INVESTIGATION ON THE OVERVOLTAGE SURGES AND ITS PREVENTION AND PROTECTION

LIEW HONG THYE

A project report submitted in partial fulfilment of the requirements for the award of Master of Engineering (Electrical)

Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature	:	
Name	:	Liew Hong Thye
ID No.	:	17UEM00010
Date	:	

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"INVESTIGATION ON THE OVERVOLTAGE SURGES AND ITS PREVENTION AND PROTECTION"** was prepared by **LIEW HONG THYE** has met the required standard for submission in partial fulfilment of the requirements for the award of Master of Engineering (Electrical) at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ____________________________

Supervisor : Dr Chew Kuew Wai

Date : ____________________________

Specially dedicated to

my beloved grandmother, mother and father

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INVESTIGATION ON THE OVERVOLTAGE SURGES AND ITS PREVENTION AND PROTECTION

ABSTRACT

The reasons of carrying out this research are to investigate the different types of overvoltage surges, the effects of overvoltage surges, to figure out overvoltage surges prevention methods and its protection methods. Different types of overvoltage surges such as switching surge and lightning surge are identified. Each of the overvoltage surges have their own sources and effects. The overvoltage surges prevention methods such as the shield wire and grounding system are identified and discussed. The overvoltage surges protection systems are also identified. The protection method for lightning overvoltage surges on high power system using surge arresters is focused in this research. A switching overvoltage surges circuit is modelled using MATLAB and its protection method of converting power factor correction capacitor bank into harmonic filter is tested and verified. Apart from that, a lightning overvoltage surges circuit is designed to model the lightning overvoltage surges characteristic using MATLAB. Different types of protection circuit are simulated and analysed to prove that the protection circuit does indeed work. By implementing some recommendations such as carrying out the experiment practically by modelling the actual circuit, results that are more accurate can be obtained.

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LIST OF SYMBOLS / ABBREVIATIONS

BIL	Basic Insulation Impulse Level
C	capacitance
I	current
IGBT	Insulated-Gate Bipolar Transistor
LPL	Lightning Protection Level
LPS	Lightning Protection System
LPZ	Lightning Protection Zone
t_f	front time
t_t	tail time
R	resistor
SPD	Surge Protection Device
t	time
V	voltage
Z	Impedance

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CHAPTER 1

INTRODUCTION

1.1 Background

Overvoltage surges is one of the most frequent power quality issues in the power system. In the past, most of the equipment used in the power system are analogue and they can support higher overvoltage surges. However, there are more and more semiconductor electronic devices introduced nowadays and they are extremely popular due to their fast responses, high efficiency and lower cost. The semiconductor electronic devices indeed provide faster responses and high efficiency but they are very sensitive to power quality issues such as harmonics and overvoltage surges. The overvoltage surges are lethal to the semiconductor electronic devices as the thermal capacity of semiconductor electronic devices are very low. Figure 1.1 shows the damage of overvoltage surges on electronic devices.

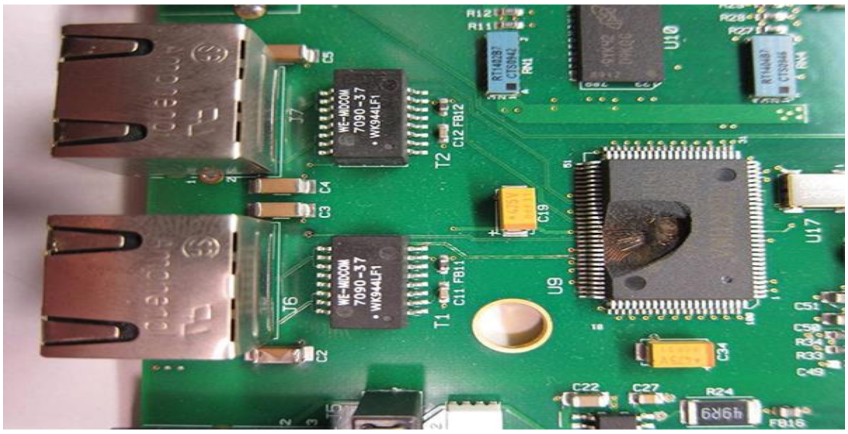


Figure 1.1: Figure of Damage on Semiconductor Electronic Devices Due to Overvoltage Surges

The overvoltage surges not only able to damage the equipment at consumer's end but also at utility's end such as transformer, motor and even transmission line. This is extremely alarming as damage on such important equipment may cause failure of the whole power system and thus causing power interruption and affect the reliability of the power system. (Agrawal and Nigam, 2014). The reliability of the power system is extremely important to every consumer especially those companies with servers and those manufacturing company. Any power outage may cause those companies to lose up to millions or even billions of dollars. Figure 1.2 shows the annual business losses from grid problems in United States of America.

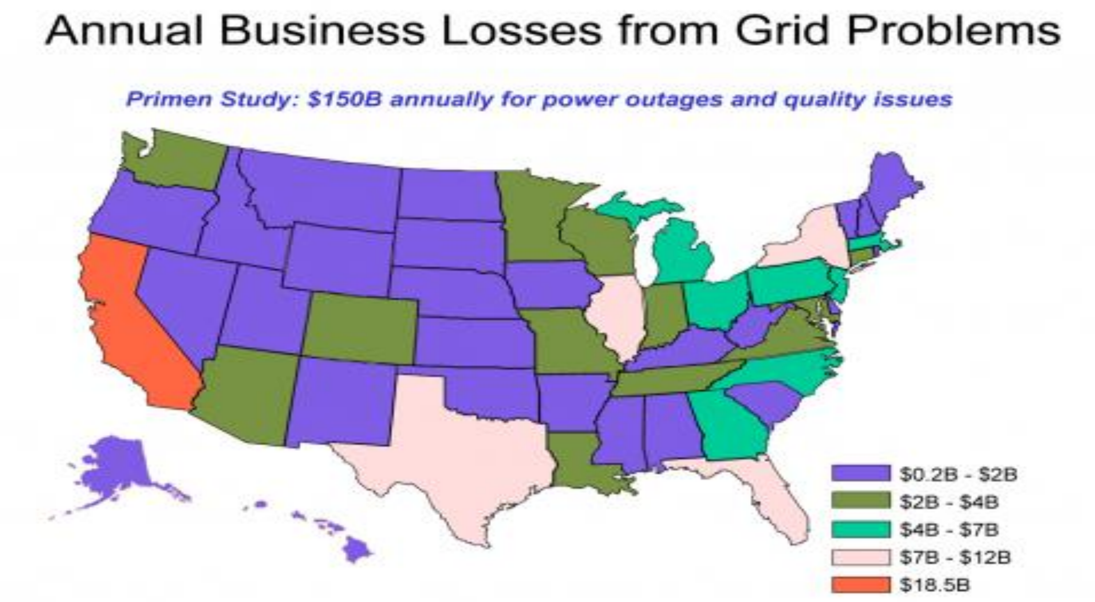


Figure 1.2: Figure of Annual Business Losses from Grid Problems in USA

1.2 Problem Statement

Due to increase in sensitive equipment, the impacts of overvoltage surges greatly increase. In order to maintain high reliability of the power system, overvoltage surges which may damage and cause malfunction of equipment need to be prevented or the equipment needs to be protected from these overvoltage surges. Therefore, this research will investigate and identify the types of overvoltage surges. After that, the causes and effects of those overvoltage surges will be investigated and identified. Then, methods of prevention on those overvoltage surges will be investigated and identified. Finally, in case methods of prevention are not feasible, protection methods against those overvoltage surges are also investigated and identified.

1.3 Aims and Objectives

The aims of undergoing this research are to investigate the overvoltage surges and determine its prevention and protection methods.

The objectives of carrying out this research are:

1) Investigate and identify the different types of overvoltage surges.
2) Investigate and determine the causes and effects of different types of overvoltage surges.
3) Research and identify the method of prevention against different types of overvoltage surges.
4) Research, identify and verify the method of protection against different types of overvoltage surges using simulation.

1.4 Structure of the Research Report

This research report consists of five main chapters:

1) Chapter 1 (Introduction). In this chapter, the brief background of the research, the problem statement as of why we need to carry out this research and the aims and objectives of this research are stated.
2) Chapter 2 (Literature review). In this chapter, different types of overvoltage surges are identified and discussed. Information about lightning impulse waveform and lightning protection standards are also investigated and

discussed. The methods of prevention and protection for different types of overvoltage are identified and discussed.

3) Chapter 3 (Methodology). In this chapter, the switching overvoltage surge and lightning overvoltage surge circuits and the protection circuits are modelled and simulated using MATLAB.
4) Chapter 4 (Results and Discussions). In this chapter, the graphical results of the protection circuits modelled and simulated are acquired and analyzed.
5) Chapter 5 (Conclusion and Recommendations). In this chapter, the conclusion is drawn by using the results obtained from the research. Some recommendations are also given.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the sources and types of overvoltage surges will be stated and explained. Information about lightning impulse waveform and lightning protection standards are also discussed. the methods of prevention and protection against different types of overvoltage surges are identified and discussed. In this research, higher priority is given to the overvoltage surges occur in high power system. According to statistic, the damage caused by lightning overvoltage surges are more severe as compared to switching overvoltage surges as the magnitude is much higher. Most of the equipment in high power system have certain voltage ride-through capability and most of the switching overvoltage surges lies in the margin. Therefore, higher priority is given to lightning overvoltage surges in this research.

This chapter will be talking about:

1) Sources and Types of Overvoltage Surges
    1.1) Capacitor Switching
        1.1.1) Isolated Capacitor Switching
        1.1.2) Back to Back Capacitor Switching
        1.1.3) Capacitor Switch Restrike
    1.2) Ferroresonance
    1.3) Lightning
        1.3.1) Lightning Impulse
        1.3.2) Lightning Protection Standard

2) Prevention of Overvoltage Surges
3) Protection of Switching Overvoltage Surges
4) Protection of Lightning Overvoltage Surges
    4.1) Surge Arrester
        4.1.1) Principal of Operation of Surge Arrester
        4.1.2) Surge Arrester Design
        4.1.3) Surge Arrester Characteristic
        4.1.4) Metal Oxide Varistor (MOV) Surge Arrester)

2.2 Sources and Types of Overvoltage Surges

Overvoltage surges on power system come from external and internal sources. The three major sources of overvoltage surges are capacitor switching, ferroresonance and lightning. (Pawar and Shembekar, 2013)

2.2.1 Capacitor Switching

Capacitor switching is an event that are very common in power systems. This is due to the mass usage of capacitor bank to provide reactive power for power factor correction. The drawback of using capacitor banks for power factor correction is the oscillatory transient produced during switching. There are few types of capacitor switching overvoltage surges. (Bacvarov, Lee and Jackson, 1984)

2.2.1.1 Isolated Capacitor Switching

Isolated capacitor switching is the switching on of an isolated single or three-phase capacitor bank. When multiple capacitor banks are located nearby, switching on only one of them while the others remain offline is also considered as isolated capacitor switching. The equivalent circuits of isolated capacitor switching are shown in the figure below. (Dugan et al.,2012)

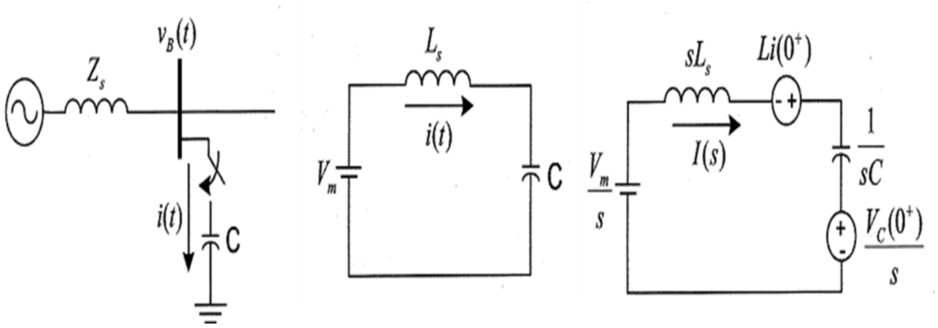


Figure 2.1: Figure of Equivalent Circuits of Isolated Capacitor Switching (Dugan et al.,2012)

The figure above shows the single line diagram of isolated capacitor switching, equivalent circuits of isolated capacitor switching in time-domain and s-domain. The isolated capacitor switching will cause the overvoltage surges on phase voltage and current. Figure 2.2 shows the overvoltage surges produced from isolated capacitor switching. (Dugan et al.,2012)

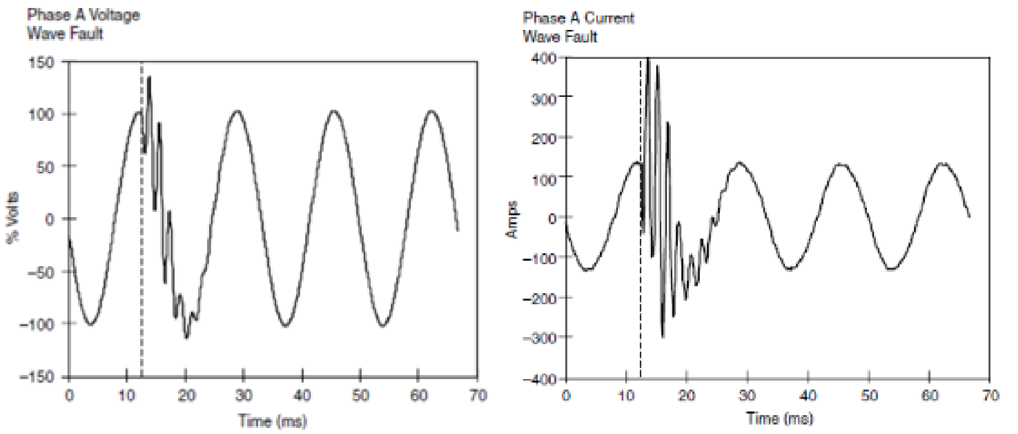


Figure 2.2: Figure of Overvoltage Surges due to Isolated Capacitor Switching (Dugan et al.,2012)

2.2.1.2 Back to Back Capacitor Switching

Back to back capacitor switching is the switching on of a capacitor bank when one or more nearby capacitor banks area in service. The equivalent circuits of back to back capacitor switching are shown in the figure below. (Dugan et al.,2012)

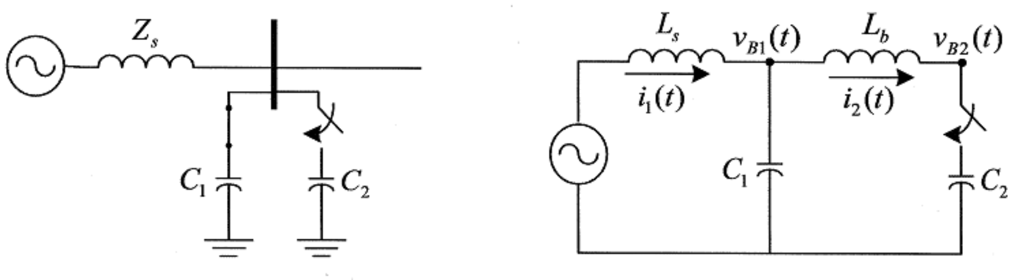


Figure 2.3: Figure of Equivalent Circuits of Back to Back Capacitor Switching (Dugan et al.,2012)

The size of capacitor bank that are already in service (C_1) and the size of capacitor bank (C_2) that switch on will affect the magnitude of overvoltage surges.

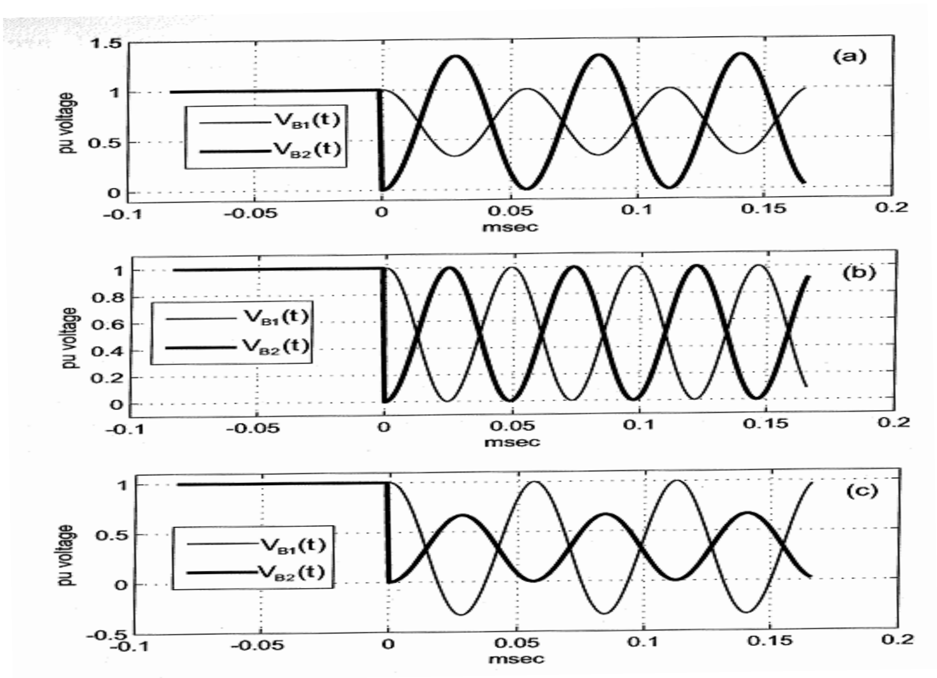


Figure 2.4: Figure of Overvoltage Surges due to Back to Back Capacitor Switching (Dugan et al.,2012)

Figure 2.4 shows the overvoltage surges produced from back to back capacitor switching with different sizes of capacitors. (Dugan et al.,2012) When $C_1 = 0.5C_2$, the overvoltage surges may reach a magnitude more than 1 pu. When $C_1 = C_2$, the overvoltage surges may reach magnitude of 1 pu. When $C_1 = 2C_2$, the overvoltage surges will reach magnitude less than 1 pu. The adding of power factor correction capacitor bank at the end-user location may produce the side effect of increasing the impact of utility capacitor switching overvoltage surges on end-user equipment. The capacitor on the high voltage system has much larger capacity than the capacitor at the low voltage bus. Therefore, when the utility capacitor is switched on, the overvoltage surges on the low voltage bus will be very high and potentially damaging the end-user equipment.

2.2.1.3 Capacitor Switch Restrike

De-energizing capacitor usually does not result in any overvoltage surges. However, if the contactor does not open successfully due to contamination or insulation failure during the de-energizing process, arc will be established between the contacts and the capacitor will be re-energized. This restrike process will cause overvoltage surges. Figure 2.5 shows the equivalent circuit of capacitor de-energizing. (Dugan et al.,2012) while overvoltage surges produced from capacitor switch restrike is shown in Figure 2.6. (Dugan et al.,2012)

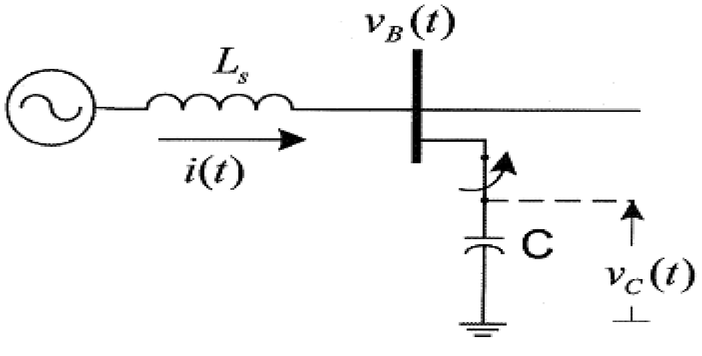


Figure 2.5: Figure of Equivalent Circuit of Capacitor De-energizing (Dugan et al.,2012)

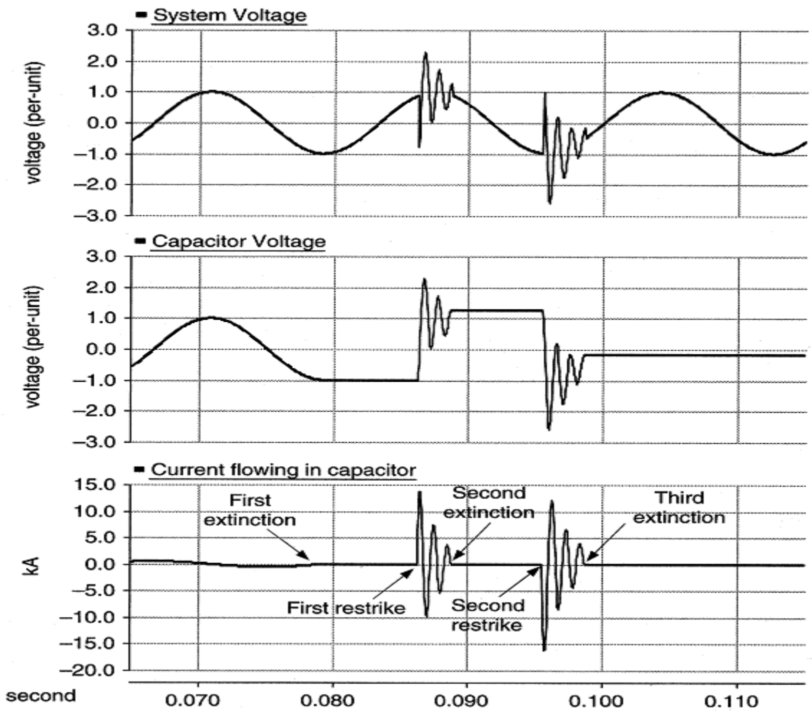


Figure 2.6: Figure of Overvoltage Surges due to Capacitor Switch Restrike (Dugan et al.,2012)

2.2.2 Ferroresonance

Ferroresonance is a kind of resonance that occurs between capacitance and inductance. It normally occurs when the magnetizing impedance of a working transformer is positioned in series with a capacitor bank. Figure 2.7 shows the common system conditions where ferroresonance occurs and Figure 2.8 shows stable and unstable ferroresonance overvoltage surges. (Dugan et al.,2012) The most common events that causes ferroresonance are:

1) Manual switching on or off an unloaded 3-phase transformer where only one of the phases is closed.
2) Manual switching on or off an unloaded 3-phase transformer where only one of the phases is open.
3) One of two riser-pole fuses malfunction causing 3-phase transformer with one or two of the phases open.

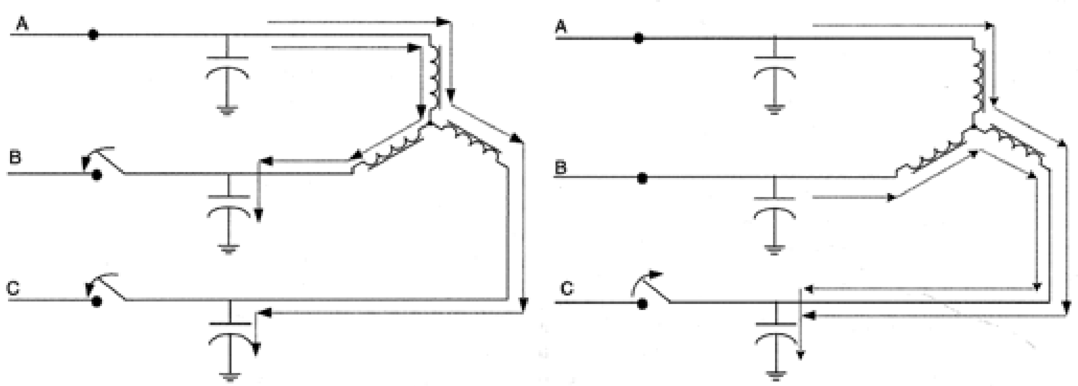


Figure 2.7: Figure of Common System Conditions where Ferroresonance Occurs (Dugan et al.,2012)

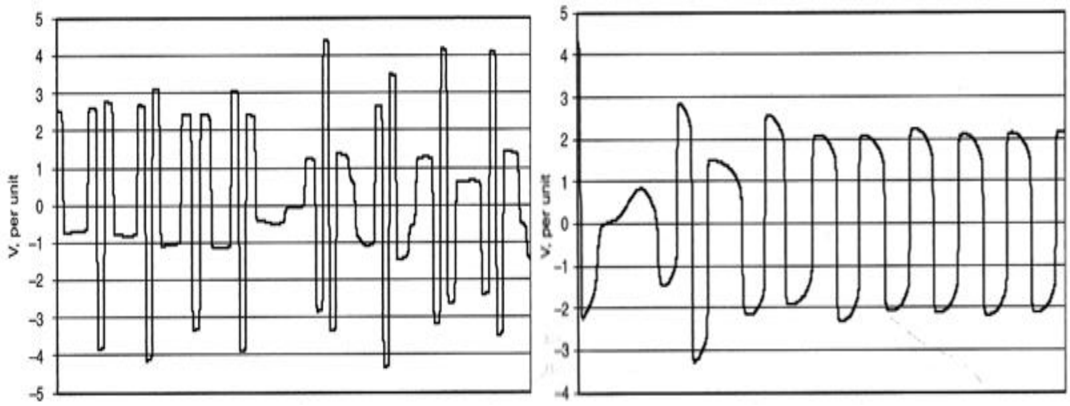


Figure 2.8: Figure of Stable and Unstable Ferroresonance Overvoltage Surges after Initial Transient (Dugan et al.,2012)

2.2.3 Lightning

Lightning is the most common source of overvoltage surges. There are two ways lightning can generate overvoltage surges which are direct strike and flashover. Direct strike is just as the name indicate which is the direct strike of lightning on the phase conductor which will generate very high overvoltage surges. As for flashover, it is the striking of the lightning near to the phase conductor which induce overvoltage surges on the phase conductor. (Golde, 1954)

2.2.3.1 Lightning Impulse

In a typical lightning impulse wave, there are two important parameters which are front time (t_f) and tail time (t_t). Front time is the time taken for the lightning impulse at 10% of its peak value to reach 90% of its peak value and tail time is the time taken for the lightning impulse to reach 50% of its peak value. A typical lightning impulse wave will front time (t_f) of 1.2µs and tail time (t_t) of 50µs. The figure below shows a typical lightning impulse waveform. (Agrawal and Nigam,2014)

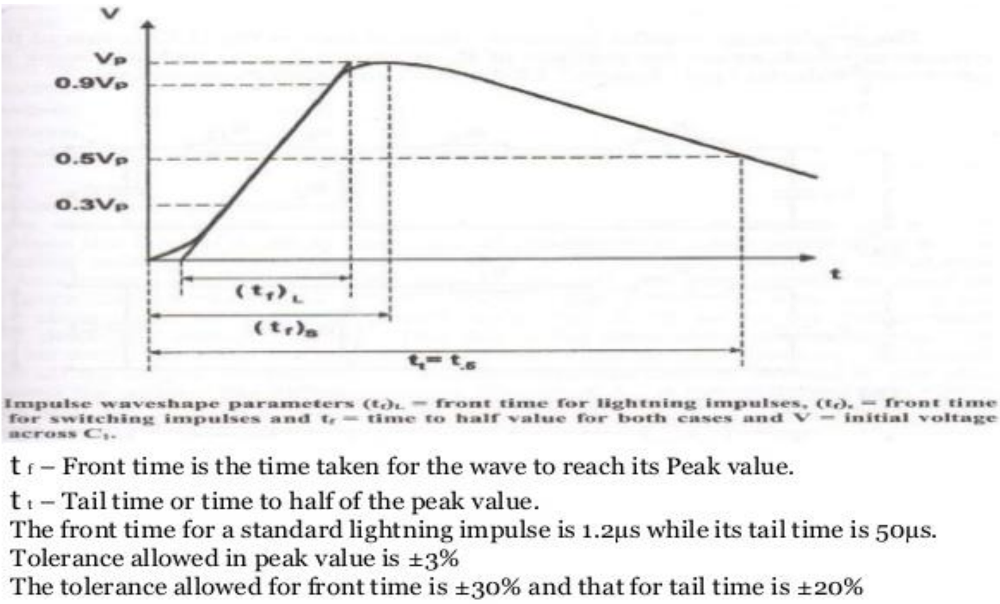


Figure 2.9: Figure of A Typical Lightning Impulse Waveform (Agrawal and Nigam, 2014)

2.2.3.2 Lightning Protection Standards

There are lightning protection standards that needed to be followed. The BS EN/IEC 62305 lightning protection standard is used by Tenaga Nasional Berhand (TNB) in Malaysia. There are four main sources of lightning which will produce three types of damage and causing four types of losses. A building can be divided into different Lightning Protection Zone (LPZ) as shown in Figure 2.10. The Lightning Protection Zone (LPZ) is divided according to the probability of lightning strikes. The

Lightning Protection Level (LPL) can be classified into 4 classes, each with their own maximum and minimum lightning current as shown in Table 2.1. Each of the Lightning Protection Level (LPL) need to be protected by their own level of Lightning Protection System (LPS) as shown in Table 2.2. The BS EN/IEC 62305 lightning protection standard is attached in the appendixes.

LPL	I	II	III	IV
Maximum current (kA)	200	150	100	100
Minimum current (kA)	3	5	10	16

Table 2.1: Table of Lightning Protection Level Characterization (BS EN/IEC 62305)

LPL	Class of LPS
I	I
II	II
III	III
IV	IV

Table 2.2: Table of Relation between Lightning Protection Level and Class of Lightning Protection System (BS EN/ IEC 62305)

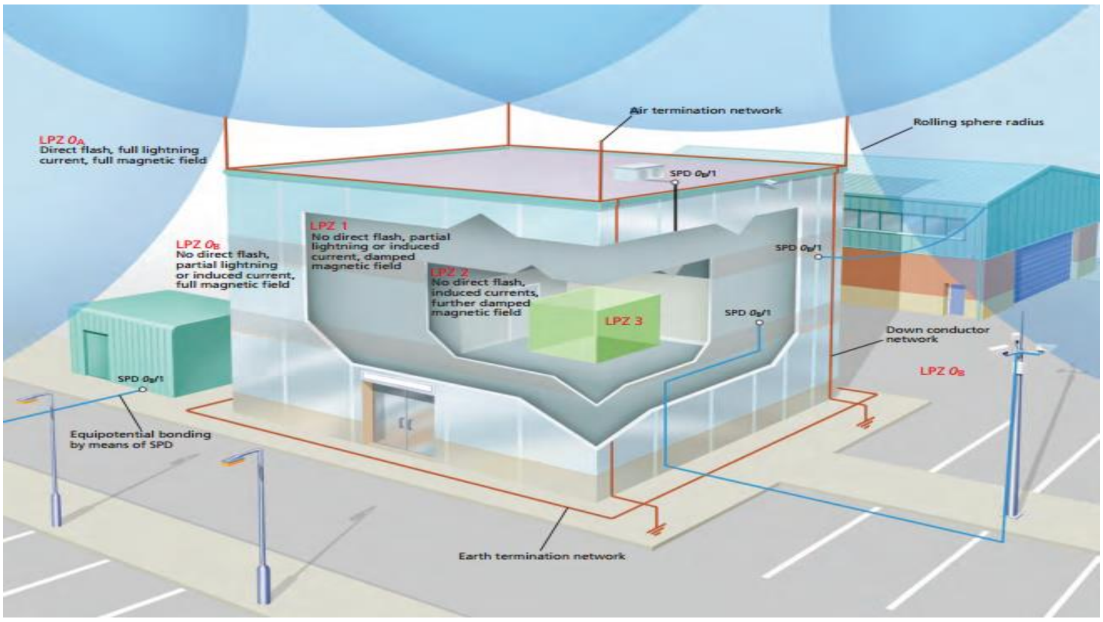


Figure 2.10: Figure of Lightning Protection Zone Characterization (BS EN/IEC 62305)

2.3 Prevention of Overvoltage Surges

For switching overvoltage surges, synchronous closing control can be used. (Alexander, 1985). The overvoltage surges can be prevented by switching the capacitor contact at the instant of system voltage matches the capacitor voltage which is normally during the change of positive to negative cycle of the phase voltage. It avoids the sudden change in voltage when capacitor banks are switched on. The timing required for synchronous closing control is determined by forecasting upcoming system voltage when it reaches zero. Due to the requirement of anticipating and forecasting, each of the switches requires microprocessor to process and provide the closing signal. Figure 2.11 shows the comparison of switching overvoltage surges with and without synchronous closing control. (Dugan et al.,2012)

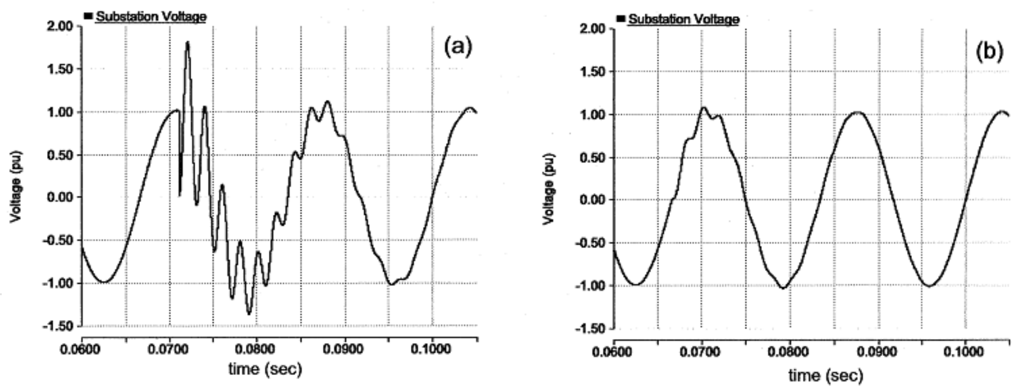


Figure 2.11: Figure of Comparison of Overvoltage Surges without Synchronous Closing Control (a) and with Synchronous Closing Control (b) (Dugan et al.,2012)

For the prevention method of capacitor switch restrike, regular checking and maintenance can be carried out to make sure the contact must not be contaminated and the insulation must not fail. Without the presences of insulation failure on the contact, capacitor switch restrike will not occur and the overvoltage surges will be prevented.

For lightning overvoltage surges, it is impossible to prevent lightning from happening since it is a natural phenomenon. Thus, the only way to prevent lightning overvoltage surges is to prevent the lightning inducing any overvoltage surges on the phase conductor. This can be achieved by using shield wire. The overhead transmission lines can be protected from lightning overvoltage surges by shield wire above the conductor lines. In order to limit the overvoltage developed on the shield wire due to lightning strikes, the tower footing resistance need to be less than 25Ω. (Mahmoudian and Niasati, 2016). The figure bellows shows placement of a shield wire on top of phase wire.

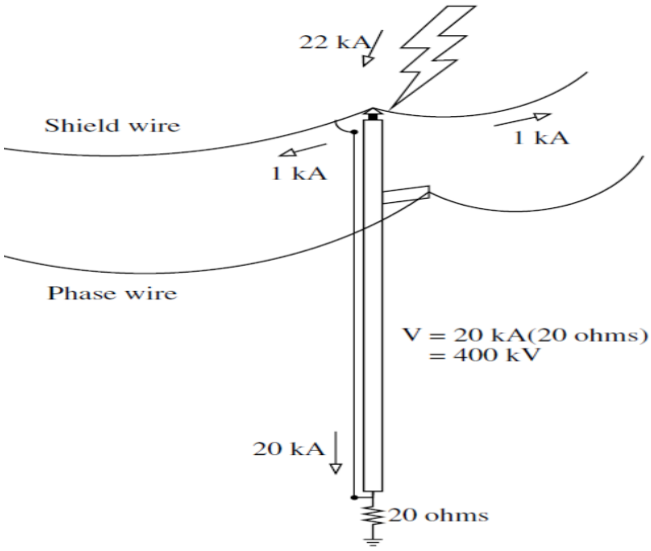


Figure 2.12: Figure of Shield Wire on top of Phase Wire (Mahmoudian and Niasati, 2016).

2.4 Protection of Switching Overvoltage Surges

To protect against switching overvoltage surges, synchronous closing breakers with pre-insertion resistors can be used. When the switch is closed, the switching overvoltage surges will occur. However, due to the presence of the resistors, the overvoltage surges will be damped to a negligible level. Significant power loss is the major disadvantages of using this method to protect against switching overvoltage surges.

Apart from that, the conversion of consumer's power factor correction capacitor banks into harmonic filters can also be used as protection against switching overvoltage surges. Inductor is added in series with the capacitor bank to create a harmonic filter. The adding of inductor in series with the capacitor bank will damp the overvoltage surges to acceptable levels. This is the more preferred method as it provides three positive improvements which are power factor correction, work as harmonic filter and the limiting of overvoltage surges.

2.5 Protection of Lightning Overvoltage Surges

Every equipment such as transformers and motors in high power system have a Basic Impulse Insulation Level (BIL). Basic Impulse Insulation Level (BIL) is a reference insulation level expressed as an impulse crest voltage with a standard wave not longer than 1.2μs - 50μs wave which is identical to the typical lightning impulse waveform as shown in Figure 2.13. (Sporn and Powel,1940) In short, any waveform below the Basic Impulse Insulation Level (BIL) will not damage the equipment while any waveform above the Basic Impulse Insulation Level (BIL) will damage the equipment. Therefore, voltage input to the equipment must be always lower than Basic Impulse Insulation Level (BIL) so that the equipment will be protected. Basic Impulse Insulation Level (BIL) is normally established at 25% - 30% above the protection level as shown in Figure 2.14 and Figure 2.15. (Sporn and Powel,1940)

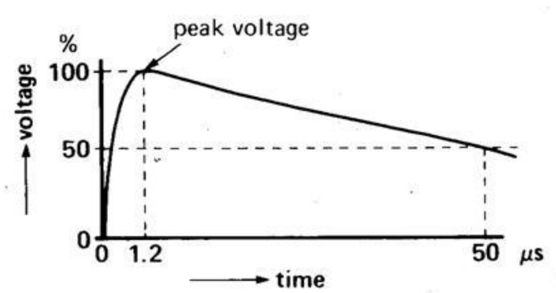


Figure 2.13: Figure of Basic Impulse Insulation Level (BIL) (Sporn and Powel, 1940)

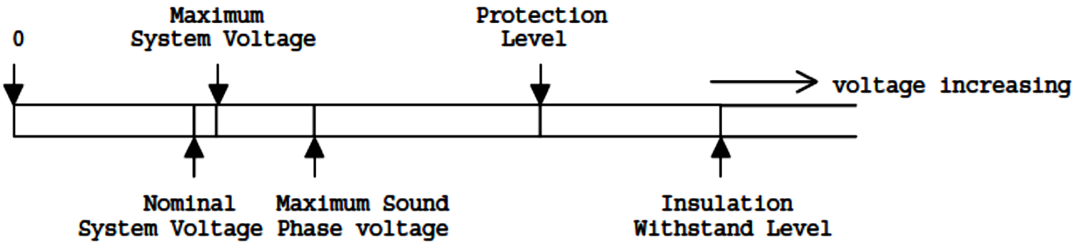


Figure 2.14: Figure of Protection Level 25% - 30% lower than Basic Impulse Insulation Level (BIL) (Sporn and Powel, 1940)

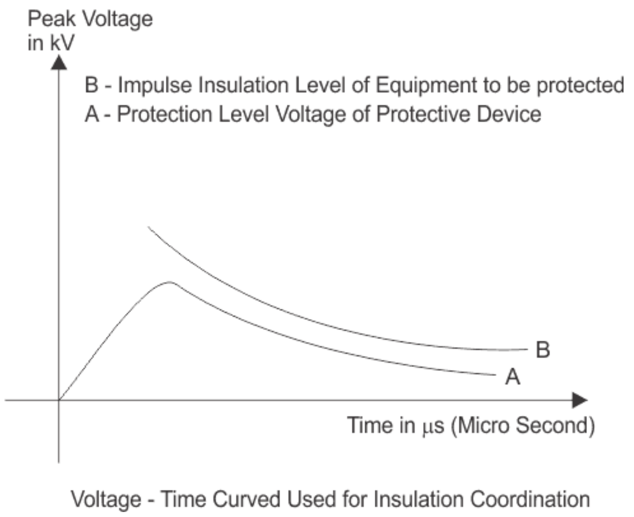


Figure 2.15: Figure of Relationship of Protection Level with Basic Impulse Insulation Level (BIL) (Sporn and Powel, 1940)

There are six principles of overvoltage protection (A. Rakov, 2012):

1) Limit the voltage
2) Divert the overvoltage surge away from the load
3) Block the overvoltage surge from entering the load
4) Equipotential bonding of ground
5) Reduce or prevent the surge current from flowing between grounds
6) Create a low-pass filter for limiting and blocking of overvoltage surge

2.5.1 Surge Arrester

Surge arrester is a protective device designed for limiting of overvoltage surges into the sensitive equipment in an electrical power system by diverting the surges current to the ground. It allows discharge of any dangerous overvoltage surges before it do any damage and restore the line to normal operation after the discharge. (Ehtishaan et al., n.d.) Surge Arrester is a type of surge protection device (SPD).

2.5.1.1 Principle of Operation of Surge Arrester

When an overvoltage surge occurs, it will travel along the phase conductor. When the overvoltage surge reaches the point at which a surge arrester (SPD) is installed, it will find a lower resistance path to the ground than that presented by the equipment or line. The overvoltage surge usually breaks down the insulation of the arrester momentarily allowing the overvoltage surges to travel to the ground and dissipate itself. The insulation of the surge arrester then recovers its properties and prevents further current from flowing to the ground.

A surge arrester (SPD) must not allow current to flow to ground as long as the system voltage remains normal. It provides a path to ground when the voltage rises over a predetermined value above normal, to dissipate the energy from the overvoltage surge without raising the voltage at which the system is operating. It stops the flow of surge current to ground as soon as the voltage drops below the predetermined value and restore the insulating qualities between the conductor and ground. Surge arrester will not be damaged by the discharge and are capable to repeat the discharge action every time when an overvoltage surge occurs.

2.5.1.2 Surge Arresters Design

An equivalent circuit of surge arrester will be non-linear resistors in series with spark gaps as shown in Figure 2.16. (Dugan et al.,2012) The spark gap inside the surge arrester acts as a switch while the non-linear resistors provide the low impedance to ground path. The overvoltage surge causes an arc to form across the air gap just like the switch is turned on. The surge current is then discharge to the ground through the arc and non-linear resistors. There are different types of surge arrester. All of them have resistive element and may or may not have spark gap. They differ only in mechanical construction and in the type of resistive element employed. Although there are different types of surge arresters such as silicon carbide (SiC) arresters with spark gaps, silicon carbine (SiC) arresters with current limiting gaps, gapless metal oxide (zinc oxide) varistor (MOV) arresters and hybrid of metal oxide varistor and silicon carbine (SiC), the surge arresters normally divided into two major types which are the surge arresters with spark gap and the metal oxide varistor (MOV) surge arrester without spark gap. Figure 2.17 shows the appearances of surge arrester and Figure 2.18 shows the internal construction of surge arrester.

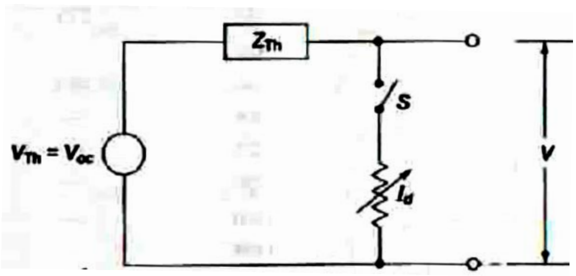


Figure 2.16: Figure of Equivalent Circuit for Surge Arrester (Dugan et al.,2012)

Figure 2.17: Figure of Appearances of Surge Arrester

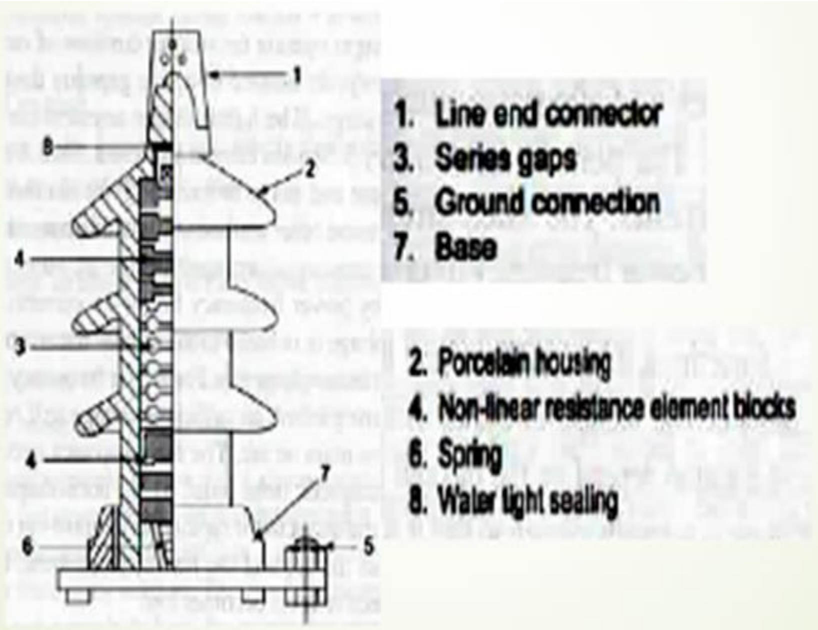


Figure 2.18: Figure of Internal Construction of Surge Arrester (Dugan et al.,2012)

2.5.1.3 Surge Arresters Characteristic

Surge arrester has a characteristic equation of

$$V = kI^d \tag{2.1}$$

Where

V = applied voltage across the element,

I = discharge current,

k, d = constant depending on the material and dimensions of element

When an overvoltage surge passes through the surge arrester, it breaks down and discharge the surge current and maintains a voltage across it. Therefore, it provides a protection to the equipment at a certain voltage protection level. Figure 2.19 shows the characteristic curves for surge arrester.

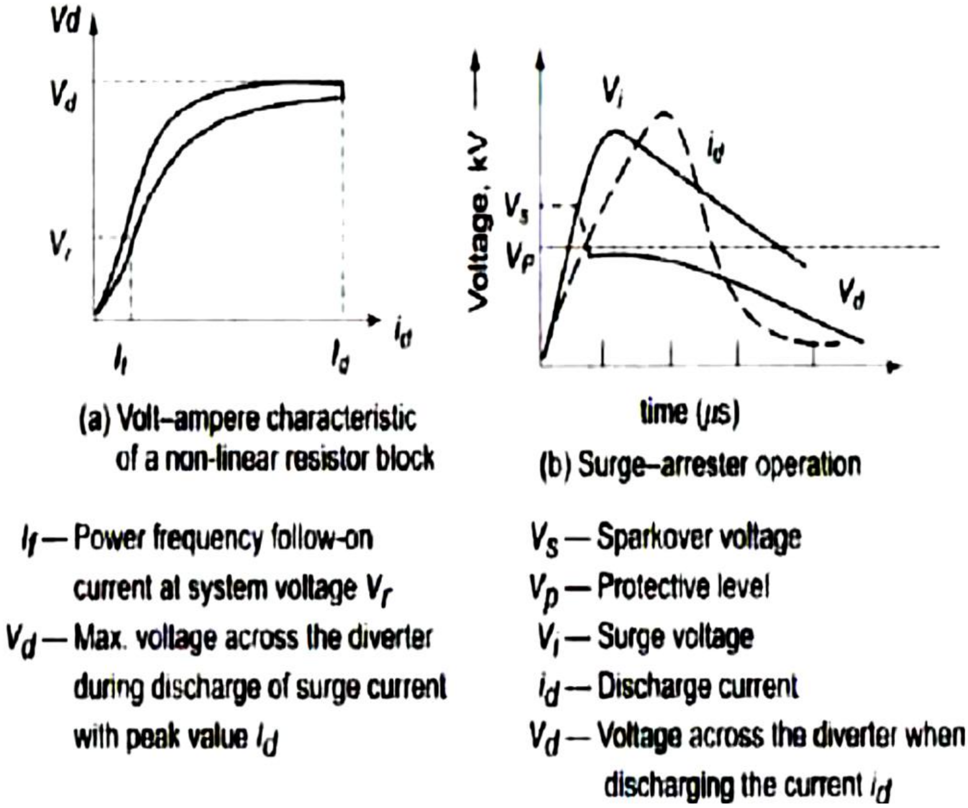


Figure 2.19: Figure of Surge Arrester Characteristic Curves (Dugan et al.,2012)

2.5.1.4 Metal Oxide Varistor (MOV) Surge Arrester

Metal oxide (zinc oxide) arrester consists of disks of zinc oxide material that produces characteristics of low resistance at high voltage and high resistance at low voltage. By selecting the appropriate configuration of disk material, the surge arrester will conduct a low current of a few milli-amperes during normal system voltage. During conditions of overvoltage surges, the surge current will be limited by the circuit. The disks are placed in porcelain enclosures which provide physical support and heat dissipation. It is also sealed for isolation to prevent any contamination from the environment. Figure 2.20 shows a metal oxide varistor (MOV) surge arrester while Figure 2.21 shows the characteristic curves of metal oxide varistor (MOV) surge arrester.

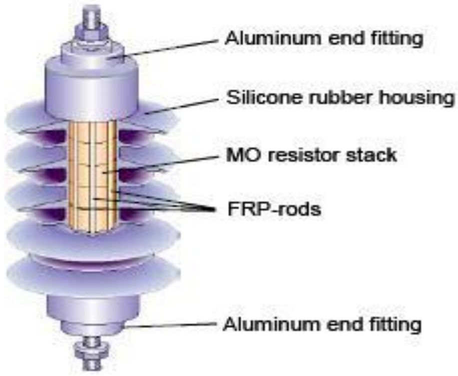


Figure 2.20: Figure of Metal Oxide Varistor (MOV) Surge Arrester

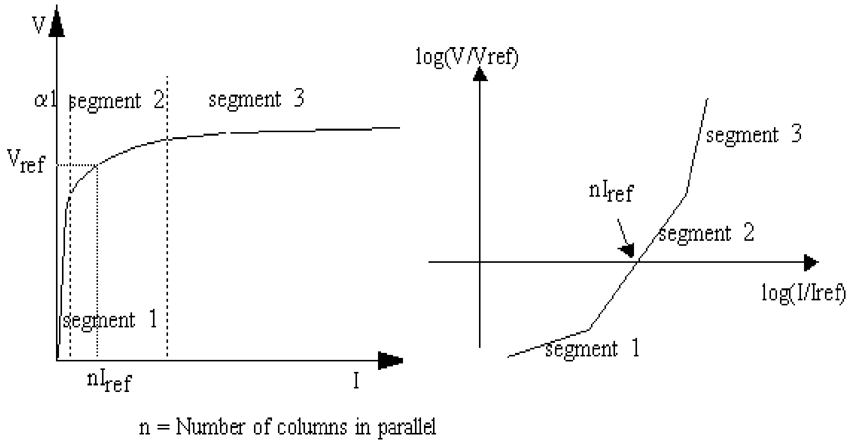


Figure 2.21: Figure of Characteristic Curves of Metal Oxide Varistor (MOV) Surge Arrester

Metal Oxide Varistor (MOV) surge arresters have several advantages. They are simple in construction, have flat V-I characteristic over a wide current range and they do not have spark gap. However, the continuous flow of power frequency current even during normal system voltage cause some power loss in the system. In high power system, Metal Oxide Varistor (MOV) surge arresters are much more preferable due to their absence of spark gap which produces steep voltage gradients when sparking occurs. In high power system, this steep voltage has very high magnitude and it may cause some damage to the equipment. Thus, it is not desired. Although there is continuous current flow which result in power loss, the current flow to the ground is just in milli-amperes which result in insignificant power loss in high power system.

2.6 Conclusion

In short, there are three major sources of overvoltage surges which are capacitor switching, ferroresonance and lightning. Although the most frequent overvoltage surges among those three will be capacitor switching overvoltage surges, the lightning overvoltage surges are more severe in high power system and thus, it will be the main focus of this research. The standards of lightning protection system are also identified. There are prevention methods against overvoltage surges such as synchronous closing control for capacitor switching overvoltage surges and shield wire for lightning overvoltage surges. As for protection method, power factor correction bank can be configured into low pass filter by connecting inductance in series to damp the switching overvoltage surges. Apart from that, surge arrester can be implemented to protect power system equipment against lightning overvoltage surges. The main focus of the research will be on surge arrester.

CHAPTER 3

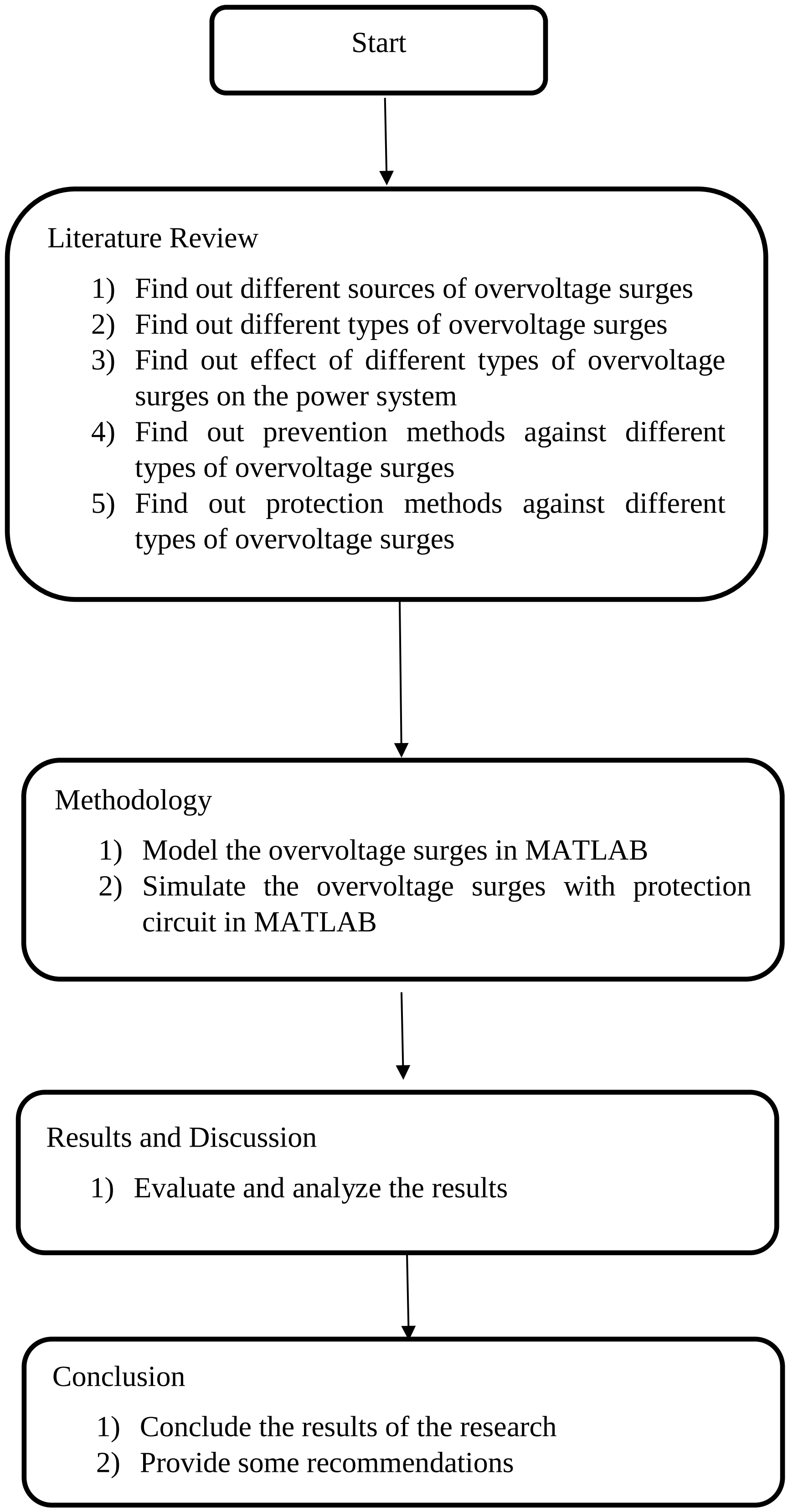
METHODOLOGY

3.1 Introduction

In this chapter, the protection method of overvoltage surges which is verified using simulation. First, circuit models switching overvoltage surge and lightning overvoltage surge is designed in MATLAB SIMULINK to generate the overvoltage surges. After that, the protection methods are implemented into the design of the models. This chapter covers:

1) Switching Overvoltage Surges Circuit
2) Switching Overvoltage Surges Protection by Adding Inductance in Series with Capacitor Bank
3) Lightning Overvoltage Surges Circuit
4) Lightning Overvoltage Surges Protection using Surge Arrester
5) Lightning Overvoltage Surges Protection using Equivalent Circuit of Surge Arrester (IGBT)
6) Lightning Overvoltage Surges Protection using Equivalent Circuit of Surge Arrester (Thyristor)

3.2 Project Pathway



3.3 Switching Overvoltage Surges Circuit

Switching overvoltage surges circuit is constructed by with a few simple components such as AC source, transformer and most importantly capacitor bank and its contactor. The components are used to represent a very simple power system which contains its own 3-phase power source, transformer, capacitor banks and the load. A simple circuit representing power factor correction capacitor bank in the power system is modelled. The voltage level is set to be 11kV and 400V to match actual power system's voltages. By switching on the capacitor bank through the contactor will produce switching overvoltage surges to the system. The switching overvoltage surges circuit modelled in MATLAB SIMULINK is shown in the figure below.

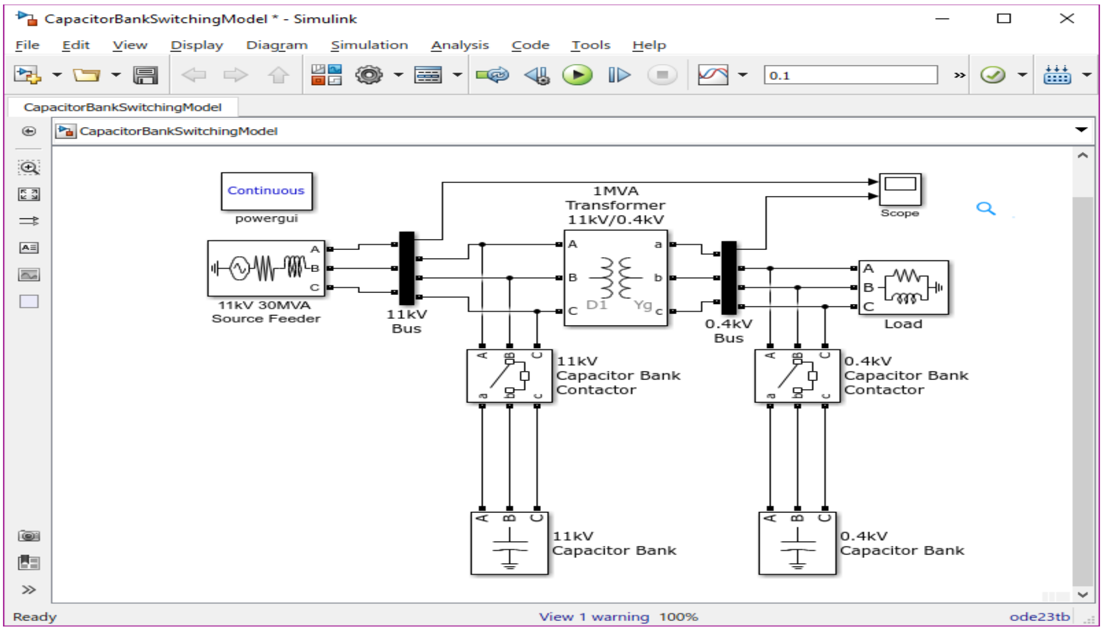


Figure 3.1: Figure of Switching Overvoltage Surges Circuit modelled in MATLAB SIMULINK

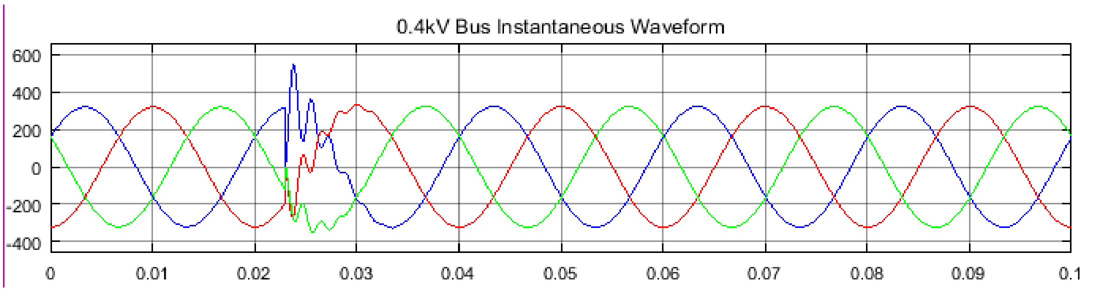


Figure 3.2: Figure of Switching Overvoltage Surges Simulated from Modelled Circuit

Figure 3.2 shows the overvoltage surges simulated from the modelled circuit. The 0.4kV capacitor bank is switched on at 0.023s. From the results simulated, it is shown that switching overvoltage surges occur at the instant the capacitor bank switched on. Thus, the switching overvoltage surges are successfully modelled.

3.4 Switching Overvoltage Surges Protection by Adding Inductance in Series with Capacitor Bank

In the previous literature review, switching overvoltage surges is said to be able to be protected by converting capacitor bank into harmonic filters. Therefore, an inductor is added in series with the capacitor bank at phase A. The modified circuit is shown in the figure below.

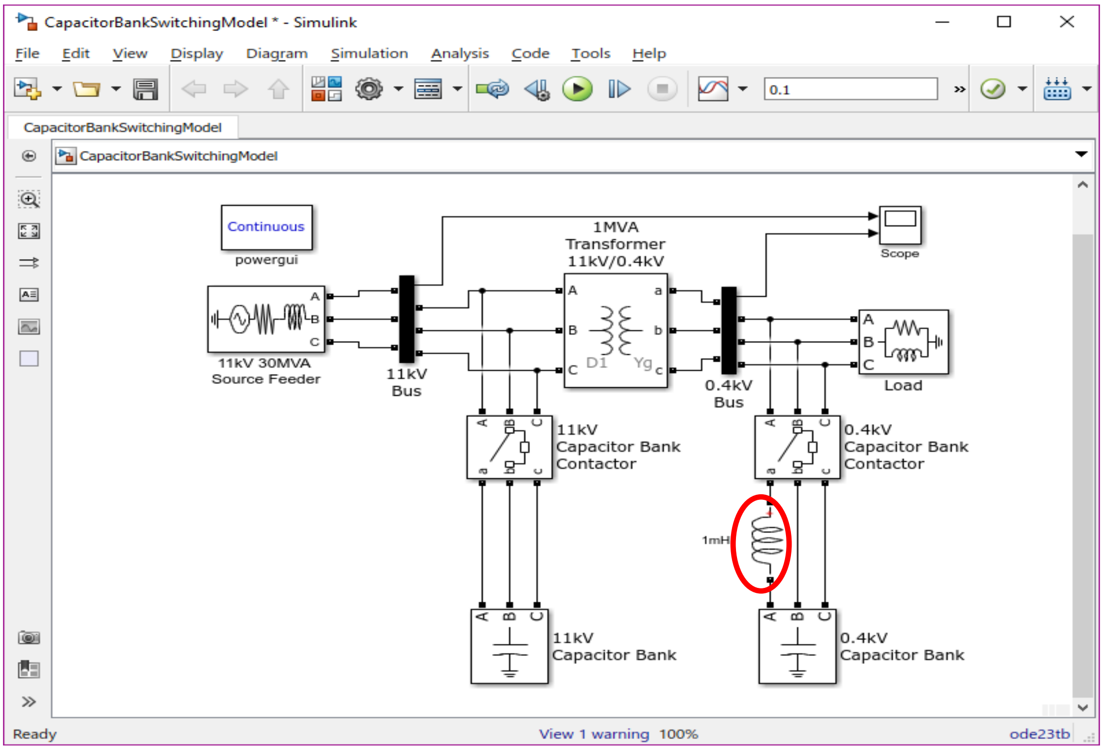


Figure 3.3: Figure of Simulation Model of Switching Overvoltage Surges Protection by Adding Inductance in Series with Capacitor Bank

3.5 Lightning Overvoltage Surges Circuit

Lightning overvoltage surges circuit can be constructed by using only a few simple components such as spark gaps, resistor and capacitor. By arranging the components in a certain manner and supply it with an input voltage source, lightning overvoltage surges can be generated. There are two circuits that are commonly used to generate the lightning overvoltage surges as shown in Figure 3.4 and Figure 3.5.

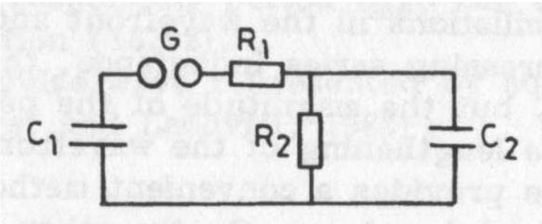


Figure 3.4: Lightning Overvoltage Surges Circuit (a)

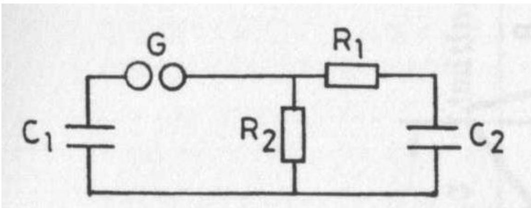


Figure 3.5: Lightning Overvoltage Surges Circuit (b)

In analysis of lightning overvoltage surges circuit (a), the current in generator circuit is I(t) at any time (t) after the gap sparks over.

By using Laplace transform, the impedance of circuit is

$$Z(s) = R_1 + \frac{1}{C_1 s} + \frac{R_2}{R_2 C_2 s + 1} = \frac{R_1 R_2 C_1 C_2 s^2 + (R_1 C_1 + R_2 C_2 + R_2 C_1)s + 1}{C_1 s(R_2 C_2 s + 1)} \quad (3.1)$$

Current is

$$I(s) = \frac{V_0}{sZ(s)} = \left(\frac{V_0}{s}\right)\left[\frac{C_1 s(R_2 C_2 s + 1)}{R_1 R_2 C_1 C_2 s^2 + (R_1 C_1 + R_2 C_2 + R_2 C_1)s + 1}\right] \quad (3.2)$$

Output voltage is

$$v(s) = I(s)\left[\frac{R_2}{sR_2C_2 + 1}\right] = \frac{V_0 R_2 C_1}{R_1R_2C_1C_2s^2 + (R_1C_1 + R_2C_2 + R_2C_1)s + 1} \qquad (3.3)$$

The output voltage can be further simplified into

$$v(s) = \left[\frac{V_0R_2C_1}{R_1R_2C_1C_2}\right]\left[\frac{1}{s^2 + as + b}\right] = \left[\frac{V_0}{R_1C_2}\right]\left(\frac{1}{(s+\alpha-\beta)(s+\alpha+\beta)}\right) \qquad (3.4)$$

where

$a = \dfrac{1}{R_2C_2} + \dfrac{1}{R_1C_1} + \dfrac{1}{R_1C_2}$,

$b = \dfrac{1}{\mathrm{R_1C_1R_2C_2}}$,

$\alpha = \left(\dfrac{a}{2}\right)$, and

$\beta = \sqrt{\left(\dfrac{a}{2}\right)^2 - b}$

By using inverse Laplace transform, the output voltage is

$$v(t) = \left(\frac{V_0}{2\beta R_1C_2}\right)\left[e^{-(\alpha-\beta)t} - e^{-(\alpha+\beta)t}\right] \qquad (3.5)$$

or

$$v(t) = \left[\frac{V_0}{2R_1C_2\beta}\right]\left\{e^{-\alpha_1 t_f} - e^{-\alpha_2 t_f}\right\} \qquad (3.6)$$

where

$\alpha_1 = \left(\dfrac{a}{2}\right) - \sqrt{\left(\dfrac{a}{2}\right)^2 - b} = \alpha - \beta$,

$\alpha_2 = \left(\dfrac{a}{2}\right) + \sqrt{\left(\dfrac{a}{2}\right)^2 - b} = \alpha + \beta$,

$T_f = \left(\frac{1}{2\beta}\right)\ln\left[\frac{\alpha+\beta}{\alpha-\beta}\right]$,

$T_t = KT_f$, and

$$K - 1 = \frac{0.7}{(\alpha-\beta)T_f}$$

Similar analysis is carried out for lightning overvoltage surges circuit (b).

The output voltage is

$$v(t) = \left(\frac{V_0}{2\beta R_1 C_2}\right)\left[e^{-(\alpha-\beta)t} - e^{-(\alpha+\beta)t}\right] \qquad (3.7)$$

or

$$v(t) = \left[\frac{V_0}{2R_1 C_2 \beta}\right]\left\{e^{-\alpha_1 t_f} - e^{-\alpha_2 t_f}\right\} \qquad (3.8)$$

where

$$a = \frac{1}{R_1C_1} + \frac{1}{R_2C_1} + \frac{1}{R_1C_2},$$

$$b = \frac{1}{R_1C_1R_2C_2},$$

$$\alpha = \left(\frac{a}{2}\right),$$

$$\beta = \sqrt{\left(\frac{a}{2}\right)^2 - b},$$

$$\alpha_1 = \left(\frac{a}{2}\right) - \sqrt{\left(\frac{a}{2}\right)^2 - b} = \alpha - \beta,$$

$$\alpha_2 = \left(\frac{a}{2}\right) + \sqrt{\left(\frac{a}{2}\right)^2 - b} = \alpha + \beta,$$

$T_f = \left(\frac{1}{2\beta}\right)\ln\left[\frac{\alpha+\beta}{\alpha-\beta}\right]$,

$T_t = KT_f$, and

$$K - 1 = \frac{0.7}{(\alpha-\beta)T_f}$$

In lightning overvoltage surges circuit (a), the R_2 is on the load side of R_1 and this forms a potential divider which reduce the output voltage. On the other hand, in lightning overvoltage surges circuit (b), the R_2 is on the generator side of R_1. Therefore, the reduction of output voltage is absent. Due to the absent in loss of output voltage, lightning overvoltage surges circuit (b) is chosen to be modelled in MATLAB SIMULINK. A typical lightning overvoltage surges have a front time, t_f of 1.2μs and a tail time, t_t of 50μs. In order to model the lightning overvoltage surge, the input voltage source is assumed to be 400kV, C_1 = 0.125μF and C_2 = 1nF. The resistance R_1 and R_2 are calculated by using the formulas from the circuit analysis. The calculation of resistance R_1 and R_2 is shown below:

$$\therefore K - 1 = \frac{0.7}{(\alpha - \beta)T_f}$$

$$\frac{T_t}{T_f} - 1 = \frac{0.7}{(\alpha - \beta)T_f}$$

$$\frac{50\mu}{1.2\mu} - 1 = \frac{0.7}{(\alpha - \beta)1.2\mu}$$

$$\therefore (\alpha - \beta) = 14344.2623$$

$$\because R_2 = \frac{1}{C_1(\alpha - \beta)}$$

$$R_2 = \frac{1}{0.125\mu(14344.2623)}$$

$$\therefore R_2 = 557.714\ G\Omega$$

$$\therefore T_f = \left(\frac{1}{2\beta}\right)\ln[\frac{\alpha + \beta}{\alpha - \beta}]$$

$$1.2u = \left(\frac{1}{2\beta}\right)\ln\left[\frac{2\beta + 14344.2623}{14344.2623}\right]$$

$$\beta = 2428185.929$$

$$(\alpha + \beta) = 2\beta + 14344.2623$$

$$(\alpha + \beta) = 2(2428185.929) + 14344.2623$$

$$(\alpha + \beta) = 4870716.12$$

$$R_1 = \frac{1}{C_1(\alpha + \beta)} + \frac{1}{C_2(\alpha + \beta)}$$

$$R_1 = \frac{1}{0.125u(4870716.12)} + \frac{1}{1n(4870716.12)}$$

$$R_1 = 206.951\Omega$$

The lightning overvoltage surges circuit is modelled based on the information obtained. The figure below shows the lightning overvoltage surge circuit modelled.

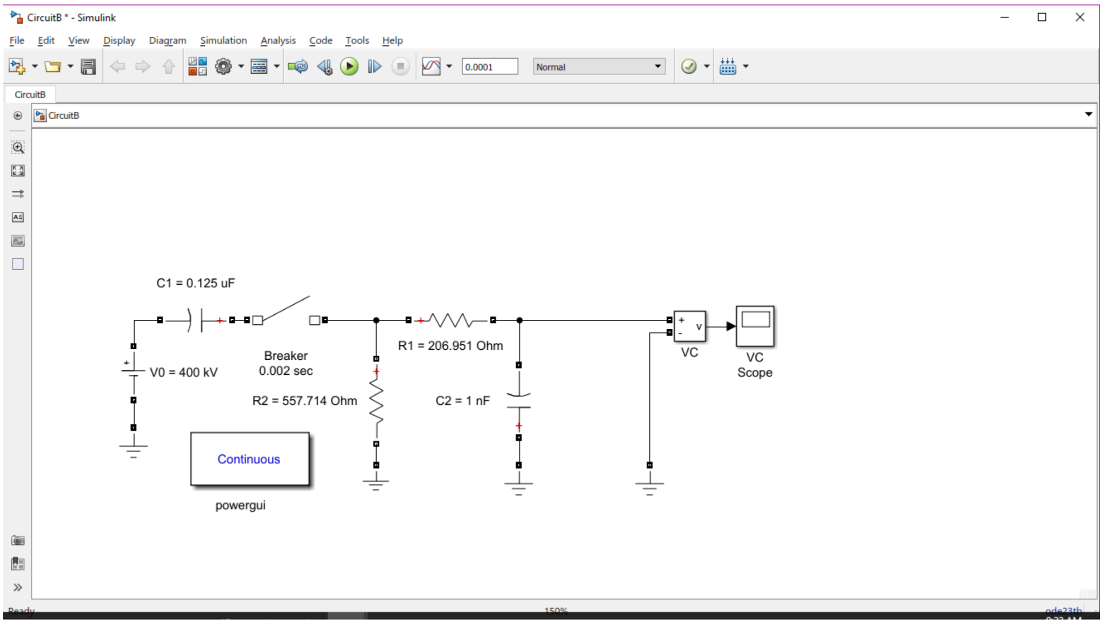


Figure 3.6: Figure of Lightning Overvoltage Surges Circuit Modelled in MATLAB SIMULINK

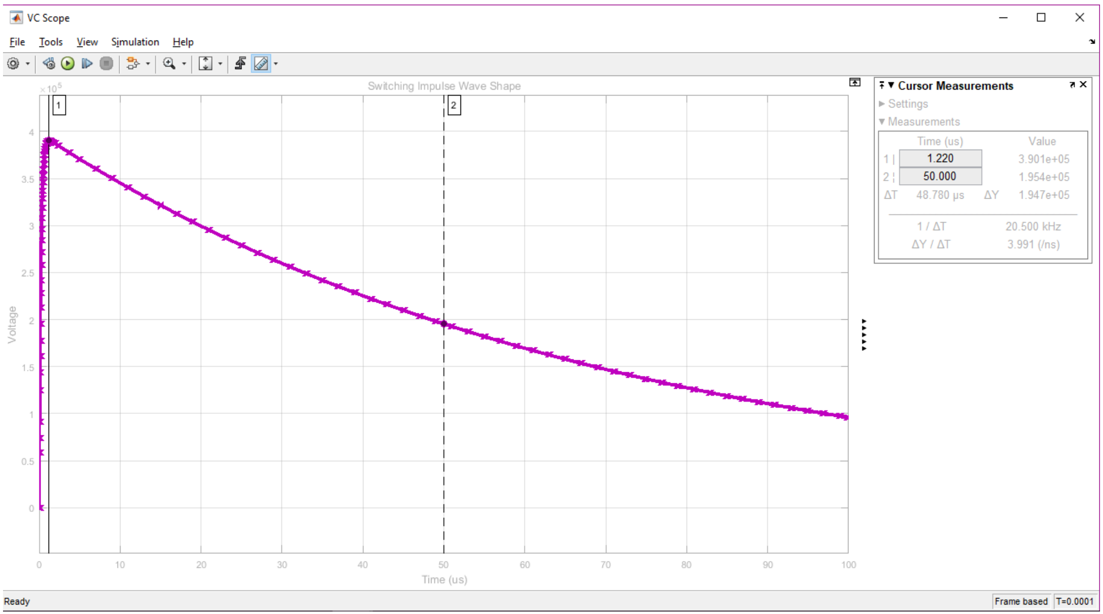


Figure 3.7: Figure of Lightning Overvoltage Surges Simulated from Modelled Circuit

From Figure 3.7, the waveform of lightning overvoltage surges simulated from modelled circuit is identical to the typical lightning overvoltage surges which have front time, t_f of 1.2μs and tail time, t_t of 50μs. Different magnitude of the lightning overvoltage surges can be obtained by changing the magnitude of the input voltage source. Different front time, t_f and tail time, t_t can also be obtained by changing the resistance R_1 and R_2 and capacitance C_1 and C_2.

3.6 Lightning Overvoltage Surges Protection using Surge Arrester

In the previous literature review, lightning overvoltage surges is said to be able to be protected by using surge arrester (SPD). Therefore, the surge arrester is connected at the output of lightning overvoltage surges circuit to verify its protection against lightning overvoltage surges. The simulation circuit is shown in the figure below.

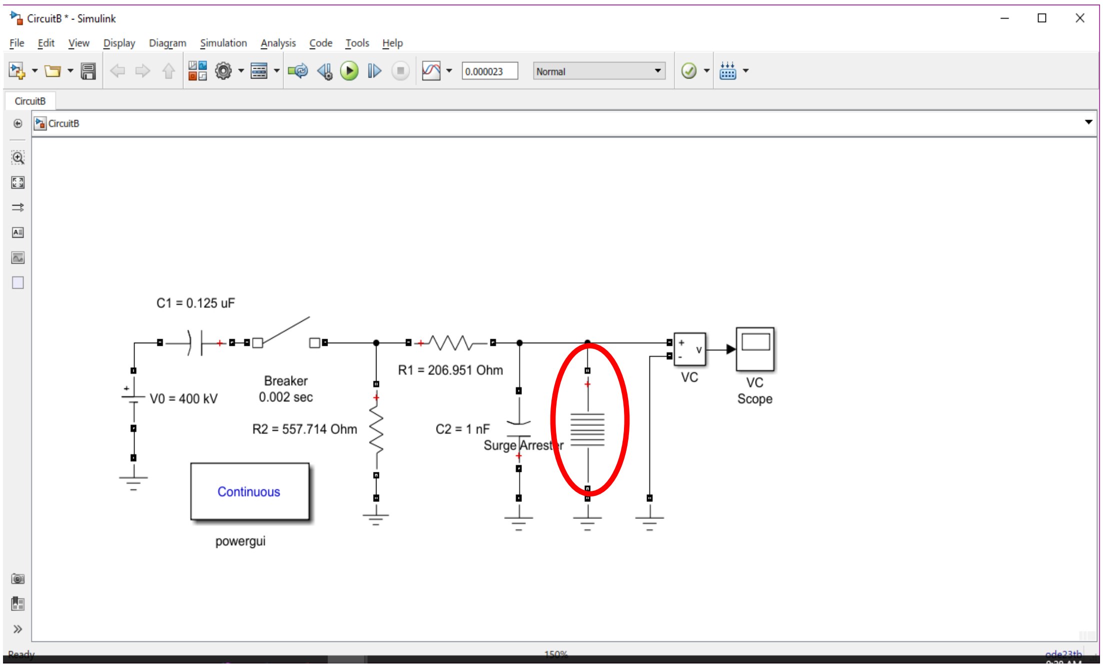


Figure 3.8: Figure of Simulation Model for Lighting Overvoltage Surges Protection using Surge Arrester

3.7 Lightning Overvoltage Surges Protection Modelled using Equivalent Circuit of Surge Arrester (IGBT)

Equivalent circuit of surge arrester is modelled together with lightning overvoltage surges circuit to investigate the effectiveness. An equivalent circuit of surge arrester is just a switch connected in series with non-linear resistance. In this model, Insulated-Gate Bipolar Transistor (IGBT) is used as the switch connected in series with non-linear resistance. The simulation circuit is shown in the figure below.

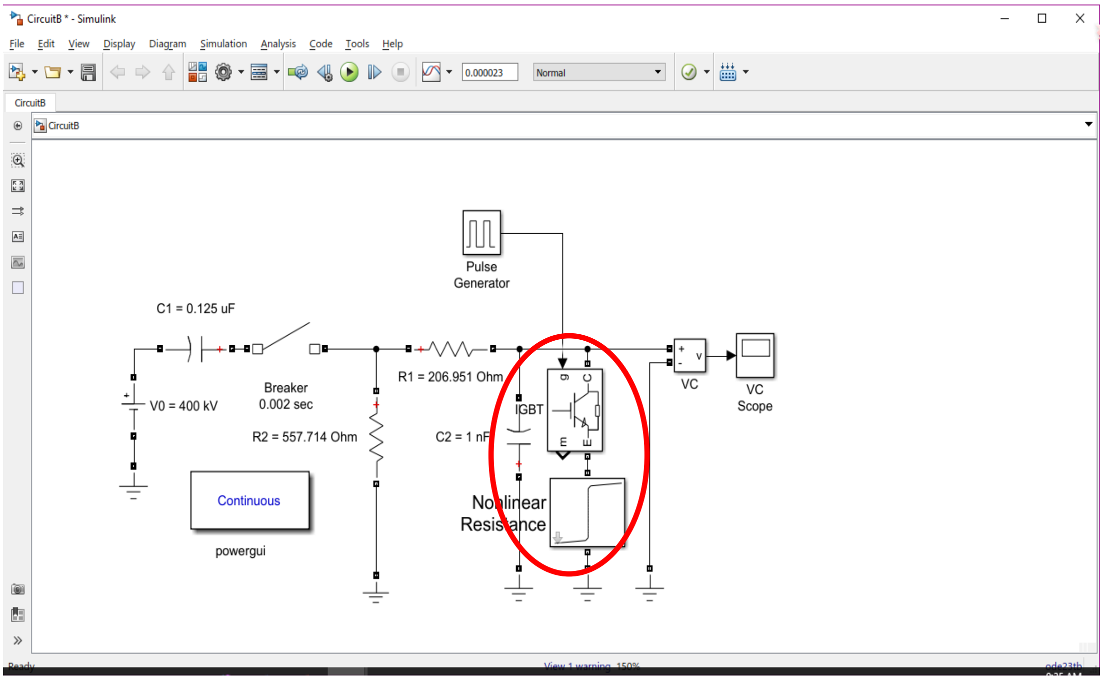


Figure 3.9: Figure of Simulation Model for Lighting Overvoltage Surges Protection using Equivalent Circuit of Surge Arrester (IGBT)

3.8 Lightning Overvoltage Surges Protection Modelled using Equivalent Circuit of Surge Arrester (Thyristor)

Equivalent circuit of surge arrester is modelled together with lightning overvoltage surges circuit to investigate the effectiveness. An equivalent circuit of surge arrester is just a switch connected in series with non-linear resistance. In this model, thyristor is used as the switch connected in series with non-linear resistance. The simulation circuit is shown in the figure below.

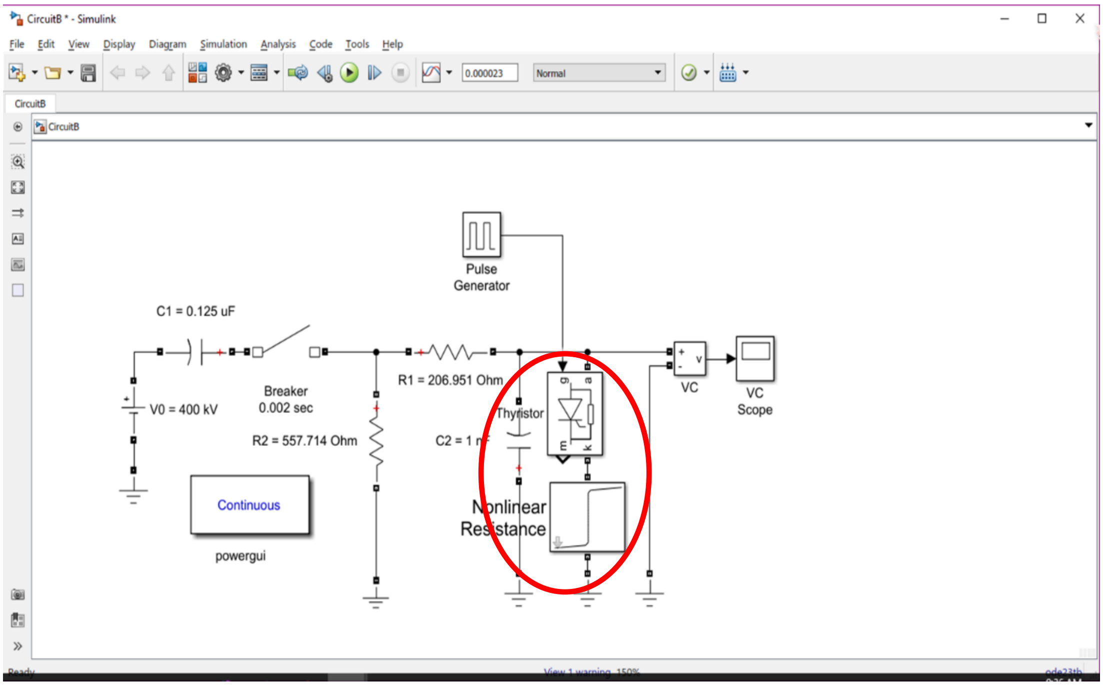


Figure 3.10: Figure of Simulation Model for Lighting Overvoltage Surges Protection using Equivalent Circuit of Surge Arrester (Thyristor)

3.9 Conclusion

As a conclusion, the switching overvoltage surge and lightning overvoltage surge circuit are modelled and the overvoltage surges are simulated. Both the switching overvoltage surge and lightning overvoltage surge simulated followed the typical pattern of the overvoltage surges. The protection methods for the overvoltage surges are implemented into the models for further simulation, verification and analysis.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the protection methods of overvoltage surges implemented into the models designed in MATLAB SIMULINK are simulated and the effectiveness are verified. The graphical results obtained from the simulation is analysed and conclusion is drawn from the analysis. This chapter covers:

1) Results and Analysis of Switching Overvoltage Surges Protection by Adding Inductance in Series with Capacitor Bank
2) Results and Analysis of Lightning Overvoltage Surges Protection using Surge Arrester
3) Results and Analysis of Lightning Overvoltage Surges Protection using Equivalent Circuit of Surge Arrester (IGBT)
4) Results and Analysis of Lightning Overvoltage Surges Protection using Equivalent Circuit of Surge Arrester (Thyristor)

4.2 Results and Analysis of Switching Overvoltage Surges Protection by Adding Inductance in Series with Capacitor Bank

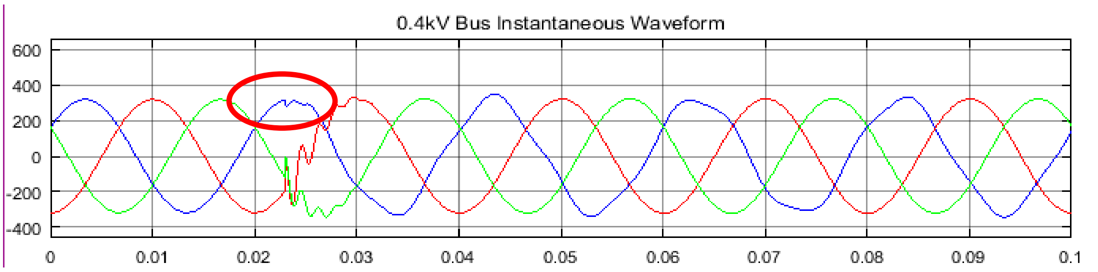


Figure 4.1: Figure of Voltage Waveform After Adding Inductance in Series with Capacitor Bank

Figure 4.1 shows the voltage waveform after converting the 0.4kV capacitor bank into harmonic filter in phase A. As the inductor is added in series with the capacitor bank in phase A, the phase A waveform is observed. From the simulated results, it is clear that the magnitude of switching overvoltage surges dramatically reduced after the addition of inductance in series with capacitor bank. Therefore, this protection method by converting power factor correction capacitor bank into harmonic filter is verified.

4.3 Results and Analysis of Lightning Overvoltage Surges Protection using Surge Arrester

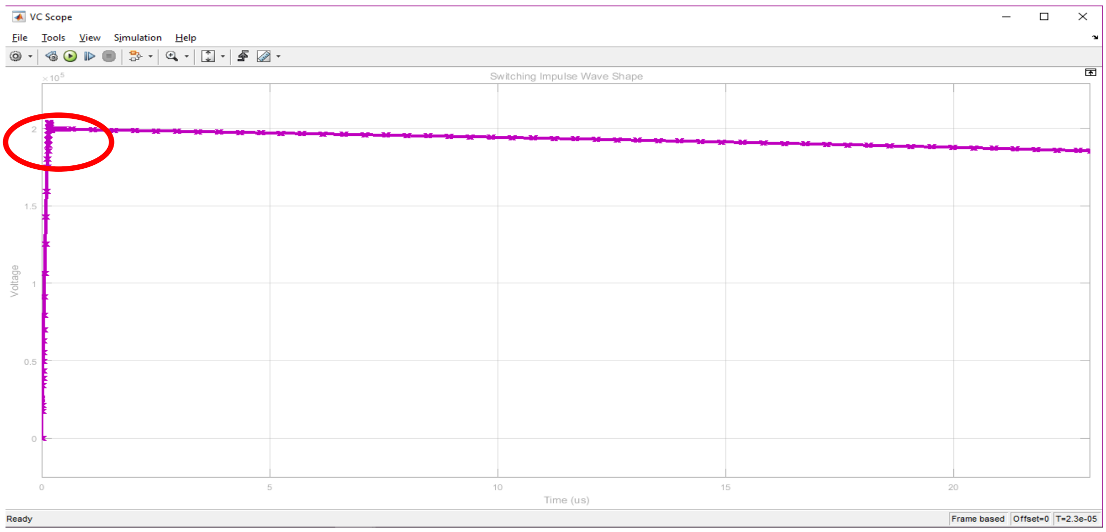


Figure 4.2: Figure of Output Voltage Waveform after Protection by Surge Arrester

Figure 4.2 shows the output voltage waveform after the protection by surge arrester. The voltage protection level of the surge arrester is chosen to be 200kV. The input lightning overvoltage surges has a peak magnitude of 390kV. From the above figure, it is clearly shown that the surge arrester function as soon as the voltage exceeds 200kV and limit the output voltage. Once the voltage exceeds the voltage protection level, the surge arrester function and the extra surge current is diverted to the ground. As soon as the voltage drops back to below the voltage protection level, the surge arrester will stop functioning. Throughout the whole process, the system reliability is not affected while the power system equipment is protected from the lightning overvoltage surges. Thus, the protection method against lightning overvoltage surges using surge arrester is verified. The type of surge arrester used is MOV arrester without spark gaps therefore the surge arrester is always on and there is always leakage current to the ground which leads to power loss.

4.4 Results and Analysis of Lightning Overvoltage Surges Protection Modelled using Equivalent Circuit of Surge Arrester (IGBT)

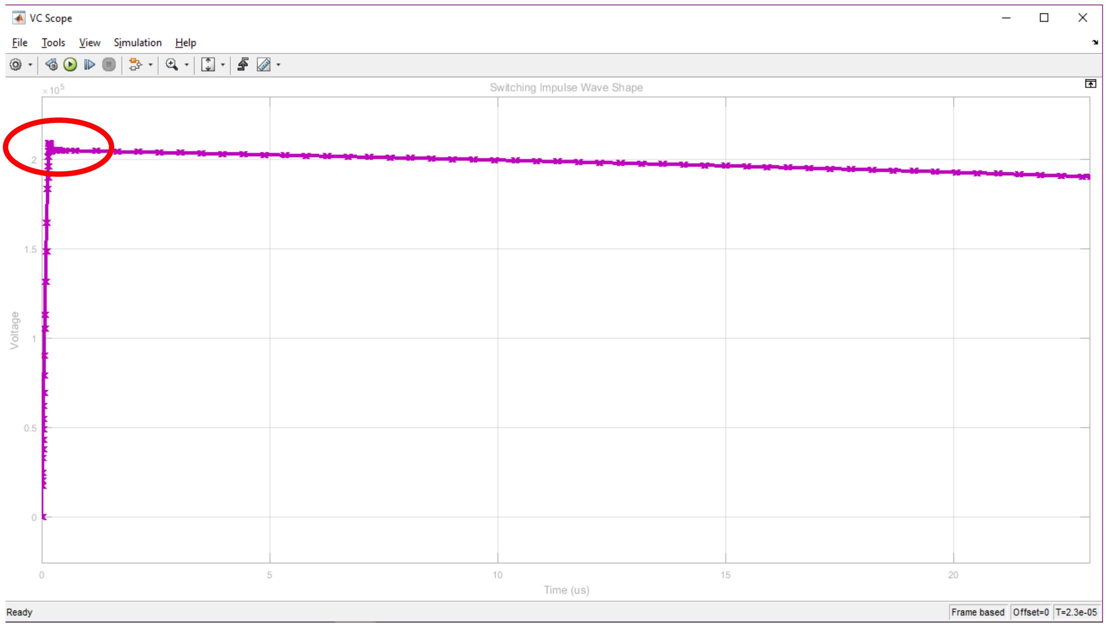


Figure 4.3: Figure of Output Voltage Waveform after Protection by Equivalent Circuit of Surge Arrester (IGBT)

Figure 4.3 shows the output voltage waveform after protection by equivalate circuit of surge arrester (IGBT). The voltage protection level of the surge arrester is chosen to be 200kV. The input lightning overvoltage surges has a peak magnitude of 390kV. From the above figure, it is clearly shown that the equivalent circuit of surge arrester function as soon as the voltage exceeds 200kV and limit the output voltage. Once the voltage exceeds the voltage protection level, a triggering signal is sent to the IGBT and it switched on. Once the IGBT is switched on, the extra surge current is diverted to the ground through the non-linear resistance. As soon as the voltage drops back to below the voltage protection level, the triggering signal disappear and the IGBT switched off. Throughout the whole process, the system reliability is not affected while the power system equipment is protected from the lightning overvoltage surges. Thus, the protection method against lightning overvoltage surges using equivalent circuit of surge arrester (IGBT) is verified. However, the peak voltage experienced by the load is slightly higher than protective level because of delay due to switching time of IGBT. This circuit does not have leakage current to the ground as the arrester only function when there are overvoltage surges higher than protection level. This circuit requires a microprocessor to process and provide the triggering signal. Therefore, the system voltage needed to be monitored and feed into the microprocessor. The method is very feasible in instrumentation level but not in high power system as the system voltage needed to be step down by another transformer which requires its own surge protection before feeding into the microprocessor.

4.5 Results and Analysis of Lightning Overvoltage Surges Protection Modelled using Equivalent Circuit of Surge Arrester (Thyristor)

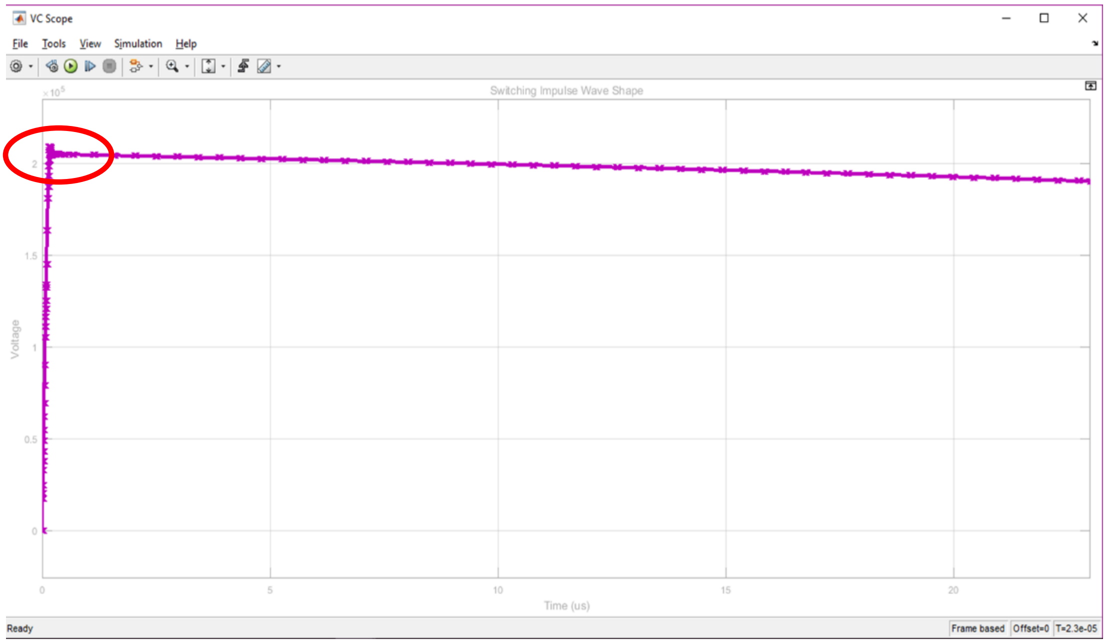


Figure 4.4: Figure of Output Voltage Waveform after Protection by Equivalent Circuit of Surge Arrester (Thyristor)

Figure 4.4 shows the output voltage waveform after protection by equivalent circuit of surge arrester (thyristor). The voltage protection level of the surge arrester is chosen to be 200kV. The input lightning overvoltage surges has a peak magnitude of 390kV. From the above figure, it is clearly shown that the equivalent circuit of surge arrester function as soon as the voltage exceeds 200kV and limit the output voltage. Once the voltage exceeds the voltage protection level, a triggering signal is sent to the thyristor and it switched on. Once the thyristor is switched on, the extra surge current is diverted to the ground through the non-linear resistance. As soon as the voltage drops back to below the voltage protection level, the triggering signal disappear and the thyristor switched off. Throughout the whole process, the system reliability is not affected while the power system equipment is protected from the lightning overvoltage surges. Thus, the protection method against lightning overvoltage surges using equivalent circuit of surge arrester (thyristor) is verified. However, the peak voltage experienced by the load is slightly higher than protective level because of delay due to switching time of thyristor. This circuit does not have leakage current to the ground as the arrester only function when there are overvoltage surges higher than protection level. This circuit requires a microprocessor to process and provide the triggering signal. Therefore, the system voltage needed to be monitored and feed into the microprocessor. The method is very feasible in instrumentation level but not in high power system as the system voltage needed to be step down by another transformer which requires its own surge protection before feeding into the microprocessor.

4.6 Conclusion

From the simulation results, it is verified that converting power factor correction capacitor bank into harmonic filter helps to protect against switching overvoltage surges. Apart from that, surge arrester is also verified to be able to protect against lightning overvoltage surges. The equivalent circuit of the surge arrester is also verified. Although the equivalent circuits are verified, they are not practical. This is due to both Insulated-Gate Bipolar Transistor (IGBT) and thyristor both requires the triggering signal to function as a switch. Most of the triggering signal are obtain from microprocessor control. Microprocessor cannot handle such a high magnitude of current input from the lightning overvoltage surges. Therefore, transformer is needed to step down the current input before feeding into microprocessor. However, this conflicts with the principle of protection as the overvoltage surges protection devices need to be located before the transformer or any other sensitive equipment to prevent any damage in case of overvoltage surges. Thus, the equivalent circuits are not implemented in practical. The summary of the results and its analysis on the protection methods in shown in the table below.

Table 4.1: Summary of Results and Analysis on the Protection Methods

Protection Method	Results and Analysis
Switching Overvoltage Surges Protection by Adding Inductance in Series with Capacitor Bank	Magnitude of switching overvoltage surges dramatically damped into an acceptable level. Thus, load is protected from overvoltage surges.
Lightning Overvoltage Surges Protection using Surge Arrester	Any lightning overvoltage surges with magnitude higher than protective level is shunted to the ground and the load is protected from the overvoltage surges. The surge arrester is always on and there is always leakage current to the ground which leads to power loss.
Lightning Overvoltage Surges Protection using Equivalent Circuit of Surge Arrester (IGBT)	Any lightning overvoltage surges with magnitude higher than protective level is shunted to the ground and the load is protected from the overvoltage surges. However, the peak voltage experienced by the load is slightly higher than protective level because of delay due to switching time of IGBT. Does not have leakage current to the ground as the arrester only function when there are overvoltage surges higher than protection level. However, it is not really practical as it needs monitoring of microprocessor on the system voltage in real time which requires another transformer to step down the voltage and that transformer needs its own surge protection.

Lightning Overvoltage Surges Protection using Equivalent Circuit of Surge Arrester (Thyristor)	Any lightning overvoltage surges with magnitude higher than protective level is shunted to the ground and the load is protected from the overvoltage surges. However, the peak voltage experienced by the load is slightly higher than protective level because of delay due to switching time of Thyristor. Does not have leakage current to the ground as the arrester only function when there are overvoltage surges higher than protection level. However, it is not really practical as it needs monitoring of microprocessor on the system voltage in real time which requires another transformer to step down the voltage and that transformer needs its own surge protection.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

After acquiring all the results and undergo analysis, the conclusion is drawn. This chapter covers:

1) Conclusion
2) Recommendations

5.2 Conclusion

As a conclusion, there are three sources of overvoltage surges which are capacitor switching, ferroresonance and lightning. The different types of capacitor switching overvoltage surges are isolated capacitor switching, back to back capacitor switching and capacitor restrike. As for lightning overvoltage surges, there are only direct strikes and flashover. Each of the overvoltage surges have their own effect and influences on the voltage waveform. The prevention method of capacitor switching overvoltage surges is synchronous closing control. By closing the power factor correction capacitor banks when the phase voltage is at level zero will eliminate the severe damage of capacitor switching overvoltage surges. Apart from that, capacitor restrike overvoltage surges can be prevented by making sure the closing contact is free of contamination and the insulation is good. The protection method of capacitor switching overvoltage surges is by configuring the capacitor banks into harmonic filter by adding inductance in series. This is the best method as it provides three positives which are power factor correction, filtering or harmonics and damping of overvoltage surges.

The only way to prevent lightning overvoltage surges is by installing shield wire on top of the phase conductor. The lightning will strike on the shield wire instead of the phase conductor and thus preventing the lightning overvoltage surges from occurring in the phase conductor. There is no any effective method to protect the lightning overvoltage surges from direct strikes. As for lightning overvoltage surges induced from flashover, the most effective method is by installing surges arresters before the critical equipment. Surge arresters will function to protect the equipment from any lightning overvoltage surges. The feasibility of protection using surge arresters is verified by using simulation.

5.3 Recommendations

This research focused on the investigating and identifying the sources, types, effect, prevention and protection method of overvoltage surges. Simulation approach is used to verify the feasibility of the protection method. Therefore, most of the parameters used are ideal parameters, which are not the case in real life. Thus, it is recommended to build the practical model to verify the feasibility of the protection method. This will provide the most accurate results, which may prove the simulation results to be wrong. Finally, more advanced software or more complex circuit can be utilized to obtain results that are more accurate and practical.

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APPENDICES

APPENDIX A: BS_EN_IEC_62305 Lightning Protection Standard

Guide to BS EN/IEC 62305 Introduction

BS EN/IEC 62305 Lightning protection standard

The BS EN/IEC 62305 Standard for lightning protection was originally published in September 2006, to supercede the previous standard, BS 6651:1999.

For a finite period, BS EN/IEC 62305 and BS 6651 ran in parallel, but as of August 2008, BS 6651 has been withdrawn and now BS EN/IEC 63205 is the recognised standard for lightning protection.

The BS EN/IEC 62305 standard reflects increased scientific understanding of lightning and its effects over the last twenty years, and takes stock of the growing impact of technology and electronic systems on our daily activities. More complex and exacting than its predecessor, BS EN/IEC 62305 includes four distinct parts - general principles, risk management, physical damage to structures and life hazard, and electronic systems protection.

These parts to the standard are introduced here. In 2010 these parts underwent periodic technical review, with updated parts 1, 3 and 4 released in 2011. Updated part 2 is currently under discussion and is expected to be published in late 2012.

Key to BS EN/IEC 62305 is that all considerations for lightning protection are driven by a comprehensive and complex risk assessment and that this assessment not only takes into account the structure to be protected, but also the services to which the structure is connected. In essence, structural lightning protection can no longer be considered in isolation, protection against transient overvoltages or electrical surges is integral to BS EN/IEC 62305.

Structure of BS EN/IEC 62305

The BS EN/IEC 62305 series consists of four parts, all of which need to be taken into consideration. These four parts are outlined below:

Part 1: General principles

BS EN/IEC 62305-1 (part 1) is an introduction to the other parts of the standard and essentially describes how to design a Lightning Protection System (LPS) in accordance with the accompanying parts of the standard.

Part 2: Risk management

BS EN/IEC 62305-2 (part 2) risk management approach, does not concentrate so much on the purely physical damage to a structure caused by a lightning discharge, but more on the risk of loss of human life, loss of service to the public, loss of cultural heritage and economic loss.

Part 3: Physical damage to structures and life hazard

BS EN/IEC 62305-3 (part 3) relates directly to the major part of BS 6651. It differs from BS 6651 in as much that this new part has four Classes or protection levels of LPS, as opposed to the basic two (ordinary and high-risk) levels in BS 6651.

Part 4: Electrical and electronic systems within structures

BS EN/IEC 62305-4 (part 4) covers the protection of electrical and electronic systems housed within structures. It embodies what Annex C in BS 6651 conveyed, but with a new zonal approach referred to as Lightning Protection Zones (LPZs). It provides information for the design, installation, maintenance & testing of a Lightning Electromagnetic Impulse (LEMP) protection system (now referred to as Surge Protection Measures - SPM) for electrical/electronic systems within a structure.

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The following table gives a broad outline as to the key variances between the previous standard, BS 6651, and the BS EN/IEC 62305.

BS 6651 standard (withdrawn August 2008)	**BS EN/IEC 62305 standard**
Document structure	
118 page document, including 9 pages devoted to risk assessment	Over 470 pages in 4 parts, including over 150 pages devoted to risk assessment (BS EN/IEC 62305-2)
Focus on Protection of Structures against Lightning	Broader focus on Protection against Lightning including the structure and services connected to the structure
Specific tables relating to choice and dimension of LPS components and conductors	Specific tables relating to sizes and types of conductor and earth electrodes. LPS components - specifically related to BS EN 50164/ IEC 62561 testing regimes
Annex B - guidance on application of BS 6651	BS EN/IEC 62305-3 Annex E - extensive guidance given on application of installation techniques complete with illustrations
Annex C - general advice (recommendation) for protection of electronic equipment with separate risk assessment	BS EN/IEC 62305-4 is devoted entirely to protection of electrical and electronic systems within the structure (integral part of standard) and is implemented through single separate risk assessment (BS EN/IEC 62305-2)
Definition of risk	
Risk (of death/injury) level set at 1 in 100,000 (1×10^{-5}) based on comparable exposures (smoking, traffic accidents, drowning etc)	3 primary risk levels defined (BS EN 62305): R_1 loss of human life 1 in 100,000 (1×10^{-5}) R_2 loss of service to the public 1 in 10,000 (1×10^{-4}) R_3 loss of cultural heritage 1 in 10,000 (1×10^{-4})
Protection measures	
Mesh arrangement is promoted as the commonly used means of air termination network	Mesh arrangement, protective angle method, catenary system, extensive use of air finials, all form part of or all of air termination network
2 levels of Lightning Protection mesh design: (20 m x 10 m; 10 m x 5 m)	4 sizes of mesh defined according to structural class of Lightning Protection System: Class I 5 m x 5 m Class II 10 m x 10 m Class III 15 m x 15 m Class IV 20 m x 20 m
2 levels of down conductor spacing: 20 m & 10 m	4 levels of down conductor spacing dependent on structural class of Lightning Protection System: Class I 10 m Class II 10 m Class III 15 m Class IV 20 m
Use of bonds promoted to minimise side flashing	Extensive sections/explanations provided on equipotential bonding
10 ohm overall earthing requirement, achieved by 10 x number of down conductors	10 ohms overall earthing requirement achieved either by Type A arrangement (rods) or Type B arrangement (ring conductor)
Requirement to bond all metallic services, (gas, water, electricity etc) to main earth terminal along with external down conductor	Requirement to bond all metallic services to main equipotential bonding bar. 'Live' electrical conductors (e.g. power, data, telecoms) bonded via Surge Protective Devices (SPDs)
Rolling sphere concept on structures over 20 m tall: 20 m sphere used on highly flammable contents/ electronic equipment within building 60 m sphere all other buildings	4 sizes of rolling sphere concept defined according to structural class of Lightning Protection System: Class I 20 m Class II 30 m Class III 45 m Class IV 60 m

BS EN/IEC 62305-1 General principles

This opening part of the BS EN/IEC 62305 suite of standards serves as an introduction to the further parts of the standard. It classifies the sources and types of damage to be evaluated and introduces the risks or types of loss to be anticipated as a result of lightning activity.

Furthermore, It defines the relationships between damage and loss that form the basis for the risk assessment calculations in part 2 of the standard.

Lightning current parameters are defined. These are used as the basis for the selection and implementation of the appropriate protection measures detailed in parts 3 and 4 of the standard.

Part 1 of the standard also introduces new concepts for consideration when preparing a lightning protection scheme, such as Lightning Protection Zones (LPZs) and separation distance.

Damage and loss

BS EN/IEC 62305 identifies four main sources of damage:

S1 Flashes to the structure

S2 Flashes near to the structure

S3 Flashes to a service

S4 Flashes near to a service

Each source of damage may result in one or more of three types of damage:

D1 Injury of living beings due to step and touch voltages

D2 Physical damage (fire, explosion, mechanical destruction, chemical release) due to lightning current effects including sparking

D3 Failure of internal systems due to Lightning Electromagnetic Impulse (LEMP)

The following types of loss may result from damage due to lightning:

L1 Loss of human life

L2 Loss of service to the public

L3 Loss of cultural heritage

L4 Loss of economic value

The relationships of all of the above parameters are summarised in Table 5.

Figure 12 on page 271 depicts the types of damage and loss resulting from lightning.

For a more detailed explanation of the general principles forming part 1 of the BS EN 62305 standard, please refer to our full reference guide 'A Guide to BS EN 62305.' Although focused on the BS EN standard, this guide may provide supporting information of interest to consultants designing to the IEC equivalent. Please see page 283 for more details about this guide.

Point of strike	Source of damage	Type of damage	Type of loss
Structure	S1	D1 D2 D3	L1, L4** L1, L2, L3, L4 L1*, L2, L4
Near a structure	S2	D3	L1*, L2, L4
Service connected to the structure	S3	D1 D2 D3	L1, L4** L1, L2, L3, L4 L1*, L2, L4
Near a service	S4	D3	L1*, L2, L4

* Only for structures with risk of explosion and for hospitals or other structures where failures of internal systems immediately endangers human life.

** Only for properties where animals may be lost.

Table 5: Damage and loss in a structure according to different points of lightning strike (BS EN/IEC 62305-1 Table 2)

Scheme design criteria

The ideal lightning protection for a structure and its connected services would be to enclose the structure within an earthed and perfectly conducting metallic shield (box), and in addition provide adequate bonding of any connected services at the entrance point into the shield.

This in essence would prevent the penetration of the lightning current and the induced electromagnetic field into the structure.

However, in practice it is not possible or indeed cost effective to go to such lengths.

This standard thus sets out a defined set of lightning current parameters where protection measures, adopted in accordance with its recommendations, will reduce any damage and consequential loss as a result of a lightning strike. This reduction in damage and consequential loss is valid provided the lightning strike parameters fall within defined limits, established as Lightning Protection Levels (LPL).

Lightning Protection Levels (LPL)

Four protection levels have been determined based on parameters obtained from previously published technical papers. Each level has a fixed set of maximum and minimum lightning current parameters. These parameters are shown in Table 6.

The maximum values have been used in the design of products such as lightning protection components and Surge Protective Devices (SPDs).

The minimum values of lightning current have been used to derive the rolling sphere radius for each level.

LPL	I	II	III	IV
Maximum current (kA)	200	150	100	100
Minimum current (kA)	3	5	10	16

Table 6: Lightning current for each LPL based on 10/350 μs waveform

For a more detailed explanation of Lightning Protection Levels and maximum/minimum current parameters please see the Furse Guide to BS EN 62305.

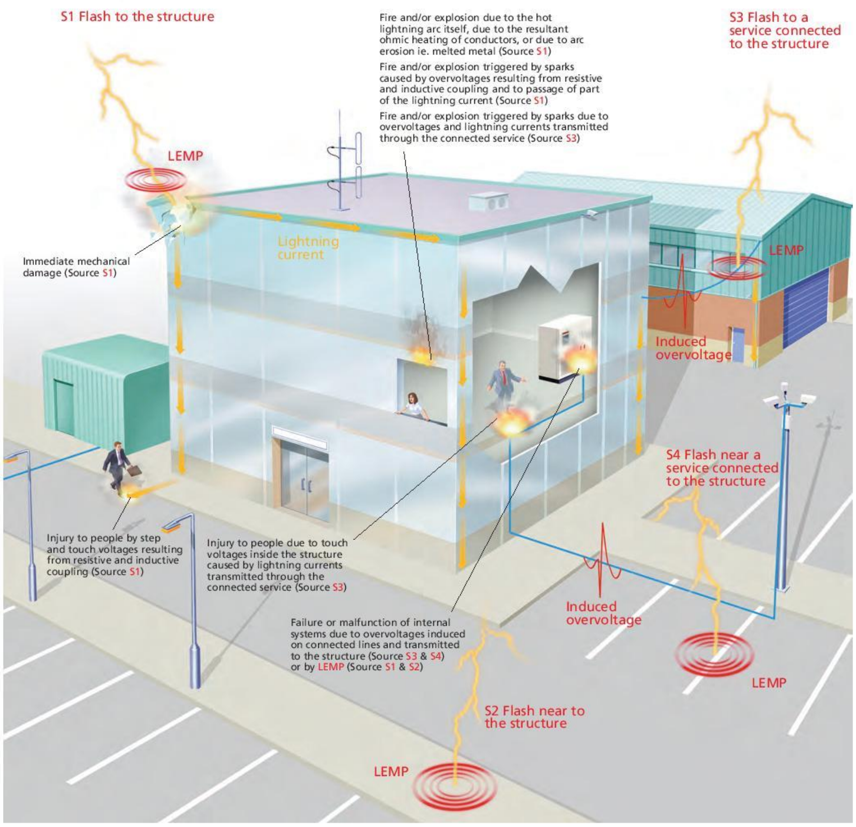


Figure 12: The types of damage and loss resulting from a lightning strike on or near a structure

Lightning Protection Zones (LPZ)

The concept of Lightning Protection Zones (LPZ) was introduced within BS EN/IEC 62305 particularly to assist in determining the protection measures required to establish protection measures to counter Lightning Electromagnetic Impulse (LEMP) within a structure.

The general principle is that the equipment requiring protection should be located in an LPZ whose electromagnetic characteristics are compatible with the equipment stress withstand or immunity capability.

The concept caters for external zones, with risk of direct lightning stroke (LPZ 0_A), or risk of partial lightning current occurring (LPZ 0_B), and levels of protection within internal zones (LPZ 1 & LPZ 2).

In general the higher the number of the zone (LPZ 2; LPZ 3 etc) the lower the electromagnetic effects expected. Typically, any sensitive electronic equipment should be located in higher numbered LPZs and be protected against LEMP by relevant Surge Protection Measures ('SPM' as defined in BS EN 62305:2011).

SPM were previously referred to as a LEMP Protection Measures System (LPMS) in BS EN/IEC 62305:2006.

Figure 13 highlights the LPZ concept as applied to the structure and to SPM. The concept is expanded upon in BS EN/IEC 62305-3 and BS EN/IEC 62305-4.

Selection of the most suitable SPM is made using the risk assessment in accordance with BS EN/IEC 62305-2.

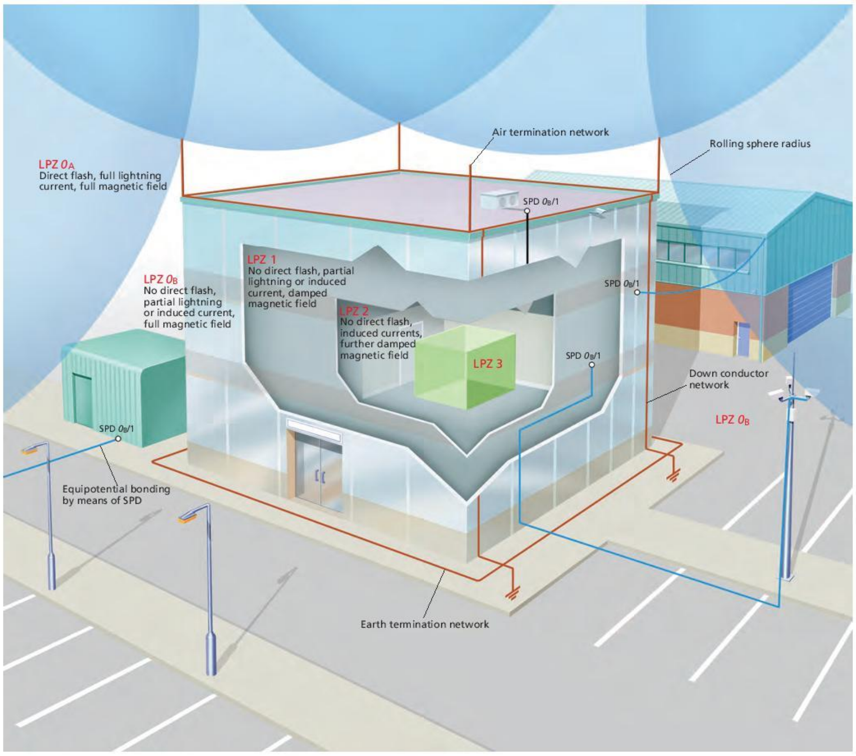


Figure 13: The LPZ concept

BS EN/IEC 62305-2 Risk management

BS EN/IEC 62305-2 is key to the correct implementation of BS EN/IEC 62305-3 and BS EN/IEC 62305-4. The assessment and management of risk is now significantly more in depth and extensive than the approach of BS 6651.

BS EN/IEC 62305-2 specifically deals with making a risk assessment, the results of which define the level of Lightning Protection System (LPS) required. While BS 6651 devoted 9 pages (including figures) to the subject of risk assessment, BS EN/IEC 62305-2 currently contains over 150 pages.

The first stage of the risk assessment is to identify which of the four types of loss (as identified in BS EN/IEC 62305-1) the structure and its contents can incur. The ultimate aim of the risk assessment is to quantify and if necessary reduce the relevant primary risks i.e.:

R_1 **risk of loss of human life**

R_2 **risk of loss of service to the public**

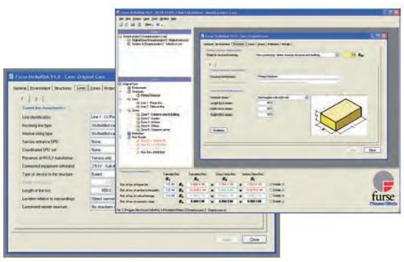
R_3 **risk of loss of cultural heritage**

R_4 **risk of loss of economic value**

For each of the first three primary risks, a tolerable risk (R_T) is set. This data can be sourced in Table 7 of IEC 62305-2 or Table NK.1 of the National Annex of BS EN 62305-2.

Each primary risk (R_n) is determined through a long series of calculations as defined within the standard. If the actual risk (R_n) is less than or equal to the tolerable risk (R_T), then no protection measures are needed. If the actual risk (R_n) is greater than its corresponding tolerable risk (R_T), then protection measures must be instigated. The above process is repeated (using new values that relate to the chosen protection measures) until R_n is less than or equal to its corresponding R_T.

It is this iterative process as shown in Figure 14 that decides the choice or indeed Lightning Protection Level (LPL) of Lightning Protection System (LPS) and Surge Protective Measures (SPM) to counter Lightning Electromagnetic impulse (LEMP).



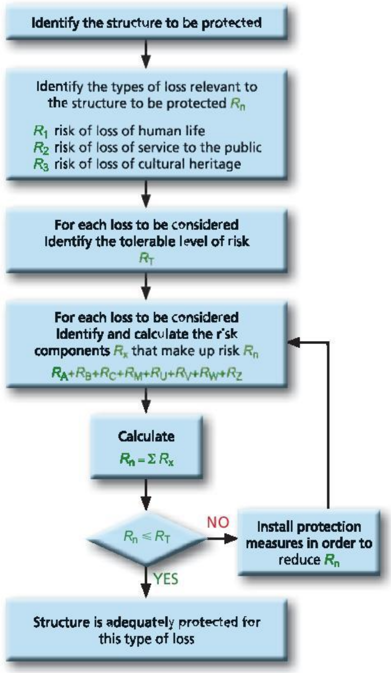


Figure 14: Procedure for deciding the need for protection (BS EN/IEC 62305-1 Figure 1)

StrikeRisk risk management software

An invaluable tool for those involved in undertaking the complex risk assessment calculations required by BS EN 62305-2, StrikeRisk facilitates the assessment of risk of loss due to lightning strikes and transient overvoltages caused by lightning.

Quick & easy to use, with full reporting capability, StrikeRisk automates risk assessment calculations and delivers results in minutes, rather than the hours or days it would take to do the same calculations by hand.

Contact Furse for more details about StrikeRisk.

BS EN/IEC 62305-3 Physical damage to structures and life hazard

This part of the suite of standards deals with protection measures in and around a structure and as such relates directly to the major part of BS 6651.

The main body of this part of the standard gives guidance on the design of an external Lightning Protection System (LPS), internal LPS and maintenance and inspection programmes.

Lightning Protection System (LPS)

BS EN/IEC 62305-1 has defined four Lightning Protection Levels (LPLs) based on probable minimum and maximum lightning currents. These LPLs equate directly to classes of Lightning Protection System (LPS).

The correlation between the four levels of LPL and LPS is identified in Table 7. In essence, the greater the LPL, the higher class of LPS is required.

LPL	Class of LPS
I	I
II	II
III	III
IV	IV

Table 7: Relation between Lightning Protection Level (LPL) and Class of LPS (BS EN/IEC 62305-3 Table 1)

The class of LPS to be installed is governed by the result of the risk assessment calculation highlighted in BS EN/IEC 62305-2.

External LPS design considerations

The lightning protection designer must initially consider the thermal and explosive effects caused at the point of a lightning strike and the consequences to the structure under consideration. Depending upon the consequences the designer may choose either of the following types of external LPS:

- Isolated
- Non-isolated

An Isolated LPS is typically chosen when the structure is constructed of combustible materials or presents a risk of explosion.

Conversely a non-isolated system may be fitted where no such danger exists.

An external LPS consists of:

- Air termination system
- Down conductor system
- Earth termination system

These individual elements of an LPS should be connected together using appropriate lightning protection components (LPC) complying (in the case of BS EN 62305) with BS EN 50164 series (note this BS EN series is due to be superceded by the BS EN/IEC 62561 series). This will ensure that in the event of a lightning current discharge to the structure, the correct design and choice of components will minimize any potential damage.

Air termination system

The role of an air termination system is to capture the lightning discharge current and dissipate it harmlessly to earth via the down conductor and earth termination system. Therefore it is vitally important to use a correctly designed air termination system.

BS EN/IEC 62305-3 advocates the following, in any combination, for the design of the air termination:

- Air rods (or finials) whether they are free standing masts or linked with conductors to form a mesh on the roof
- Catenary (or suspended) conductors, whether they are supported by free standing masts or linked with conductors to form a mesh on the roof
- Meshed conductor network that may lie in direct contact with the roof or be suspended above it (in the event that it is of paramount importance that the roof is not exposed to a direct lightning discharge)

The standard makes it quite clear that all types of air termination systems that are used shall meet the positioning requirements laid down in the body of the standard. It highlights that the air termination components should be installed on corners, exposed points and edges of the structure.

The three basic methods recommended for determining the position of the air termination systems are:

- The rolling sphere method
- The protective angle method
- The mesh method

These methods are detailed over the following pages.

The rolling sphere method

The rolling sphere method is a simple means of identifying areas of a structure that need protection, taking into account the possibility of side strikes to the structure. The basic concept of applying the rolling sphere to a structure is illustrated in Figure 15.

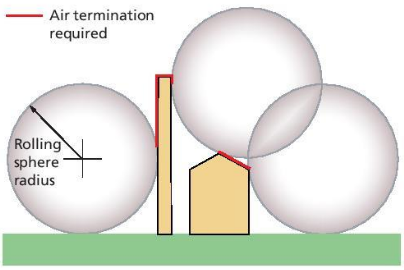


Figure 15: Application of the rolling sphere method

The rolling sphere method was used in BS 6651, the only difference being that in BS EN/IEC 62305 there are different radii of the rolling sphere that correspond to the relevant class of LPS (see Table 8).

Class of LPS	Rolling sphere radius (m)
I	20
II	30
III	45
IV	60

Table 8: Maximum values of rolling sphere radius corresponding to the Class of LPS

This method is suitable for defining zones of protection for all types of structures, particularly those of complex geometry.

The protective angle method

The protective angle method is a mathematical simplification of the rolling sphere method. The protective angle (a) is the angle created between the tip (A) of the vertical rod and a line projected down to the surface on which the rod sits (see Figure 16).

The protective angle afforded by an air rod is clearly a three dimensional concept whereby the rod is assigned a cone of protection by sweeping the line AC at the angle of protection a full 360° around the air rod.

The protective angle differs with varying height of the air rod and class of LPS. The protective angle afforded by an air rod is determined from Table 2 of BS EN/IEC 62305-3 (see Figure 17).

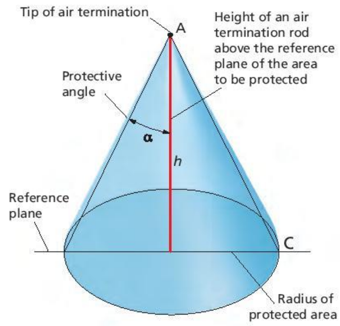
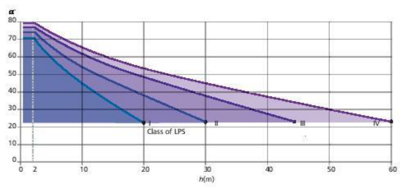


Figure 16: The protective angle method for a single air rod

Varying the protection angle is a change to the simple 45° zone of protection afforded in most cases in BS 6651. Furthermore the new standard uses the height of the air termination system above the reference plane, whether that be ground or roof level (See Figure 18).



Note 1 Not applicable beyond the values marked with ●
Only rolling sphere and mesh methods apply in these cases

Note 2 *h* is the height of air-termination above the reference plane of the area to be protected

Note 3 The angle will not change for values of *h* below 2m

Figure 17: Determination of the protective angle (BS EN/IEC 62305-3 Table 2)

The protective angle method is suitable for simple shaped buildings. However this method is only valid up to a height equal to the rolling sphere radius of the appropriate LPL.

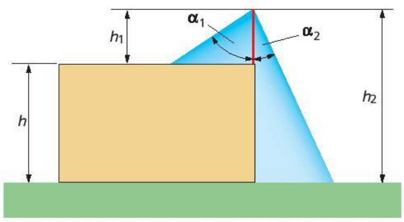


Figure 18: Effect of the height of the reference plane on the protection angle

The mesh method

This is the method that was most commonly used under the recommendations of BS 6651. Again, within BS EN/IEC 62305 four different air termination mesh sizes are defined and correspond to the relevant class of LPS (see Table 9).

Class of LPS	Mesh size (m)
I	5 x 5
II	10 x 10
III	15 x 15
IV	20 x 20

Table 9: Maximum values of mesh size corresponding to the Class of LPS

This method is suitable where plain surfaces require protection if the following conditions are met:

- Air termination conductors must be positioned at roof edges, on roof overhangs and on the ridges of roof with a pitch in excess of 1 in 10 (5.7º)
- No metal installation protrudes above the air termination system

Modern research on lightning inflicted damage has shown that the edges and corners of roofs are most susceptible to damage.

So on all structures particularly with flat roofs, perimeter conductors should be installed as close to the outer edges of the roof as is practicable.

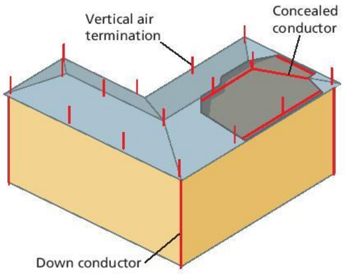


Figure 19: Concealed air termination network

As in BS 6651, the current standard permits the use of conductors (whether they be fortuitous metalwork or dedicated LP conductors) under the roof. Vertical air rods (finials) or strike plates should be mounted above the roof and connected to the conductor system beneath. The air rods should be spaced not more than 10 m apart and if strike plates are used as an alternative, these should be strategically placed over the roof area not more than 5 m apart.

Non-conventional air termination systems

A lot of technical (and commercial) debate has raged over the years regarding the validity of the claims made by the proponents of such systems.

This topic was discussed extensively within the technical working groups that compiled BS EN/IEC 62305. The outcome was to remain with the information housed within this standard.

BS EN/IEC 62305 states unequivocally that the volume or zone of protection afforded by the air termination system (e.g. air rod) shall be determined only by the real physical dimension of the air termination system.

This statement is reinforced within the 2011 version of BS EN 62305, by being incorporated in the body of the standard, rather than forming part of an Annex (Annex A of BS EN/IEC 62305-3:2006).

Typically if the air rod is 5 m tall then the only claim for the zone of protection afforded by this air rod would be based on 5 m and the relevant class of LPS and not any enhanced dimension claimed by some non-conventional air rods.

There is no other standard being contemplated to run in parallel with this standard BS EN/IEC 62305.

Natural components

When metallic roofs are being considered as a natural air termination arrangement, then BS 6651 gave guidance on the minimum thickness and type of material under consideration.

BS EN/IEC 62305-3 gives similar guidance as well as additional information if the roof has to be considered puncture proof from a lightning discharge (see Table 10).

Class of LPS	Material	Thickness(1) t (mm)	Thickness(2) t' (mm)
I to IV	Lead	-	2.0
	Steel (stainless, galvanized)	4	0.5
	Titanium	4	0.5
	Copper	5	0.5
	Aluminium	7	0.65
	Zinc	-	0.7

(1) Thickness t prevents puncture, hot spot or ignition.
(2) Thickness t' only for metal sheets if it is not important to prevent puncture, hot spot or ignition problems.

Table 10: Minimum thickness of metal sheets or metal pipes in air termination systems (BS EN/IEC 62305-3 Table 3)

Down conductors

Down conductors should within the bounds of practical constraints take the most direct route from the air termination system to the earth termination system. The greater the number of down conductors the better the lightning current is shared between them. This is enhanced further by equipotential bonding to the conductive parts of the structure.

Lateral connections sometimes referred to as coronal bands or ring conductors provided either by fortuitous metalwork or external conductors at regular intervals are also encouraged. The down conductor spacing should correspond with the relevant class of LPS (see Table 11).

Class of LPS	Typical distances (m)
I	10
II	10
III	15
IV	20

Table 11: Typical values of the distance between down conductors according to the Class of LPS (BS EN/IEC 62305-3 Table 4)

There should always be a minimum of two down conductors distributed around the perimeter of the structure. Down conductors should wherever possible be installed at each exposed corner of the structure as research has shown these to carry the major part of the lightning current.

Natural components

BS EN/IEC 62305, like BS 6651, encourages the use of fortuitous metal parts on or within the structure to be incorporated into the LPS.

Where BS 6651 encouraged an electrical continuity when using reinforcing bars located in concrete structures, so too does BS EN/IEC 62305-3. Additionally, it states that reinforcing bars are welded, clamped with suitable connection components or overlapped a minimum of 20 times the rebar diameter. This is to ensure that those reinforcing bars likely to carry lightning currents have secure connections from one length to the next.

When internal reinforcing bars are required to be connected to external down conductors or earthing network either of the arrangements shown in Figure 20 is suitable. If the connection from the bonding conductor to the rebar is to be encased in concrete then the standard recommends that two clamps are used, one connected to one length of rebar and the other to a different length of rebar. The joints should then be encased by a moisture inhibiting compound such as Denso tape.

If the reinforcing bars (or structural steel frames) are to be used as down conductors then electrical continuity should be ascertained from the air termination system to the earthing system. For new build structures this can be decided at the early construction stage by using dedicated reinforcing bars or alternatively to run a dedicated copper conductor from the top of the structure to the foundation prior to the pouring of the concrete. This dedicated copper conductor should be bonded to the adjoining/adjacent reinforcing bars periodically.

If there is doubt as to the route and continuity of the reinforcing bars within existing structures then an external down conductor system should be installed. These should ideally be bonded into the reinforcing network of the structures at the top and bottom of the structure.

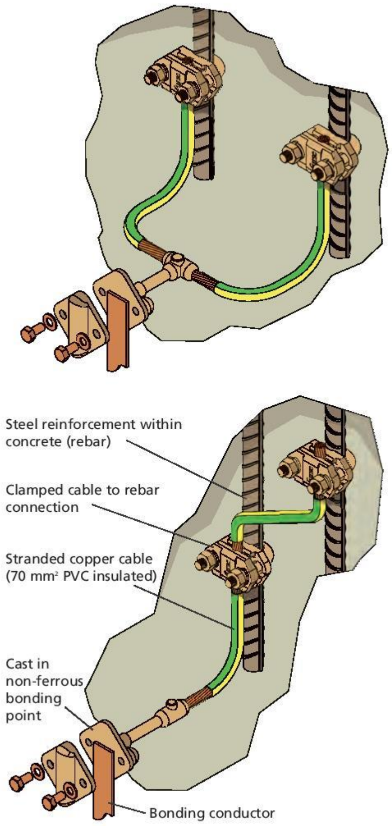


Figure 20: Typical methods of bonding to steel reinforcement within concrete

Earth termination system

The earth termination system is vital for the dispersion of lightning current safely and effectively into the ground.

In line with BS 6651, the new standard recommends a single integrated earth termination system for a structure, combining lightning protection, power and telecommunication systems. The agreement of the operating authority or owner of the relevant systems should be obtained prior to any bonding taking place.

A good earth connection should possess the following characteristics:

- Low electrical resistance between the electrode and the earth. The lower the earth electrode resistance the more likely the lightning current will choose to flow down that path in preference to any other, allowing the current to be conducted safely to and dissipated in the earth
- Good corrosion resistance. The choice of material for the earth electrode and its connections is of vital importance. It will be buried in soil for many years so has to be totally dependable

The standard advocates a low earthing resistance requirement and points out that it can be achieved with an overall earth termination system of 10 ohms or less.

Three basic earth electrode arrangements are used.

- Type A arrangement
- Type B arrangement
- Foundation earth electrodes

Type A arrangement

This consists of horizontal or vertical earth electrodes, connected to each down conductor fixed on the outside of the structure. This is in essence the earthing system used in BS 6651, where each down conductor has an earth electrode (rod) connected to it.

Type B arrangement

This arrangement is essentially a fully connected ring earth electrode that is sited around the periphery of the structure and is in contact with the surrounding soil for a minimum 80% of its total length (i.e. 20% of its overall length may be housed in say the basement of the structure and not in direct contact with the earth).

Foundation earth electrodes

This is essentially a type B earthing arrangement. It comprises conductors that are installed in the concrete foundation of the structure. If any additional lengths of electrodes are required they need to meet the same criteria as those for type B arrangement. Foundation earth electrodes can be used to augment the steel reinforcing foundation mesh.

A sample of Furse high quality earthing components.

Separation (isolation) distance of the external LPS

A separation distance (i.e. the electrical insulation) between the external LPS and the structural metal parts is essentially required. This will minimise any chance of partial lightning current being introduced internally in the structure.

This can be achieved by placing lightning conductors sufficiently far away from any conductive parts that have routes leading into the structure. So, if the lightning discharge strikes the lightning conductor, it cannot `bridge the gap' and flash over to the adjacent metalwork.

BS EN/IEC 62305 recommends a single integrated earth termination system for a structure, combining lightning protection, power and telecommunication systems.

Internal LPS design considerations

The fundamental role of the internal LPS is to ensure the avoidance of dangerous sparking occurring within the structure to be protected. This could be due, following a lightning discharge, to lightning current flowing in the external LPS or indeed other conductive parts of the structure and attempting to flash or spark over to internal metallic installations.

Carrying out appropriate equipotential bonding measures or ensuring there is a sufficient electrical insulation distance between the metallic parts can avoid dangerous sparking between different metallic parts.

Lightning equipotential bonding

Equipotential bonding is simply the electrical interconnection of all appropriate metallic installations/parts, such that in the event of lightning currents flowing, no metallic part is at a different voltage potential with respect to one another. If the metallic parts are essentially at the same potential then the risk of sparking or flashover is nullified.

This electrical interconnection can be achieved by natural/fortuitous bonding or by using specific bonding conductors that are sized according to Tables 8 and 9 of BS EN/IEC 62305-3.

Bonding can also be accomplished by the use of surge protective devices (SPDs) where the direct connection with bonding conductors is not suitable.

Figure 21 (which is based on BS EN/IEC 62305-3 fig E.43) shows a typical example of an equipotential bonding arrangement. The gas, water and central heating system are all bonded directly to the equipotential bonding bar located inside but close to an outer wall near ground level. The power cable is bonded via a suitable SPD, upstream from the electric meter, to the equipotential bonding bar. This bonding bar should be located close to the main distribution board (MDB) and also closely connected to the earth termination system with short length conductors. In larger or extended structures several bonding bars may be required but they should all be interconnected with each other.

The screen of any antenna cable along with any shielded power supply to electronic appliances being routed into the structure should also be bonded at the equipotential bar.

Further guidance relating to equipotential bonding, meshed interconnection earthing systems and SPD selection can be found in the Furse guidebook.

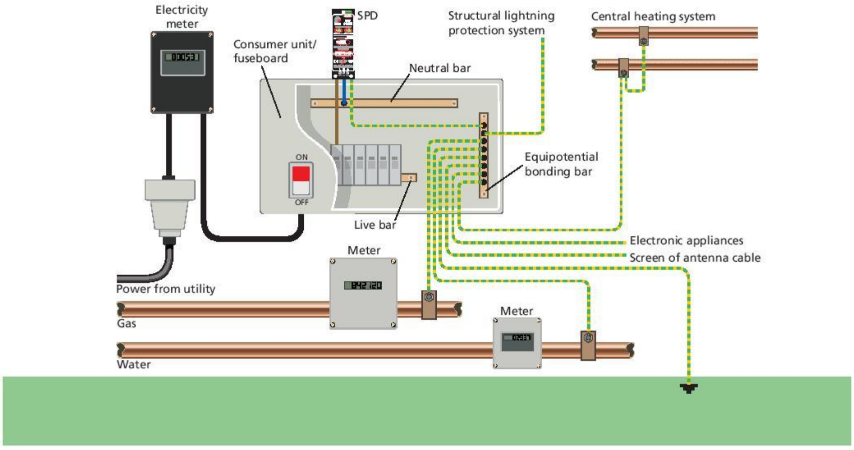


Figure 21: Example of main equipotential bonding

BS EN/IEC 62305-4 Electrical and electronic systems within structures

Electronic systems now pervade almost every aspect of our lives, from the work environment, through filling the car with petrol and even shopping at the local supermarket. As a society, we are now heavily reliant on the continuous and efficient running of such systems. The use of computers, electronic process controls and telecommunications has exploded during the last two decades. Not only are there more systems in existence, the physical size of the electronics involved has reduced considerably (smaller size means less energy required to damage circuits).

BS EN/IEC 62305 accepts that we now live in the electronic age, making LEMP (Lightning Electromagnetic Impulse) protection for electronic and electrical systems integral to the standard through part 4. LEMP is the term given to the overall electromagnetic effects of lightning, including conducted surges (transient overvoltages and currents) and radiated electromagnetic field effects.

LEMP damage is so prevalent such that it is identified as one of the specific types (D3) to be protected against and that LEMP damage can occur from ALL strike points to the structure or connected services - direct or indirect - for further reference to the types of damage caused by lightning see Table 5 on page 270. This extended approach also takes into account the danger of fire or explosion associated with services connected to the structure, e.g. power, telecoms and other metallic lines.

Lightning is not the only threat...

Transient overvoltages caused by electrical switching events are very common and can be a source of considerable interference. Current flowing through a conductor creates a magnetic field in which energy is stored. When the current is interrupted or switched off, the energy in the magnetic field is suddenly released. In an attempt to dissipate itself it becomes a high voltage transient.

Motors create switching events

The more stored energy, the larger the resulting transient. Higher currents and longer lengths of conductor both contribute to more energy stored and also released!

This is why inductive loads such as motors, transformers and electrical drives are all common causes of switching transients.

Significance of BS EN/IEC 62305-4

Previously transient overvoltage or surge protection was included as an advisory annex in the BS 6651 standard, with a separate risk assessment. As a result protection was often fitted after equipment damage was suffered, often through obligation to insurance companies. However, the single risk assessment in BS EN/IEC 62305 dictates whether structural and/or LEMP protection is required hence structural lightning protection cannot now be considered in isolation from transient overvoltage protection - known as Surge Protective Devices (SPDs) within this new standard. This in itself is a significant deviation from that of BS 6651.

Indeed, as per BS EN/IEC 62305-3, an LPS system can no longer be fitted without lightning current or equipotential bonding SPDs to incoming metallic services that have "live cores" - such as power and telecoms cables - which cannot be directly bonded to earth. Such SPDs are required to protect against the risk of loss of human life by preventing dangerous sparking that could present fire or electric shock hazards.

Lightning current or equipotential bonding SPDs are also used on overhead service lines feeding the structure that are at risk from a direct strike. However, the use of these SPDs alone "provides no effective protection against failure of sensitive electrical or electronic systems", to quote BS EN/IEC 62305 part 4, which is specifically dedicated to the protection of electrical and electronic systems within structures.

Lightning current SPDs form one part of a coordinated set of SPDs that include overvoltage SPDs - which are needed in total to effectively protect sensitive electrical and electronic systems from both lightning and switching transients.

Lightning Protection Zones (LPZs)

Whilst BS 6651 recognised a concept of zoning in Annex C (Location Categories A, B and C), BS EN/IEC 62305-4 defines the concept of Lightning Protection Zones (LPZs). Figure 22 illustrates the basic LPZ concept defined by protection measures against LEMP as detailed within part 4.

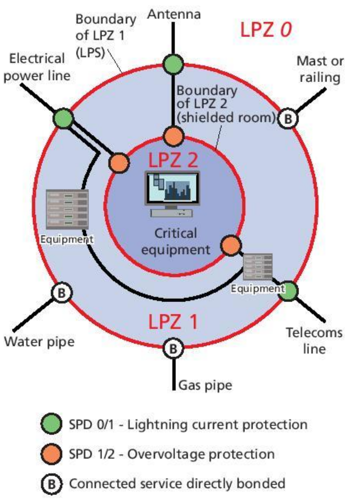


Figure 22: Basic LPZ concept - BS EN/IEC 62305-4

Within a structure a series of LPZs are created to have, or identified as already having, successively less exposure to the effects of lightning.

Successive zones use a combination of bonding, shielding and coordinated SPDs to achieve a significant reduction in LEMP severity, from conducted surge currents and transient overvoltages, as well as radiated magnetic field effects. Designers coordinate these levels so that the more sensitive equipment is sited in the more protected zones.

The LPZs can be split into two categories - 2 external zones (LPZ 0_A, LPZ 0_B) and usually 2 internal zones (LPZ 1, 2) although further zones can be introduced for a further reduction of the electromagnetic field and lightning current if required.

External zones

LPZ 0_A is the area subject to direct lightning strokes and therefore may have to carry up to the full lightning current.

This is typically the roof area of a structure. The full electromagnetic field occurs here.

LPZ 0_B is the area not subject to direct lightning strokes and is typically the sidewalls of a structure.

However the full electromagnetic field still occurs here and conducted partial lightning currents and switching surges can occur here.

Internal zones

LPZ 1 is the internal area that is subject to partial lightning currents. The conducted lightning currents and/or switching surges are reduced compared with the external zones LPZ 0_A, LPZ 0_B.

This is typically the area where services enter the structure or where the main power switchboard is located.

LPZ 2 is an internal area that is further located inside the structure where the remnants of lightning impulse currents and/or switching surges are reduced compared with LPZ 1.

This is typically a screened room or, for mains power, at the sub-distribution board area.

Protection levels within a zone must be coordinated with the immunity characteristics of the equipment to be protected, i.e., the more sensitive the equipment, the more protected the zone required.

The existing fabric and layout of a building may make readily apparent zones, or LPZ techniques may have to be applied to create the required zones.

Surge Protection Measures (SPM)

Some areas of a structure, such as a screened room, are naturally better protected from lightning than others and it is possible to extend the more protected zones by careful design of the LPS, earth bonding of metallic services such as water and gas, and cabling techniques. However it is the correct installation of coordinated Surge Protective Devices (SPDs) that protect equipment from damage as well as ensuring continuity of its operation - critical for eliminating downtime. These measures in total are referred to as Surge Protection Measures (SPM) (formerly LEMP Protection Measures System (LPMS)).

When applying bonding, shielding and SPDs, technical excellence must be balanced with economic necessity. For new builds, bonding and screening measures can be integrally designed to form part of the complete SPM. However, for an existing structure, retrofitting a set of coordinated SPDs is likely to be the easiest and most cost-effective solution.

Coordinated SPDs

BS EN/IEC 62305-4 emphasises the use of coordinated SPDs for the protection of equipment within their environment. This simply means a series of SPDs whose locations and LEMP handling attributes are coordinated in such a way as to protect the equipment in their environment by reducing the LEMP effects to a safe level. So there may be a heavy duty lightning current SPD at the service entrance to handle the majority of the surge energy (partial lightning current from an LPS and/or overhead lines) with the respective transient overvoltage controlled to safe levels by coordinated plus downstream overvoltage SPDs to protect terminal equipment including potential damage by switching sources, e.g. large inductive motors. Appropriate SPDs should be fitted wherever services cross from one LPZ to another.

Coordinated SPDs have to effectively operate together as a cascaded system to protect equipment in their environment. For example the lightning current SPD at the service entrance should handle the majority of surge energy, sufficiently relieving the downstream overvoltage SPDs to control the overvoltage.

Appropriate SPDs should be fitted wherever services cross from one LPZ to another

Poor coordination could mean that the overvoltage SPDs are subject to too much surge energy putting both itself and potentially equipment at risk from damage.

Furthermore, voltage protection levels or let-through voltages of installed SPDs must be coordinated with the insulating withstand voltage of the parts of the installation and the immunity withstand voltage of electronic equipment.

Enhanced SPDs

Whilst outright damage to equipment is not desirable, the need to minimize downtime as a result of loss of operation or malfunction of equipment can also be critical. This is particularly important for industries that serve the public, be they hospitals, financial institutions, manufacturing plants or commercial businesses, where the inability to provide their service due to the loss of operation of equipment would result in significant health and safety and/or financial consequences.

Standard SPDs may only protect against common mode surges (between live conductors and earth), providing effective protection against outright damage but not against downtime due to system disruption.

BS EN 62305 therefore considers the use of enhanced SPDs (SPD*) that further reduce the risk of damage and malfunction to critical equipment where continuous operation is required. Installers will therefore need to be much more aware of the application and installation requirements of SPDs than perhaps they may have been previously.

Superior or enhanced SPDs provide lower (better) let-through voltage protection against surges in both common mode and differential mode (between live conductors) and therefore also provide additional protection over bonding and shielding measures.

Such enhanced SPDs can even offer up to mains Type 1+2+3 or data/telecom Test Cat D+C+B protection within one unit. As terminal equipment, e.g. computers, tends to be more vulnerable to differential mode surges, this additional protection can be a vital consideration.

Furthermore, the capacity to protect against common and differential mode surges permits equipment to remain in continued operation during surge activity - offering considerable benefit to commercial, industrial and public service organisations alike.

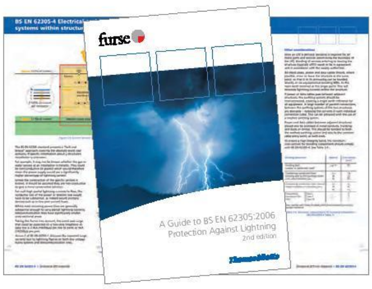
All Furse SPDs offer enhanced SPD performance with industry leading low let-through voltages (voltage protection level, U_p), as this is the best choice to achieve cost-effective, maintenance-free repeated protection in addition to preventing costly system downtime. Low let-through voltage protection in all common and differential modes means fewer units are required to provide protection, which saves on unit and installation costs, as well as installation time.

All Furse SPDs offer enhanced SPD performance with industry leading low let-through voltage

Conclusion

Lightning poses a clear threat to a structure but a growing threat to the systems within the structure due to the increased use and reliance of electrical and electronic equipment. The BS EN/IEC 62305 series of standards clearly acknowledge this. Structural lightning protection can no longer be in isolation from transient overvoltage or surge protection of equipment. The use of enhanced SPDs provides a practical cost-effective means of protection allowing continuous operation of critical systems during LEMP activity.

A Guide to BS EN 62305 Protection Against Lightning



Further to this summary on BS EN/IEC 62305, we have available a comprehensive guide to the BS EN 62305 standard for those interested in learning more about the new developments governing lightning protection design and installation. This A4 Guide helps to explain in clear terms the requirements of BS EN 62305. Following the 4 sections of the standard (Part 1 - General principles; Part 2 - Risk management; Part 3 - Physical damage to structures and life hazard; and Part 4 - Electrical and electronic systems within structures) the Guide provides the information necessary to enable the reader to identify all risks and calculate the required level of protection in accordance with BS EN 62305.

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