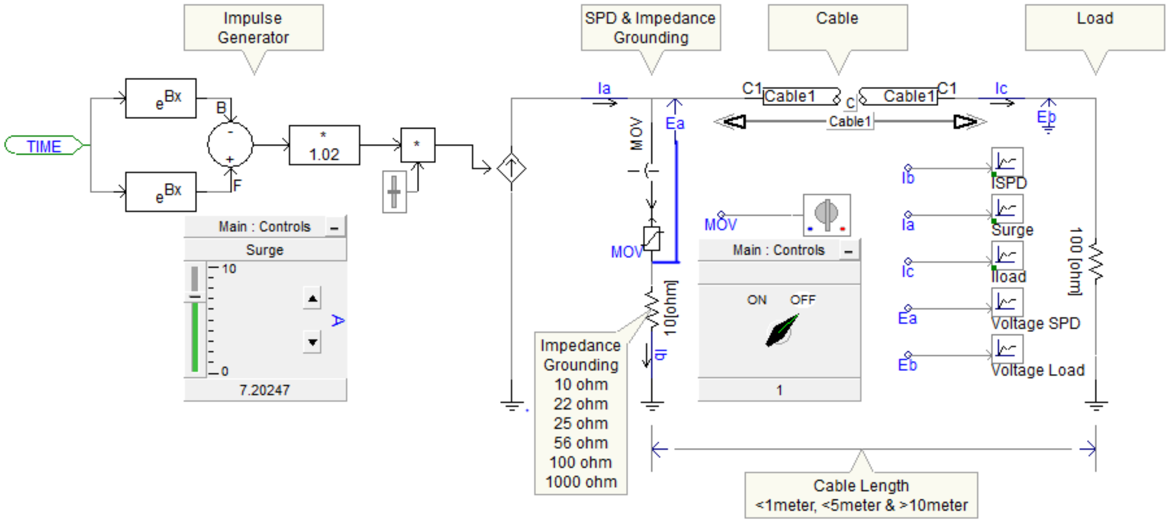

Figure 4.1: Simulation Design

4.2.2 Hardware Experiment Achievement

Figure 4.2 shows setup for the hardware experiment SPD at low voltage system. In this experiment, supply 240V AC to the transformer was controlled by using switch one way. ON and OFF the switch where be produce the over voltage to the system. The range voltage surge produced by this experiment is a 0 < Vsurge < 1.5kV. While the range current surge produced by this experiment is a 0 < Isurge < 10A.

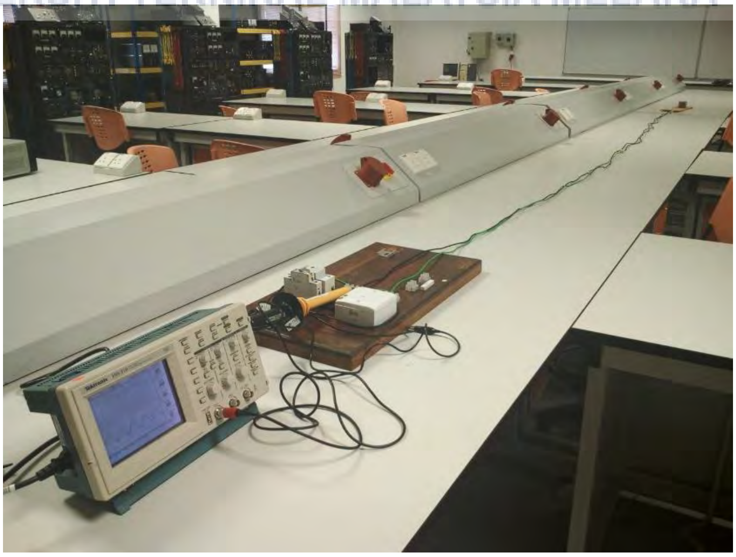

Figure 4.2: Hardware Experiment Design

Based on Figure 4.3 shows the output surge voltage wave form happen at load during the switch ON and OFF transformer for produce the switching impulse. The yellow colour wave shape shows the highest surge happen during value impedance grounding at 1000Ω. Meanwhile, the red colour wave shape was the lowest surge happen during value impedance grounding assigned at 10Ω to the system.

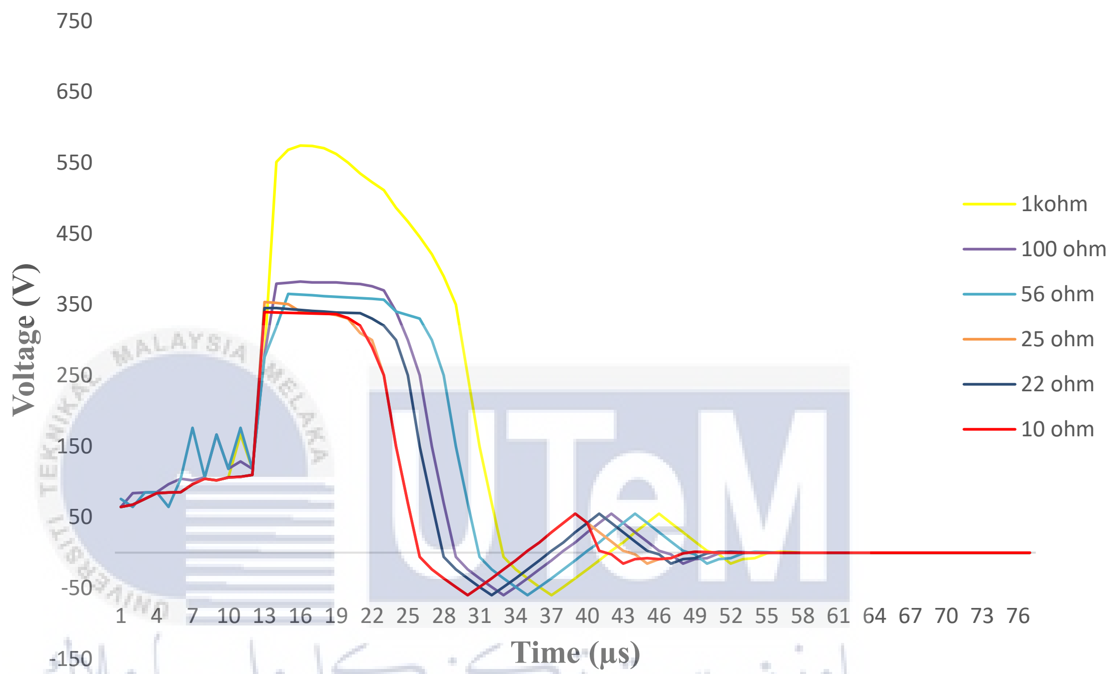

Figure 4.3: Hardware Experiment with Impedance Grounding

4.3 Evaluate Wave Form Simulation and Hardware Experiment Switching Surge

4.3.1 Wave Form Simulation

Referring to Figure 4.4 shows the surge voltage wave form happen produced by simulation. The switching impulse wave shape was produced by this simulation is a 237/2533 µs. Based on observations, it is still at the range requirement. The range requirement for switching impulse wave shape is a at 250 µs ± 20% at front time and 2500 µs ± 60% at tail time. The red colour wave shape is a surge happen at load. The blue colour wave shape is a surge happen after installation surge protective device near to the load. The higher surge happened when surge coming into the load without installation any surge protective device. The wave form of surge produce was decreased as installation surge protective device near to the load. The peak voltage surge produces by this simulation with connection without installing surge protective device is at 719V. Meanwhile, the peak voltage surge at load with connection surge protective device that is 293V. This simulation shows the surge protective device can reduce up to 60% of voltage spikes that occur to an appropriate value if the condition of grounding impedance and voltage protection level SPD at requirement

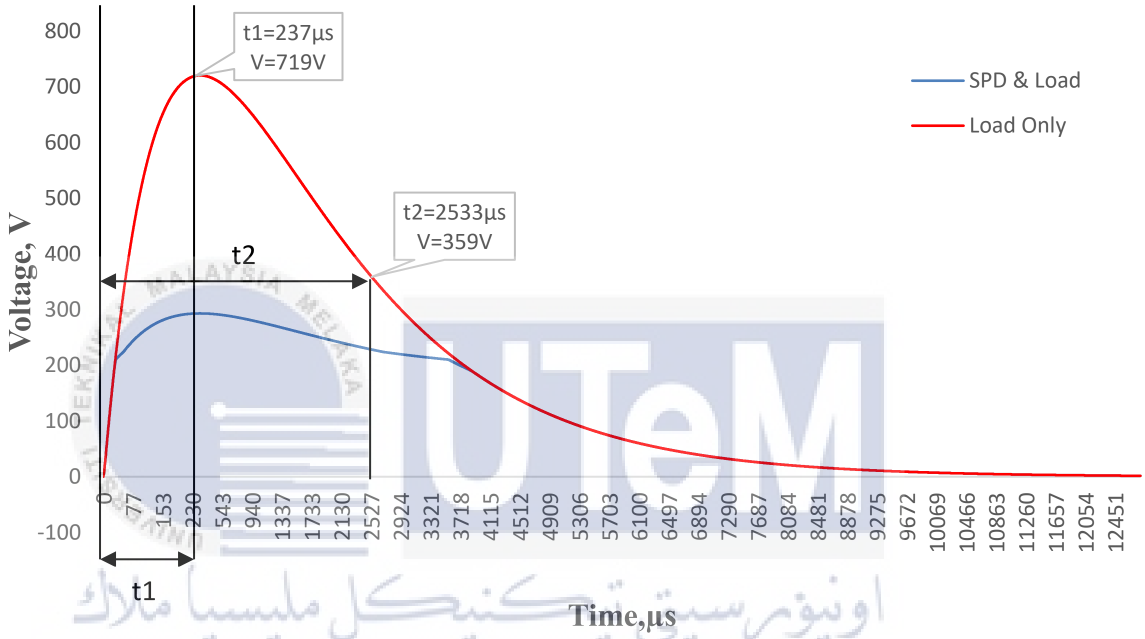

Figure 4.4: Simulation Waveform

4.3.2 Wave Form Hardware Experiment

The output surge voltage wave form at load done by hardware experiment. The switching impulse wave shape produce by this hardware experiment is a 200/1700 µs was shown in Figure 4.5. Based on observations, it is also still at the range requirement for switching impulse. The standard range for wave shape switching impulse that is at 250 µs ± 20% at front time and 2500 µs ± 60% at tail time. The red colour wave shape is a surge wave form happen at load. And blue colour wave shape is a surge wave form happen after installation surge protective device near to the load. The hardware experiment also shows the higher wave shape happen at load if no has any installation surge protective device. Meanwhile, when installation surge protective device near to the load, the wave form surge produce also will decrease. The peak voltage surge produces by this hardware experiment with connection without installing surge protective device is at 720V. Meanwhile, the peak voltage surge at load with connection surge protective device that is 354V. This hardware experiment shows the surge protective device can reduce up to 51% of voltage spikes that occur to an appropriate value if the condition of grounding impedance and voltage protection level SPD at requirement

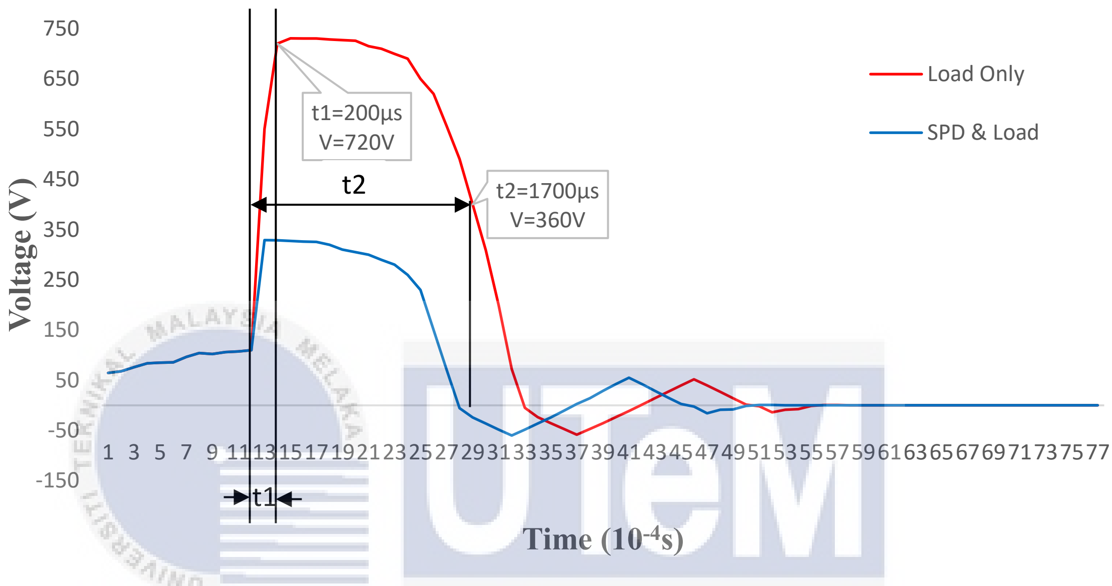

Figure 4.5: Hardware Experiment Waveform

As depicted in figure above, both experiment shows the increases and decreases trend shape of wave form when applying surge to the system was similar. The surge was through to the load without any decreases if the system no has installation surge protective device. Meanwhile, when has installation surge protective device near to the load, the voltage surge through to the load has limitation.

Base on the both experiment showing, when has installation surge protective device near to the load, it can reduce 60% and 51% voltage surge happen at load. This is because the function of the metal oxide veristor (MOV) inside this surge protective device, it can clamp the voltage at certain value. For this experiment, the result simulation so close to the hardware. It because the setting I-V characteristic MOV at simulation PSCAD was using the data sheet from same manufacture made the SPD that use at hardware experiment. The different between simulation and hardware only at 9%. From the data sheet, the maximum clamping voltage is a at 845V. However, the grounding system must at a good condition.

Meanwhile the selection of voltage protection level SPD must follow the standard requirement coordination for SPD.

By comparing the switching impulse produce by the simulation and hardware experiment. The error at front time only at 5.2% mean while the error at the tail time only at 1.32% during switching impulse was produced by simulation. Besides that, the switching impulse produce by hardware experiment has 20% error at front time and 32% error at tail time compare to the standard requirement. Both experiment shows different percentage error, it is because to generate the impulse for hardware experiment only using the small power transformer. However, both switching impulse still at the range standard requirement that is $200 < t1 < 300$ μs for front time and $1000 < t2 < 4000$ μs at tail time.

Based on observations, the hardware experiment and simulation still at the range standard. So, for the overall discussion all the data from both experiment can be used for the analysis.

4.4 Case 1: Effect of Different Value Impedance Grounding

4.4.1 Voltage Profile at Load

Base on Table 4.1, shows the performance surge protective device for reduce the surge happen at load from both experiment. This performance was comparing between the reference (connection load only without SPD) at normal system grounding and the connection (SPD and load) that has enhancement impedance grounding. When 10Ω resistor applied, the simulation shows the surge voltage can reduce 58.6%. It produced the surge voltage at load is 298V. Meanwhile, for hardware experiment it can reduce around 52.9% surge voltage happen at load. It produces surge voltage happen at load is 339V. The different between simulation and hardware only at 5.7%.

Another that, if resistor increase to 1000Ω, the simulation shows the surge voltage happen at load was reduce around 22.9%. It also produced the surge voltage at load is 554V. The hardware experiment only can reduce about 20.3% surge voltage and it produce surge voltage happen at load is 574V. The different between both experiment is around 2.6%.

From this experiment, the performance SPD simulation is much better than the hardware experiment. This is because, may be has some error while performing wiring connection and observation errors measuring during hardware experiment. Overall, the SPD for both experiment can function very well for reduce or clamping the voltage surge happen at the load.

Table 4.1: Performance SPD for Reduce Voltage Surge at Load

Impedance Grounding (Ω)	Simulation (V)	% Performance	Hardware Experiment (V)	% Performance
10Ω	298V	58.6	339V	52.9
22Ω	322V	55.2	354V	50.8
25Ω	328V	54.4	368V	48.9
56Ω	373V	48.1	382V	46.9
100Ω	415V	42.3	396V	45.0
1000Ω	554V	22.9	574V	20.3

Figure 4.6, shows the trend voltage surge at load between simulation and hardware experiment with different impedance grounding. Both experiment shows impedance grounding to the system, the voltage surge happen at load was higher than the references (connection SPD and Load only) when 10Ω was applied. It also shows, when the impedance grounding was increasing at 22Ω, 25Ω, 56Ω, 100Ω and 1000Ω, voltage surge happens at load also increased. That means the value voltage surge at load increased proportional to the increases the value impedance grounding.

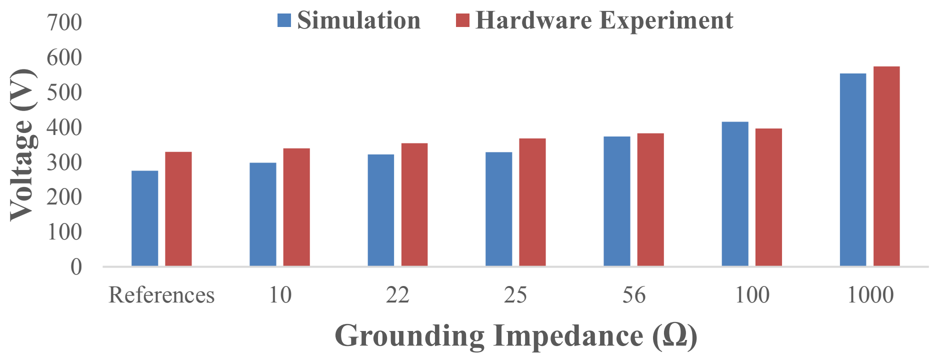

Figure 4.6: Comparison Simulation and Hardware Experiment at Voltage Load

4.4.2 Voltage Profile at Surge Protective Device

As scheduled in Table 4.2, shows the result performance surge protective device for limit the surge happen at SPD from both experiment. This result was comparing between the reference (connection load only without SPD) at normal system grounding and the connection (SPD and load) that has enhancement impedance grounding. When 10Ω resistor applied, the simulation experiment can limit the surge voltage about 62.4% surge voltage happen at SPD. It produced the surge voltage at SPD is 270V. Meanwhile, for hardware experiment it can reduce limit the surge voltage 52.1% surge voltage happen at SPD. It produces surge voltage happen at load is 345V. The different between simulation and hardware only at 10.3%.

Another that, if 1000Ω resistor applied, the simulation can limit around 70.4% surge voltage happen at load. It produced the surge voltage at SPD is 213V. The hardware experiment only can limit about 54.3% surge voltage happen at SPD and it produce surge voltage happen at SPD is 329V. The different between both experiment is around 16.1%.

From this experiment, the performance SPD simulation is much better than the hardware experiment. This is because, may be has some error while performing wiring connection and observation errors measuring during hardware experiment. Overall, the SPD for both experiment can function very well for reduce or clamping the voltage surge happen before the surge voltage happen at the load.

Table 4.2: Performance SPD for Limit Voltage Surge at SPD

Impedance Grounding (Ω)	Simulation (V)	% Performance	Hardware Experiment (V)	% Performance
10Ω	270V	62.4	345V	52.1
22Ω	264V	63.3	339V	52.9
25Ω	263V	63.4	339V	52.9
56Ω	251V	65.1	330V	54.2
100Ω	242V	66.3	329V	54.3
1000Ω	213V	70.4	329V	54.3

Figure 4.7, show the comparison voltage surge happen at surge protective device between simulation and hardware experiment with different impedance grounding. Both

experiment shows when applied 10Ω impedance grounding to the system, the voltage surge happen at surge protective device was lowest than the references (connection SPD and Load only). It also shows, when the impedance grounding was increasing at 22Ω, 25Ω, 56Ω, 100Ω and 1000Ω the voltage surge happens at load also decrease. That means the value voltage surge at surge protective device decreased proportional to the increases the value impedance grounding.

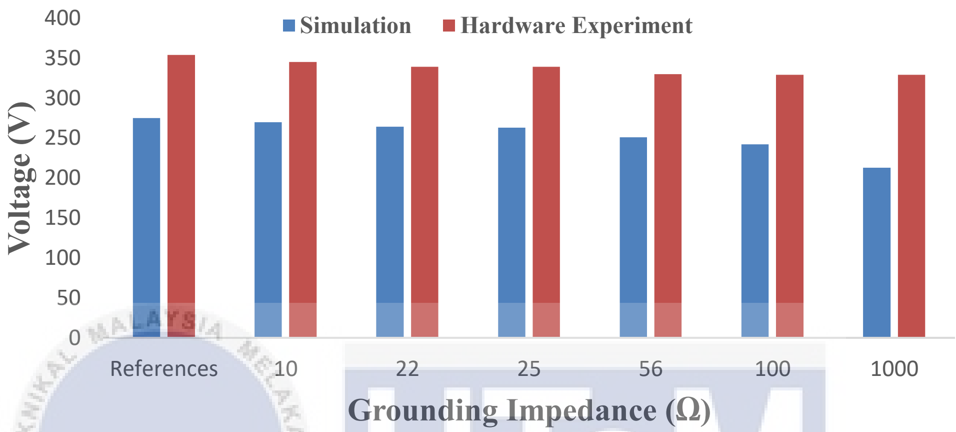

Figure 4.7: Comparison Simulation and Hardware Experiment at Voltage SPD

4.4.3 Conclusion Voltage Profile at Load and Surge Protective Device

In general, both experiment shows the voltage surge at load will increase and voltage surge at surge protective device will decrease when value impedance grounding increase. During surge event, the surge protective device will clamp surge voltage. Besides that, the characteristic impedance surge protective device will conduct first from high impedance to low impedance state for by pass the surge. That means the surge protective device depend on the value impedance grounding design. Surge protective device cannot function very well to clamping the voltage surge into the load if the value impedance grounding very high from the requirement. This is because the SPD did not too by pass the current surge to the ground caused the effect of impedance grounding very high. It will be the surge protective device become not very active component during surge happen. The voltage drops at surge protective device depend on how much current discharge into the grounding.

4.4.4 Current Profile at Load

As scheduled in Table 4.3, shows the result performance surge protective device for reduce the current surge happen at load from both experiment. This result was comparing between the reference (connection load only without SPD) at normal system grounding and the connection (SPD and load) that has enhancement impedance grounding. When 10Ω resistor applied, the simulation experiment can reduce about 49% surge current happen at load. Meanwhile, for hardware experiment it can reduce around 71.4% surge current happen at load. The different between simulation and hardware only at 22.4%. Another that, if 1000Ω resistor applied, the simulation can reduce around 5.8% surge current happen at load. The hardware experiment can reduce about 14.3% surge current happen at load. The different between both experiment is around 8.6%.

Base on this experiment, the lower value impedance grounding system applied means the best performance for SPD to limit the surge current happen at load. Meanwhile, when the increasing value impedance grounding can reduce the performance for SPD to limit the surge current happen at load. From this experiment, the hardware experiment is much better than the simulation. This is because, may be have some lack during insert the data setting for setting the cable using simulation PSCAD. Overall, the SPD for both experiment can function very well for reduce the current surge happen at the load.

Table 4.3: Performance SPD for Limit Current Surge at Load

Impedance Grounding (Ω)	Simulation (A)	% Performance	Hardware Experiment (A)	% Performance
10Ω	2.98A	49.0	0.02A	71.4
22Ω	3.22A	44.9	0.03A	57.1
25Ω	3.3A	43.5	0.04A	42.9
56Ω	3.7A	36.6	0.05A	28.6
100Ω	4.15A	28.9	0.05A	28.6
1000Ω	5.5A	5.8	0.06A	14.3

As depicted in Figure 4.8, shows the trend current surge at load between simulation and hardware experiment with different impedance grounding. Both experiment shows impedance grounding to the system when applied 1000Ω, the current surge happen at load was higher. It also shows, when the impedance grounding was increased at 10Ω, 22Ω, 25Ω, 56Ω, 100Ω and 1000Ω the current surge happens at load also increase. That means the value current surge at load increased proportional to the increases the value impedance grounding.

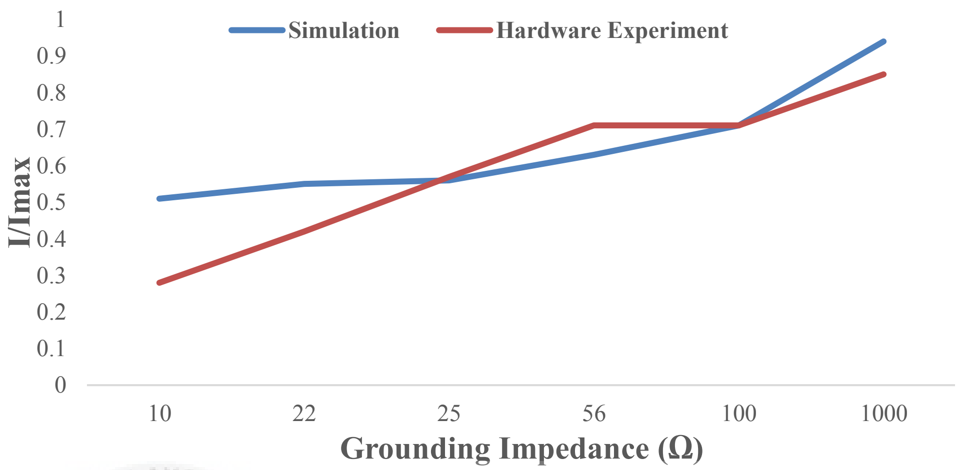

Figure 4.8: Comparison Simulation and Hardware Experiment at Current Load

4.4.5 Current Profile at Surge Protective Device

Base on Table 4.4, shows the result performance surge protective device for bypass the current surge happen at load from both experiment. This result comparing the reference (connection load only without SPD) at normal system grounding with connection (SPD and load) that has enhancement impedance grounding. When 10Ω resistor applied, the simulation experiment can bypass about 49.7% surge current to the ground. Meanwhile, for hardware experiment it can bypass around 57.1% surge current to the ground. The different between simulation and hardware only at 7.4%. Another that, if 1000Ω resistor applied, the simulation can bypass around 5.1% surge current to the ground. Meanwhile, the hardware experiment can bypass about 14.3% surge current happen to the ground. The different between both experiment is around 9.2%.

The lower value impedance grounding system applied means the best performance for SPD to bypass the surge current the ground. Meanwhile, when the increasing value impedance grounding can reduce the performance for SPD to bypass the surge current to the ground. From this experiment, the hardware experiment is much better compare to the simulation. This is because, may be have some lack during insert the data setting for setting the MOV using simulation PSCAD. Another that, the hardware experiment is doing at a real equipment. Overall, the SPD for both experiment can function very well for bypass the current surge to the ground.

Table 4.4: Performance SPD for bypass Current Surge at SPD

Impedance Grounding (Ω)	Simulation (A)	% Performance	Hardware Experiment (A)	% Performance
10Ω	2.9A	49.7	0.04A	57.1
22Ω	2.7A	46.2	0.03A	42.9
25Ω	2.6A	44.5	0.03A	42.9
56Ω	2.2A	37.7	0.02A	28.6
100Ω	1.7A	29.1	0.01A	14.3
1000Ω	0.3A	5.1	0.01A	14.3

The trend current surge at surge protective device between simulation and hardware experiment with different impedance grounding based on Figure 4.9. Both experiment shows when applied 1000Ω impedance grounding to the system, the current surge happen at surge protective device was decrease. It also shows, when the impedance grounding was increased at 10Ω, 22Ω, 25Ω, 56Ω, 100Ω and 1000Ω the current surge happens at surge protective device also decrease. That means the value current surge at surge protective device decreased proportional to the increases the value impedance grounding.

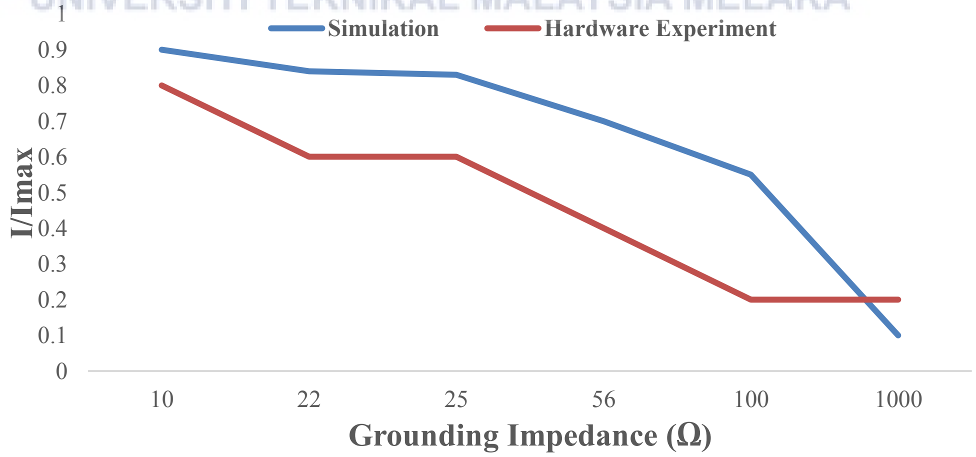

Figure 4.9: Comparison Simulation and Hardware Experiment at Current SPD

4.4.6 Conclusions Current Profile at Load and Surge Protective Device

In a nutshell, both experiment shows the current surge at load was increased and current surge at surge protective device was decreased when value impedance grounding was increased. During surge event, the metal oxide varistor (MOV) will clamp surge voltage. Besides that, the characteristic impedance MOV will conduct first from high impedance to low impedance state for by pass the surge current. That means the surge protective device depend on the value impedance grounding design. Surge protective device cannot function very well to bypass the current surge into the ground if the value impedance grounding very high from the requirement. Because it, the current surge occur at the load was increases. It will be the surge protective device become not very active component during surge happen. The proper design and maintenance the system grounding was a first action before installing the surge protective device.

4.4.7 Safety Level of Equipment

Figure 4.10, shows the voltage surge at load between simulation and hardware experiment be compared to the standard impulse withstand voltage protection level equipment Category 1. The standard minimum impulse withstand equipment Category 1 is an 800V. Both experiment show when the impedance grounding was increase at 10Ω, 22Ω, 25Ω, 56Ω, 100Ω and 1000Ω, the voltage surge happens at load also increase. The highest value voltage surge occurs at load is a 574V for hardware experiment and 554V for simulation. The percentage different it around 3.5% between both experiment. It happens when the value impedance grounding increased at 1000Ω. Base on figure, showing the trend voltage surge happen at load more highest during run the hardware experiment compare to simulation. It is because this experiment was doing at real situation. The increasing voltage surge at load is approaching to the minimum impulse withstand for equipment Category 1.

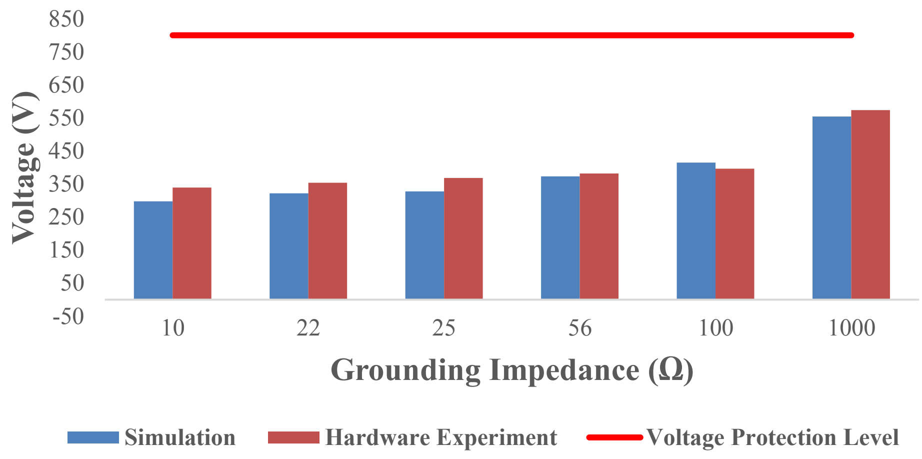

Figure 4.10: Investigation for Voltage Protection Level Category 1

In a nutshell, both experiment show the voltage surge at load were increased when value impedance grounding increase. That means the surge protective device depend on the value impedance grounding design. The investigations show, the surge occurs at load approaching to the standard impulse withstand for equipment Category 1. If the voltage surge occurs at load exceed the maximum impulse withstand, the capability of equipment Category 1 for withstand from surge will not happen. Voltage protection level *Up* must be below or equal to the overvoltage withstand capability of the loads. This is a condition for SPD can protect the equipment. Surge protective device only function for limiting the voltage surge occur and by pass the surge current discharge to the ground. It not fully protects the equipment from the surge coming. Therefore, the coordination surge protective device must follow the standard requirement. Besides that, the selection surge protective device must as appropriate the equipment that to be protected. The selection the suitable voltage protection level *Up* for surge protective device must be considered.

4.5 Case 2: Effect of Different Length

Figure 4.11, shows the comparison voltage surge happen at load between simulation and hardware experiment with different length of cable. Both experiment shows when length of cable between surge protective device and load above than 10 meters, the voltage surge happen at load was highest. It produces surge voltage happen at load is 354V by hardware and 275V by simulation experiment. The different percentage at 10 meters length of cable between both experiment is around 22%. It also shows, when the length of cable between surge protective device and load less than 5 meter or near to the load, the voltage surge happen at load was lowest. The different percentage between both experiment is around 19%. It also shows, the voltage surge occur at the load was similar when cable length less than 5 meter or surge protective device near to the load. The different increasing and decreasing both experiment because the hardware experiment is doing at real situation. Maybe during the experiment, the connection between component and cable is not tight. Meanwhile, the simulation experiment only depends on the modelling and inserting data requirement. This is cause some data from both experiment has differentially. However, the value voltage surge occurs at load depend on the length of cable between surge protective device and load.

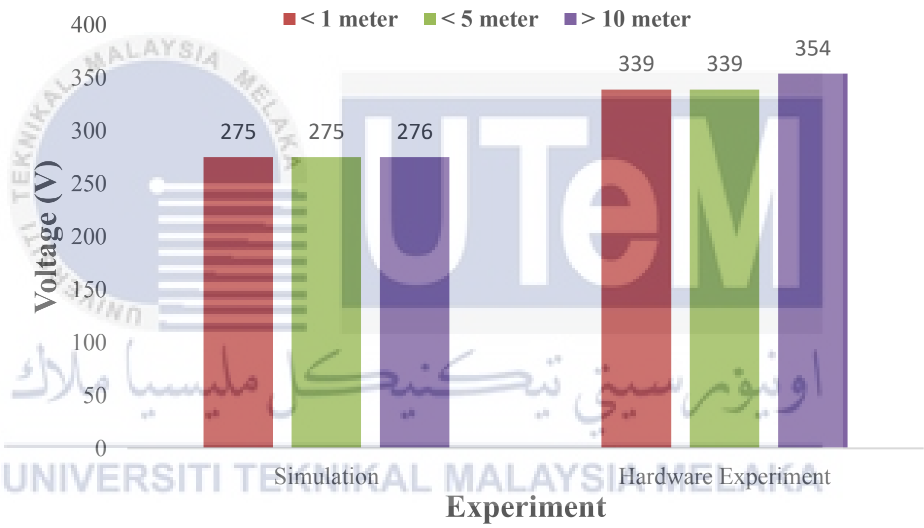

Figure 4.11: Voltage Surge at Load with Difference Length of Cable

Figure 4.12, shows the comparison current surge happen at load between simulation and hardware experiment with different length of cable. Both experiment shows when length of cable between surge protective device and load above than 10 meters, the current surge happen at load was highest. The different percentage current surge increases at 10 meters length of cable between both experiment is around 17%. It also shows, when the length of cable between surge protective device and load less than 5 meter or near to the load, the current surge happen at load was lowest. The different percentage between both experiment is around 39%. It also shows, the current surge occur at the load was similar when cable length less than 5 meter or surge protective device near to the load. The different increasing and decreasing both experiment because the hardware experiment is doing at real situation. Maybe during the experiment, the connection between component and cable is not tight. Meanwhile, the simulation experiment only depends on the modelling and inserting data requirement. This is cause some data from both experiment has differentially. However, the value current surge occurs at load also depend on the length of cable between surge protective device and load.

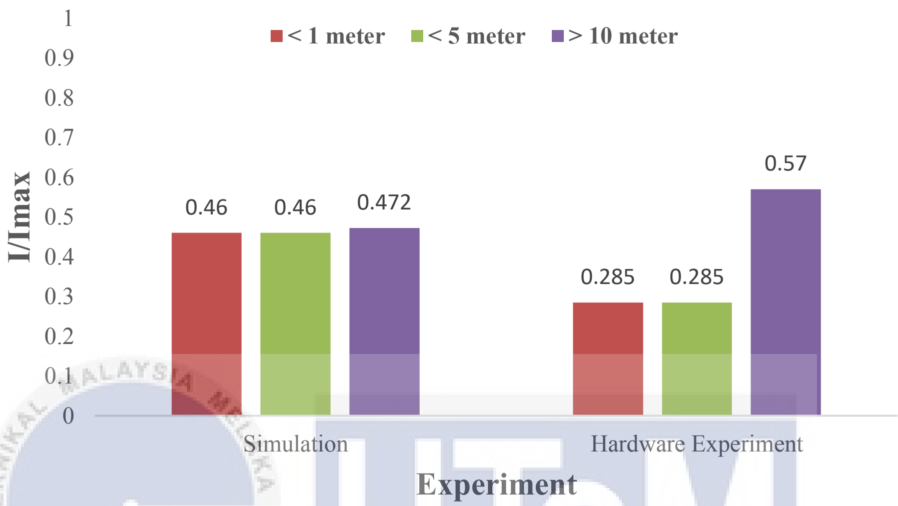

Figure 4.12: Current Surge at Load with Difference Length of Cable

On the overall, both experiment shows the voltage surge and current surge at load were increased when the connection cable it very long between surge protective device and load. It because the effect of the surges leads to oscillation phenomenon. During the surge happen, the fast transient was traveling along the connecting cable between surge protective device and load. Considering the inductance of the cable, the cable length and the duration of the surge travels very fast, it will result in over voltage at the load. In this case, the surge voltage can be increased again at terminal of load. Generally, the effective voltage protection distance of surge protective device must less than 10 meters. If more than that, it need another surge protective device or another protection scheme especially for protect the sensitive equipment.

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

This project describes about performance SPD when different impedance grounding of grounding system is implemented. The effect of different grounding impedance especially when it high will be reduce the SPD performance to bypass the switching current flow through the earth. Based on the case study, the performance SPD also depend on the switching surge level, coordination SPD, length of cable and load. All this parameter used to perform this project for analysis SPD performance.

In order to analyse the performance of SPD, this project conducted in software simulation and real equipment experimental. The different set of resistor will be use as a different grounding system. This experiment only conducted with three different length of cable and with constant value of load. Types 2 SPD are selected and will connected parallel with the load. The characteristics SPD such as current surge SPD (I_{SPD}), voltage surge SPD (V_{SPD}), voltage protection level SPD (Up) and voltage load ($Vload$) will be analyse. This analysis is based on data obtained will be described in the form of tables and graphs appropriate. Correlation and comparison of the graph will be the basis of discussion for this project.

Based on result, the surge current I_{SPD} and voltage surge V_{SPD} are affected by the different design impedance grounding. The value I_{SPD} and V_{SPD} was increase if impedance grounding (Rg) decrease. This is in condition grounding arrangement at good condition and SPD will bypass the surge current to the earth. For a good condition design grounding should be less than 10Ω. That mean if the value impedance grounding is high it can give the effect to the current discharge to flow to the earth. It because during surge event, the characteristic impedance surge protective device will conduct first from high impedance to low impedance state for by pass the surge. If the value impedance grounding is high, the SPD cannot function very well to bypass the surge current to the earth.

Voltage protection level *Up* must be below or equal to the overvoltage withstand capability of the loads. This is a condition for SPD can protect the equipment. For analysis oscillation phenomena, more depend on the length cable. If cable length more 10 meter the oscillation phenomena can be occur at the load. During the surge happen, the fast transient was traveling along the connecting cable between surge protective device and load. Considering the inductance of the cable, the cable length, and the duration of the surge travels very fast, it will result in over voltage at the load. In this case, the surge voltage can be increased again at terminal of load. This problem can be solved by installation SPD so closes to load.

Overall conclusion, the main objectives for this project have been achieved based on analysing the behaviour of characteristic of SPD by hardware experiment and simulation using PSCAD software.

5.2 Recommendations

In surge protection system, further studies and analysis is required on the multiple surge given in low voltage system. It is because, some of surge protection device design did not withstand from multiple surge. Besides that, every surge protection device has different characteristic and operating. So, it is suggested that in order to ensure using the right and suitable type of class protection device will increase their performance and not too complicated. Therefore, for further studies, it is recommended to test at different load given in order to investigate the surge protection device performance.

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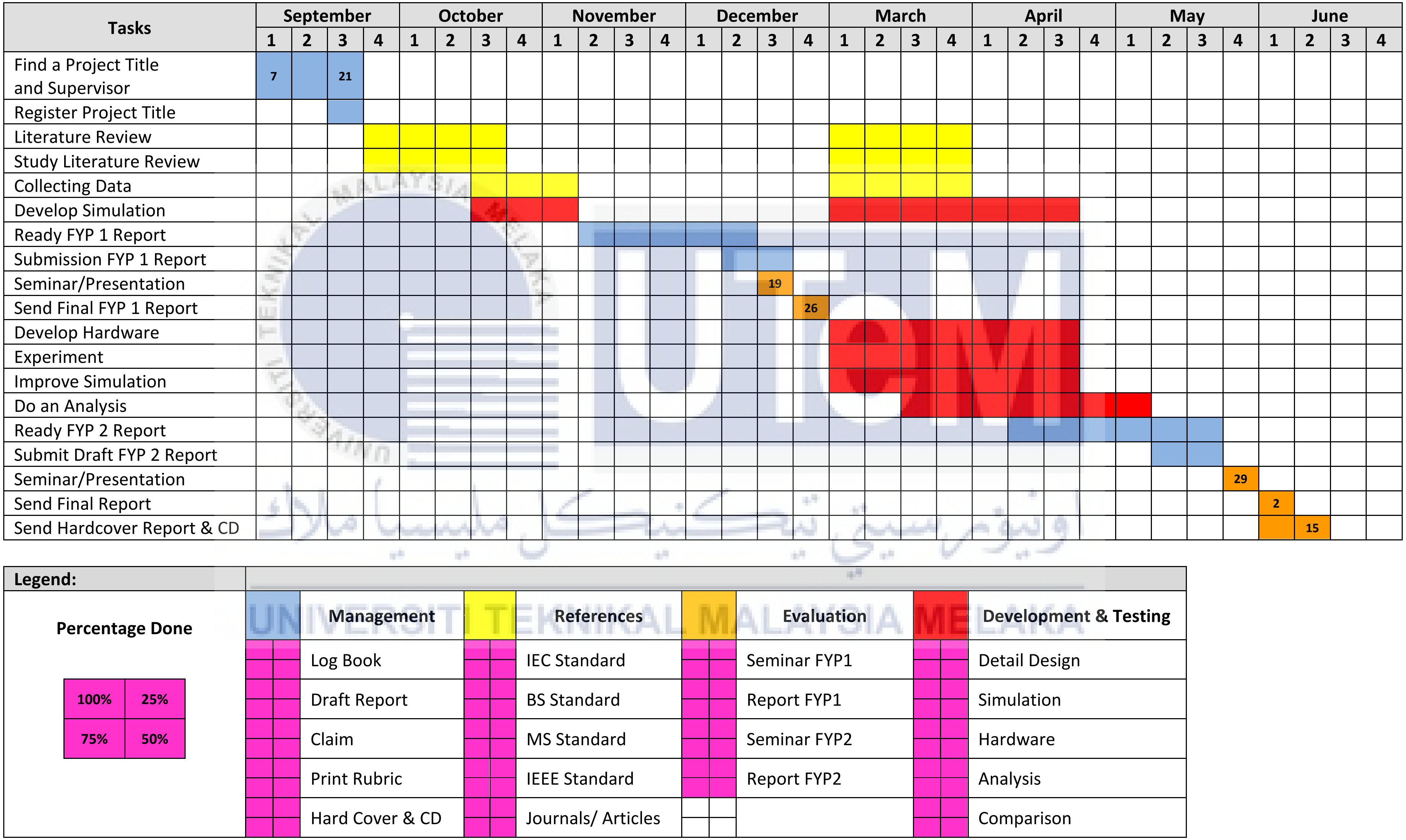
APPENDICES

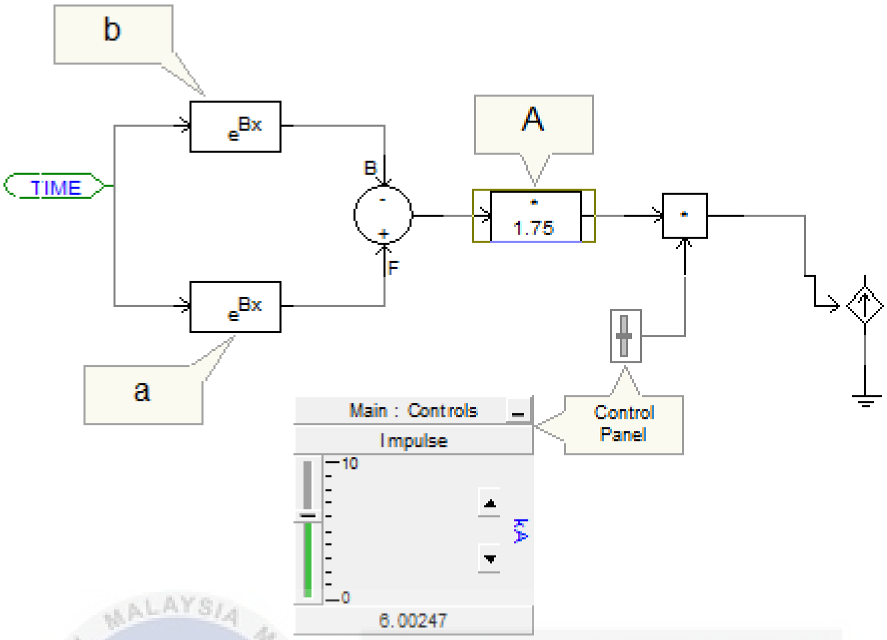
A. Key Milestone

Project Progress	Duration
Collect all of Journal and Literature Review	September 2016
Collect the initial data	October 2016
Develop Simulation	October 2016
Write progress report draft	October 2016
Submit report	November 2016
First seminar	December 2016
Develop Hardware and Simulation	January 2017-April 2017
Do an final analysis	May 2017
Write a report	April 2017- May 2017
Final Seminar	May 2017
Submit report	June 2017
Hard Cover & CD	June 2017

B. Gantt Chart



C. Setting Simulation PSCAD: Impulse Generator



Data Impulse Requirement:

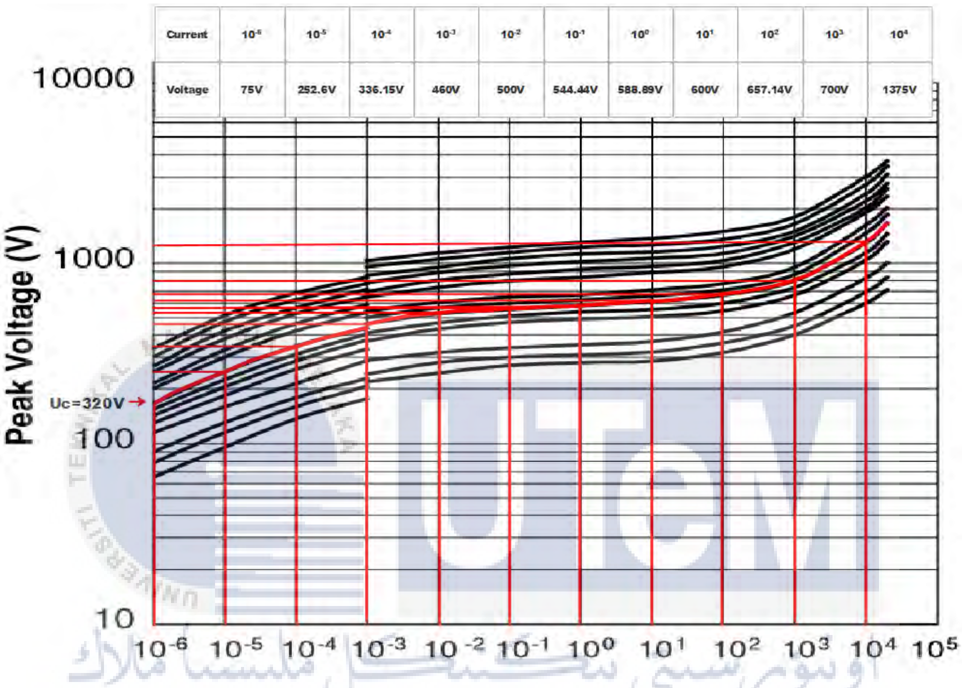
Equation Current Test: $I_{test} = A*I1 * [EXP(-a* t) - EXP(-b* t)]$

No.	Surge	A	a	B
1.	1.2*50 µsec	1.02	1.3×10^4	4.4×10^6
2.	8*20 µsec	4.5	0.866×10^5	1.732×10^5
3.	300*1000 µsec	1.75	1233	6781.5

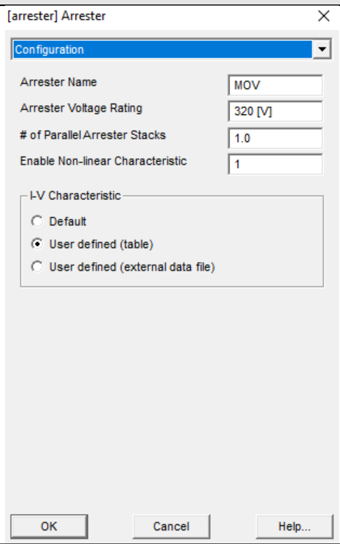
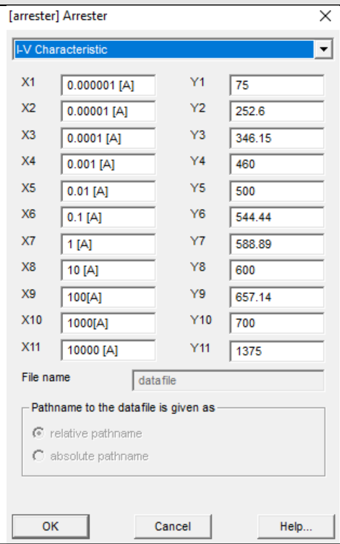
D. Setting Simulation PSCAD: SPD (MOV)

i. From Data Sheet Metal Oxide Varistor (I-V Characteristic)

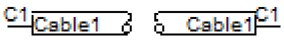
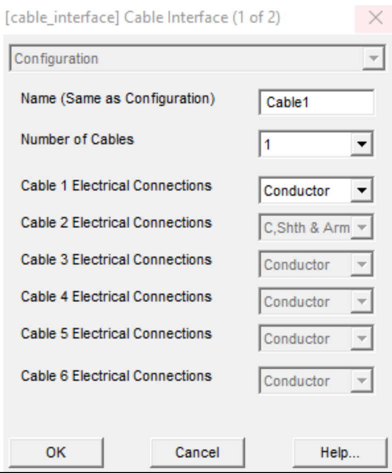
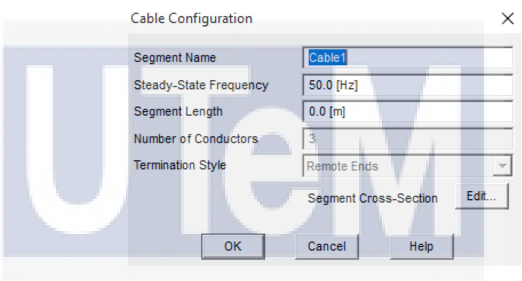
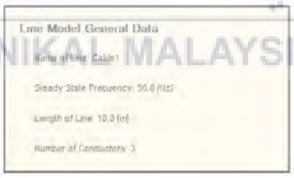
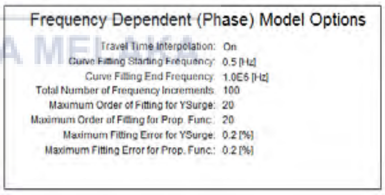
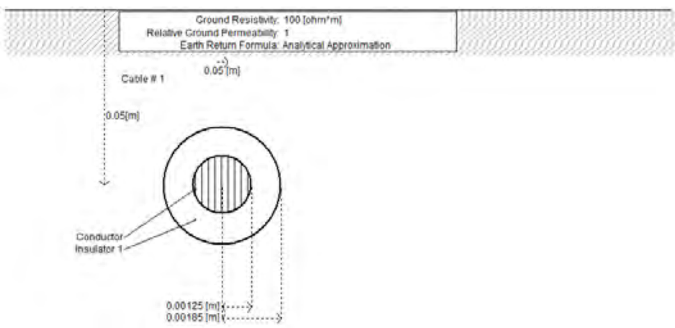
Size Disk = 34mm
Uc = 320 VAC
Maximum Voltage Clamping = 845VAC



ii. Setting MOV at PSCAD

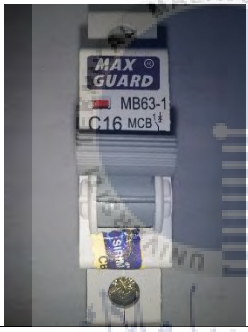
Uc	I-V Characteristic
	

E. Setting Simulation PSCAD: Length of Cable

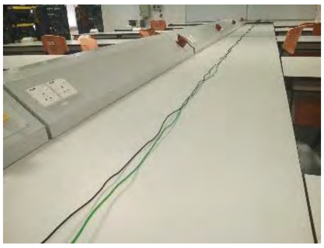
No.	Component	Setup
i.		a) Number and type of cable 
ii.		a) Cable configuration  b) Frequency dependent (phase) model options  c) Cable constants coax cable data 

F. Setup Hardware Experiment:

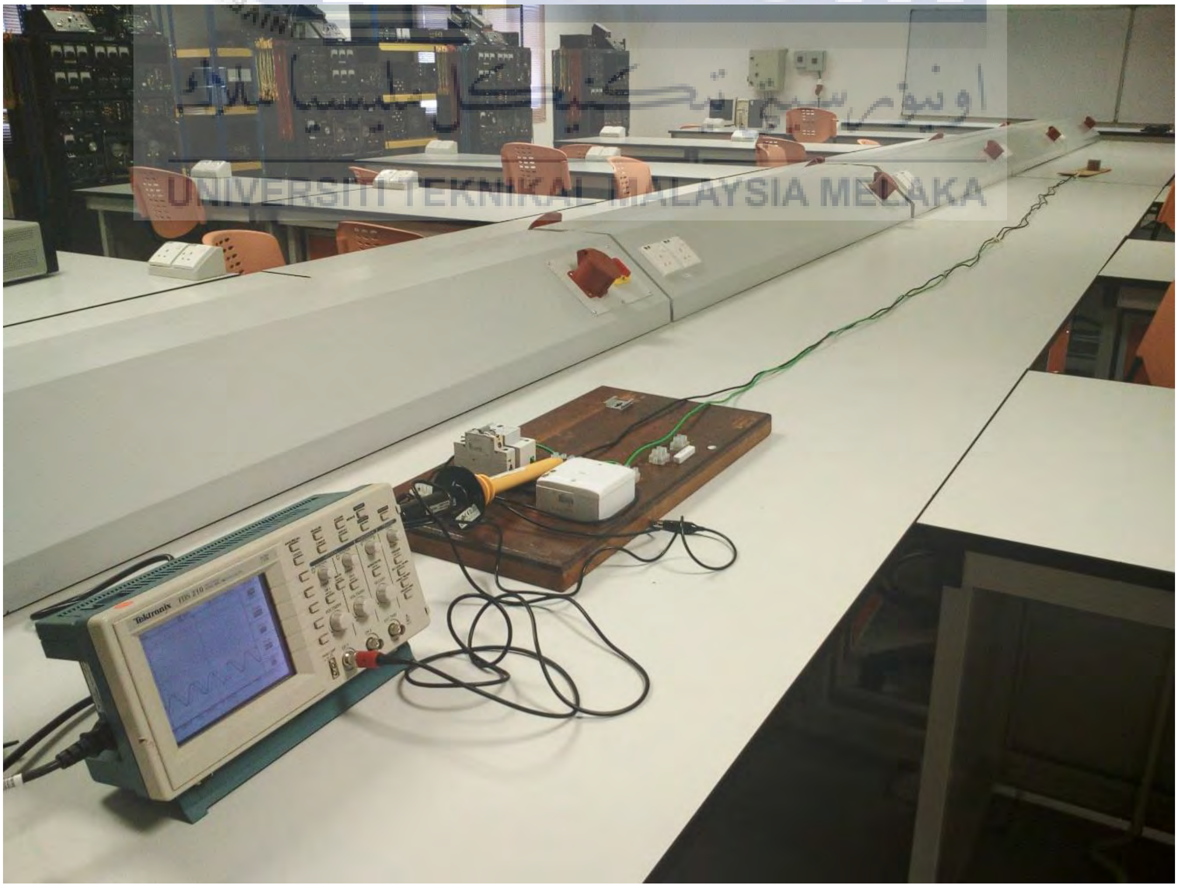
List of Component:

No.	Component	Specification
i.	Surge Protection Device 	Brand : EPS SPD Model : BYC-1 Rated Voltage : 240V Uc : 320V Imax : 40kA In : 20kA Up : < 1.5kV
ii.	Miniature Circuit Breaker 	Brand : MAX GUARD Model : MB63-1 Rated Voltage : 240/415V Max. Current : 16A
iii.	AC Power Transformer (Step Up) 	Brand : TELETRON Model : T66-2402 Input Voltage : 0-115V-240V Output Voltage : 24V-0-24V/ 2A Output Power : 96VA
iv.	Power Resistor 	10Ω, 22Ω, 25Ω, 56Ω, 100Ω, 1000Ω for above 10watt

List of Component:

No.	Component	Specification
v.	Cable 	Model : BV Rated Voltage : 240/450V Insulation Material : PVC (Polyvinyl Chloride) No. of Conductor : 1 No. of Copper Wire : 7 Cross-section : 2.5mm Conductor Material : Copper
vi.	Load 	Brand : OSRAM Model : CLAS P CL 25 Watt : 25watt Rated Voltage : 240V Load Impedance : 100Ω

Picture Hardware Experiment Setup:



G. Result Simulation and Hardware Experiment

i. Data Voltage Surge at Load

Experiment	References	Impedance Grounding (Ω)					
		10Ω	22Ω	25Ω	56Ω	100Ω	1000Ω
Simulation	275V	298V	322V	328V	373V	415V	554V
Hardware Experiment	329V	339V	354V	368V	382V	396V	574V

ii. Data Voltage Surge at SPD

Experiment	References	Impedance Grounding (Ω)					
		10Ω	22Ω	25Ω	56Ω	100Ω	1000Ω
Simulation	275V	270V	264V	263V	251V	242V	213V
Hardware Experiment	354V	345V	339V	339V	330V	329V	329V

iii. Data Current Surge at Load

Data Result:

Experiment	References (Imax)	Impedance Grounding (Ω)					
		10Ω	22Ω	25Ω	56Ω	100Ω	1000Ω
Simulation	5.84A	2.98A	3.22A	3.3A	3.7A	4.15A	5.5A
Hardware Experiment	0.07A	0.02A	0.03A	0.04A	0.05A	0.05A	0.06A

Data Analysis:

Analysis at ratio (I/Imax)	Impedance Grounding (Ω)					
	10Ω	22Ω	25Ω	56Ω	100Ω	1000Ω
Simulation	0.51	0.55	0.56	0.63	0.71	0.94
Hardware Experiment	0.28	0.42	0.57	0.71	0.71	0.85

iv. Data Current Surge at SPD

Data Result:

Experiment	References	Impedance Grounding (Ω)					
		10Ω	22Ω	25Ω	56Ω	100Ω	1000Ω
Simulation	3.1A	2.9A	2.7A	2.6A	2.2A	1.7A	0.3A
Hardware Experiment	0.05A	0.04A	0.03A	0.03A	0.02A	0.01A	0.01A

Data Analysis:

Analysis at ratio (I/Imax)	Impedance Grounding (Ω)					
	10Ω	22Ω	25Ω	56Ω	100Ω	1000Ω
Simulation	0.51	0.55	0.56	0.63	0.71	0.94
Hardware Experiment	0.28	0.42	0.57	0.71	0.71	0.85

v. Data Voltage and Current (effect of Cable Length)

Voltage Load	Length Cable		
	< 1 meter	< 5 meter	> 10 meter
Simulation	275.191V	275.192V	275.211V
Hardware Experiment	339V	339V	354V

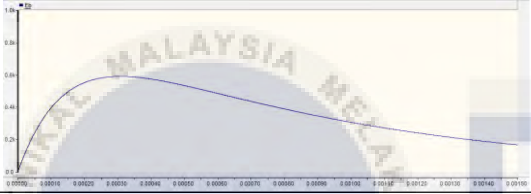
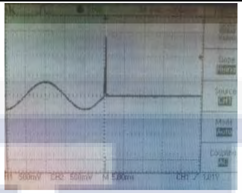
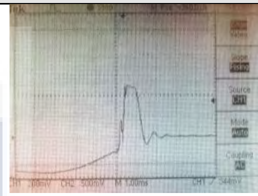
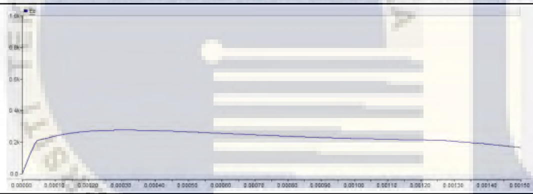
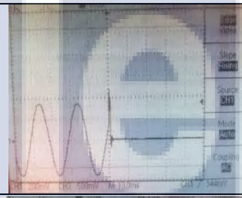
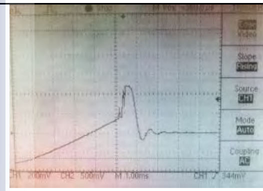
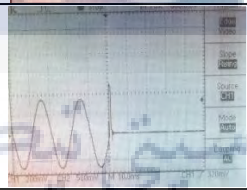
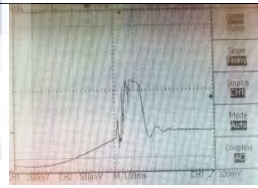
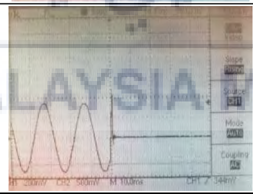
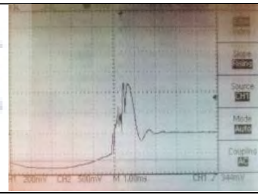
Voltage SPD	Length Cable		
	< 1 meter	< 5 meter	> 10 meter
Simulation	275.192V	275.199V	275.213V
Hardware Experiment	339V	339V	345V

Current Load	Length Cable		
	< 1 meter	< 5 meter	> 10 meter
Simulation	0.46A	0.46A	0.472A
Hardware Experiment	0.285A	0.285A	0.57A

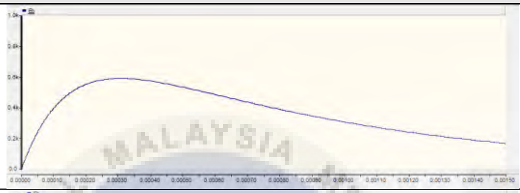
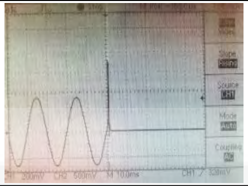
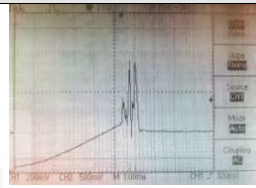
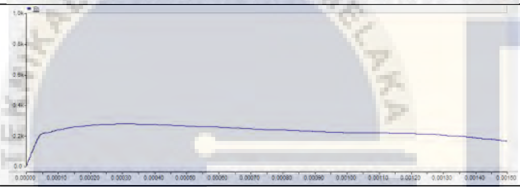
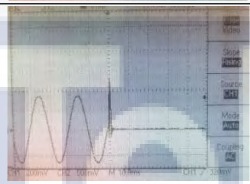
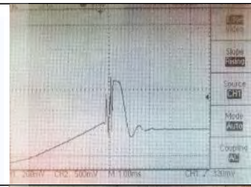
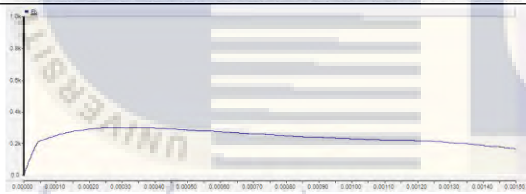
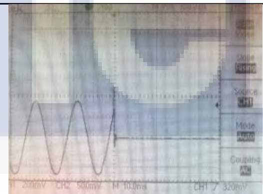
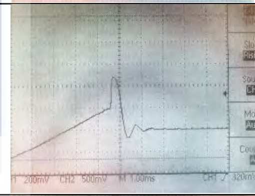
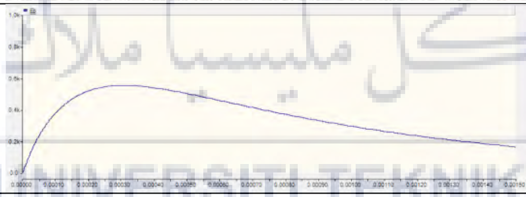
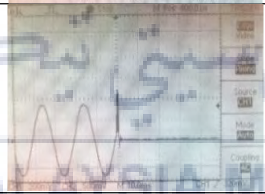
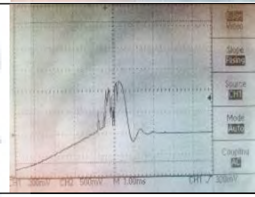
Current SPD	Length Cable		
	< 1 meter	< 5 meter	> 10 meter
Simulation	0.46A	0.46A	0.472A
Hardware Experiment	0.285A	0.285A	0.57A

vi. Example Result Wave Form Surge from Simulation and Hardware Experiment at Load

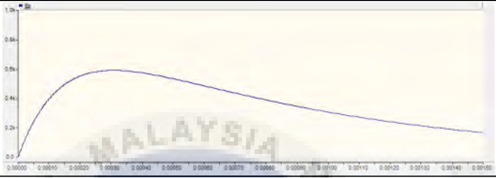
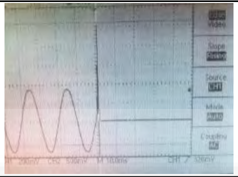
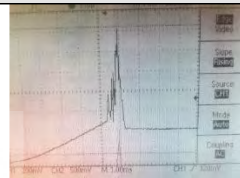
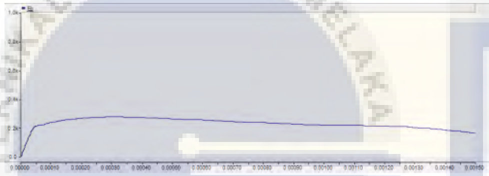
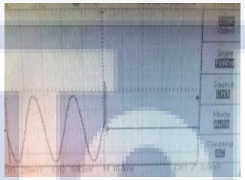
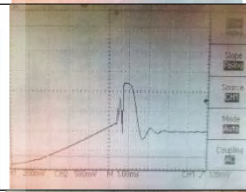
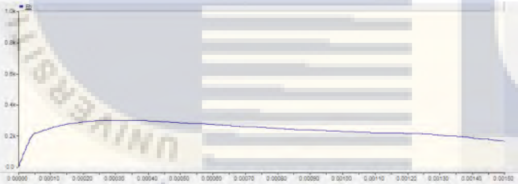
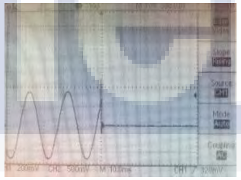
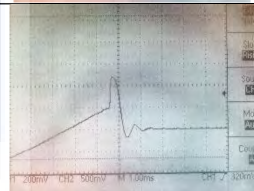
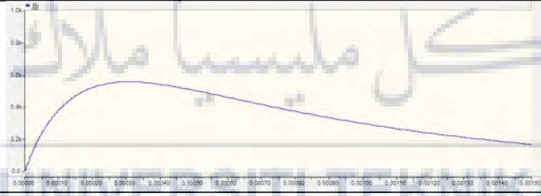
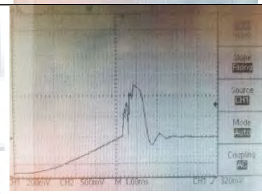
Connection: Less 1 meter

Experiment	Simulation	Hardware Experiment	
Load Only			
SPD & Load			
10Ω			
1000Ω			

Connection: Less 5 meter

Experiment	Simulation	Hardware Experiment	
Load Only			
SPD & Load			
10Ω			
1000Ω			

Connection: Above 10 meter

Experiment	Simulation	Hardware Experiment	
Load Only			
SPD & Load			
10Ω			
1000Ω			

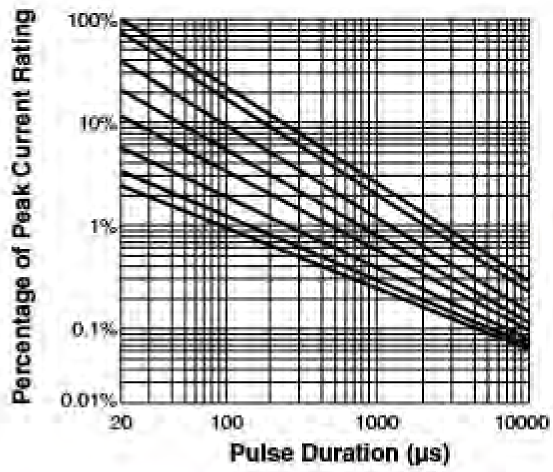
H. Data Sheet MOV (34mm diameter disk)

EV Standard Series — Electrical Characteristics

34mm

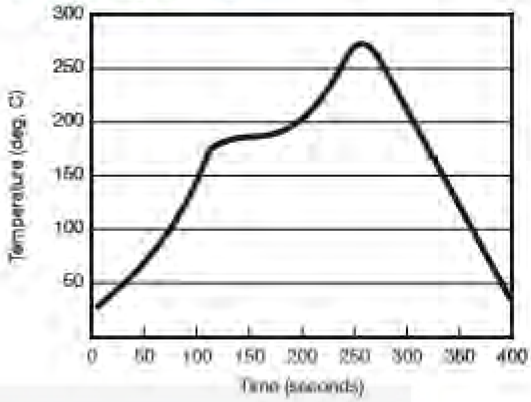
Part Number	Maximum Continuous Rated Voltage		Rated Single Pulse Transient		Varistor Voltage @1mA DC		Maximum Clamping Voltage @Test Current 8/20µs		Typical Capacitance @1KHZ 25°C
			Energy	Peak					
	AC RMS Volts	DC Volts	10/1000µs (joules)	8/20µs KA	Min Volts	Max Volts	Volts	Amps	pF
EV34D30K	30	38	96	20	42	52	93	60	35000
EV34D35K	35	45	115	20	50	63	110	60	29500
EV34D40K	40	56	136	20	61	75	135	60	24200
EV34D50K	50	65	156	30	74	90	135	300	17950
EV34D60K	60	85	195	30	90	110	165	300	15000
EV34D75K	75	100	235	45	108	132	200	300	12200
EV34D95K	95	125	296	45	135	165	250	300	10000
EV34D120K	120	150	350	45	162	198	300	300	8250
EV34D130K	130	170	400	45	185	225	340	300	6750
EV34D140K	140	180	450	45	198	242	360	300	6400
EV34D150K	150	200	480	45	222	270	395	300	5650
EV34D180K	180	225	540	45	256	310	455	300	5100
EV34D195K	195	250	600	45	270	330	500	300	4510
EV34D210K	210	275	656	50	297	363	550	300	4150
EV34D230K	230	300	745	50	324	396	595	300	3750
EV34D250K	250	320	830	50	362	440	650	300	3500
EV34D275K	275	350	920	50	387	473	710	300	2950
EV34D300K	300	385	1000	50	423	517	775	300	2880
EV34D320K	320	415	1060	50	459	561	845	300	2650
EV34D360K	360	460	1150	50	504	616	925	300	2450
EV34D390K	390	505	1260	50	558	682	1025	300	2200
EV34D420K	420	560	1250	50	612	748	1120	300	2000
EV34D460K	460	615	1280	50	675	825	1240	300	1820
EV34D485K	485	640	1350	50	702	858	1290	300	1750
EV34D510K	510	670	1395	45	738	902	1355	300	1650
EV34D550K	550	745	1475	45	819	1001	1500	300	1500
EV34D575K	575	760	1485	45	855	1045	1570	300	1430
EV34D625K	625	825	1550	45	900	1100	1650	300	1350
EV34D680K	680	895	1700	45	990	1210	1815	300	1230
EV34D750K	750	980	1750	40	1150	1320	1980	300	1135
EV34D850K	850	1120	1750	40	1315	1540	2310	300	970
EV34D1000K	1000	1320	2000	40	1550	1760	2640	300	840

Peak Current Per Pulse Versus Pulse Duration

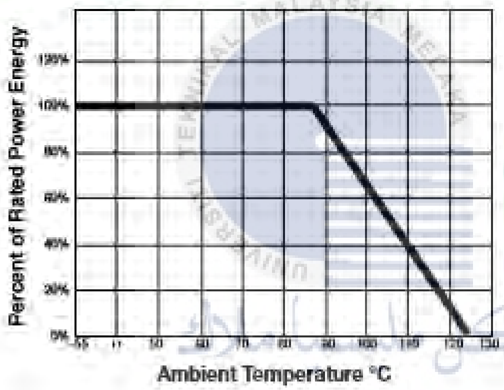


1 Repetition - (Top line on graph)
2 Repetitions
10 Repetitions
10^2 Repetitions
10^3 Repetitions
10^4 Repetitions
10^5 Repetitions
10^6 Repetitions - (Bottom line on graph)

Soldering Profile



Temperature Derating Curve Power and Energy Rating vs. Temperature



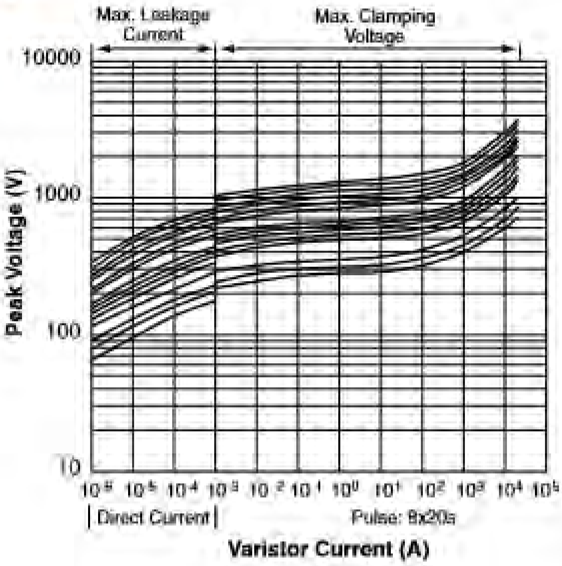
Power Dissipation Ratings

Disk Size	Pm-watts
5mm (< 50 VAC)	0.01
5mm (≥ 50 VAC)	0.20
7mm (< 50 VAC)	0.02
7mm (≥ 50 VAC)	0.25
10mm (< 50 VAC)	0.05
10mm (≥ 50 VAC)	0.40
14mm (< 50 VAC)	0.10
14mm (≥ 50 VAC)	0.60
20mm (< 50 VAC)	0.20
20mm (≥ 50 VAC)	1.00
22mm (< 50 VAC)	0.25
22mm (≥ 50 VAC)	1.20
34mm (< 50 VAC)	0.30
34mm (≥ 50 VAC)	1.40

V-I Characteristics (continued)

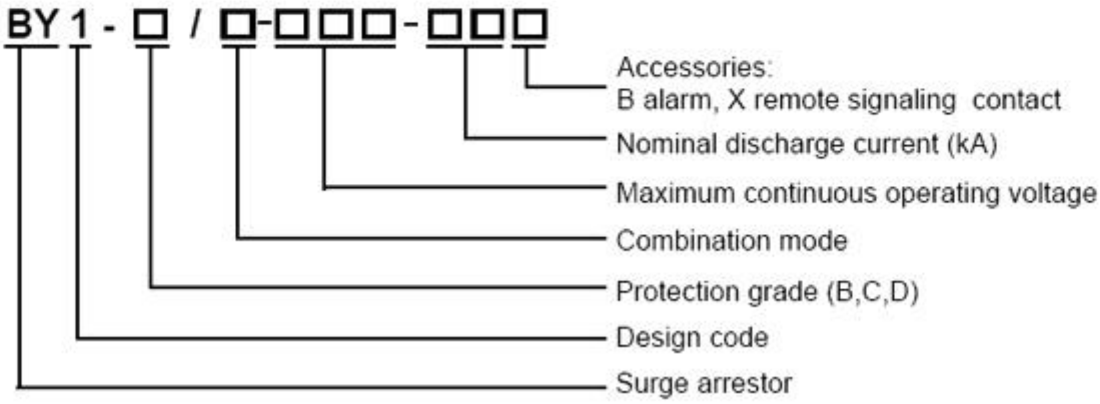
34mm Disk Size (VAC)

575 - (Top line on graph)
550
510
460
420
390
320
300
275
250
230
180
150
130 - (Bottom line on graph)



I. Data Sheet EPS SPD BY1-C

Model and meaning:



Usage and application scope:

BY1 series surge protective device (protector in short) is applied in A.C 50/60 Hz , ≤380V in the following electric power system, such as TT, IT, TN-S, TN-C and TNCS
which protects the electric net shocked by the thunder or surge over voltage.

Tripping device:

There's tripping device designed on the modular of the protector. When the protector is over heat or shocked, the tripping device can automatically separate it from the electric net, at the same time showing the indication signal. It's green when the protector is normal, red when tripping.

Alarm:

The power of the alarm is supplied by AC220V. In normal condition it is green and the opening contact is closed but the closing contact is open. It is with the function of alarming and showing: the alarm will sound and the green indicator lamp will change to red when the mould of the protective device is out of working. And the alarm will not stop until the operator pushes the stop press (but the red lamp is still showing). If the trouble can not be dealt within 24 hours, the alarm will sound again.

Remote signaling contact:

The products can be produced available with the accessory of remote signaling contact which is an opening contact. If one of the product's mould is out of working, the contact will be closed and send the trouble information. The rated data of the remote signaling contact is AC36V, 1A.

Principal parameters:

1. Maximum continuous operating voltage : Uc~140 275 320 385 420 550V
2. Test classification : II grade
3. Protection level : Up < 0.8 1.2 1.5 1.8 2.0 2.5kV
4. Max. discharging current (8/20µs) : Imax 10 40 60kA
5. Nominal discharge current (8/20µs) : In 5 15 20 30kA

Technical Parameters

		BY1-C/ 140-15	BY1-C/ -275-20	BY1-C/ -320-20	BY1-C/ -385-20	BY1-C/ -420-20	BY1-C/ -550-20
Maximum continuous operating voltage Uc		140V	275V	320V	385V	420V	550V
Voltage protection level Up <		0.8kV	1.2kV	1.5kV	2.5kV	2.5kV2	.5kV
Nominal discharge current In (8/20µs) kA		15	20	20	20	20	20
Maximum discharge current Imax (8/20µs) kA		40	40	40	40	40	40
Response time ns		<25					
Width mm		18					
Colour		Grey					
Protection level		IP20					
Shell material		enforce anti- flame PBT					
Fuse or Switch (A)		25-32A					
Connect ways	L N	2.5-35 mm^2					
	Earthing	4.0---45 mm^2					
	Signal line	1.5mm^2					

J. Data Sheet High Voltage Test Probe

Product ID: HV-40 / HVP-40

Model: HV-40
Features: Connect to any digital multimeter with industry standard jacks to measure up to 40K VDC or peak AC or 28KV rms AC.
Model: HVP-40M
Features: DC 40KV CAT II Pollution 2, 600M Ohm Impedance, 25KV ± 2%, 40KV ± 3%, T.C. 200 ppm/°C, Positive Polarity only, Resolution 1KV,
No Need power. CE, TUV GS, UL, CUL, IEC1010

Specifications:

- **HV-40**
  - Max. Working Voltage: 40kV DC or Peak AC 28kV rms AC
  - Accuracy: DC Volts : +1%(1kV to 20kV); +2%(20kV to 40kV)
  - AC Volts: Typically 5% at 60Hz
  - Division Ratio: 1000 : 1
  - Input Resistance: Approx. 1000M Ohm
  - Cable length: 1 meter
  - TECPEL C O., LTD
  - E-MAIL: sales@tecpel.com Web-site: http://www.tecpel.com
  - TEL:2-27375866 FAX:886-2-27373343
- **HVP-40M**
  - SPECIFICATIONS (20 ± 5°C, RH < 80%)
  - ! WARNING !
  - Before taking any measurements, first connect the alligator clip of this probe to earth ground and make sure connection is electrically good.
  - Input impedance:600M Ohm
  - Maximum operation voltage:40KV DC , CAT II , Pollution 2
  - Polarity:Positive only
  - Display:Analog indicate
  - Accuracy:Factory calibrater 25KV ± 2%
  - FULL scale 40KV ± 3 %
  - Temperature Coefficient:Maximum loading Current:Maximum loading power:Voltage Range:40KV / 1 Range
  - Voltage resolution:1KV
  - Power source:Need not power
  - Operating temperature:0 °C ~ + 50 °C.
  - Storage temperature:- 20 °C ~ + 70 °C.
  - Ground lead length:90cm (35 ")
  - Dimensions:420 L x 80 ø
  - Weight:360g

Certificate:

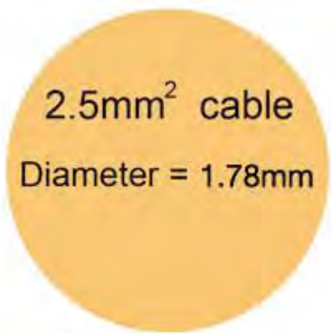
- CE_UL_TUV

K. Data Sheet Cable 2.5mm^2

Cable 2.5mm Specification

- Place of Origin : Guangdong, China (Mainland)
- Brand Name : YONGKUNTAI TIANXIANG
- Model Number : BV
- Type : Insulated
- Application : instrument or building
- Conductor Material : Copper
- Conductor Type : Rigid and Solid
- Insulation Material : PVC (Polyvinyl Chloride)
- Voltage Rating : 300/500V
- Operating temperature range : 0℃ to 70℃
- Resistivity Metal Core : 1.724 X $10^{-8}\Omega$.m
- Test voltage : 2.500V in A.C.
- Relative Dielectric Metal Core : 4.55
- Length : 50 Meters,100 Meters,500 Meters or up to you
- Number of Conductors : 1
- Number of copper wires : 1,7,19,37 or up to you
- Cross-section : 1.5, 2.5, 4, 6, 10, 16, 25, 35, 50, 70, 95, 120, 150, 185sqmm
- Color : white, grey, red, blue, black, yellow, green, brown, green/ yellow etc..

Pi times the radius squared is the area of a circle



2.5mm cable means a cross sectional area of 2.5mm of the live or neutral wire