Faculty of Engineering

MODELLING THE METAL OXIDE VARISTOR (MOV) SURGE ARRESTER FOR OVERHEAD PROTECTION IN TRANSMISSION LINE

Nur Alisah Syuhadah binti Mohd Haiza

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Grade: ______________

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Final Year Project Report	√
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To my beloved family and friends

MODELING THE METAL OXIDE VARISTOR SURGE ARRESTER FOR OVERHEAD PROTECTION IN TRANSMISSION LINE

NUR ALISAH SYUHADAH BINTI MOHD HAIZA

A dissertation submitted in partial fulfilment
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ABSTRACT

This project focused on the modelling and analysis of Metal Oxide Varistor Surge Arrester Model Type in Transmission Line for Overhead Protection. The primary cause of damage to electrical system equipment is transient overvoltage occurring in the power system. Therefore, the metal oxide surge arrester serves as a protective device to mitigate the impact of lightning and safeguard high and medium voltage system devices from switching overvoltage and lightning. The project utilized the metal oxide surge arrester to protect the transmission line insulations and equipment connected to the transmission tower. The simulation involved a lightning strike on the transmission tower, inducing a sudden high voltage in the system that could potentially damage other equipment. Moreover, this project simulated the dynamic properties of metal oxide varistor surge arresters using various proposed models, including the IEEE model, Pinceti model, and Fernandez model. These models were implemented in the PSCAD simulation software. A 1.5km single line of 275kV with 5 towers was modelled and simulated using the PSCAD software to conduct performance tests on different types of metal oxide varistor surge arrester models proposed for protecting the towers and transmission lines.

ABSTRAK

Projek ini menerangkan tentang pemodelan dan menganalisis Jenis Penahan Lonjakan Varistor Logam Oksida dalam Talian Penghantaran untuk Perlindungan Atas. Kerosakan pada peralatan sistem elektrik kebanyakannya disebabkan oleh voltan lampau sementara yang berlaku dalam sistem kuasa. Oleh itu, penangkap lonjakan oksida logam adalah salah satu alat pertahanan yang boleh mengurangkan kesan kilat dan melindungi peranti sistem voltan tinggi dan sederhana daripada menukar voltan lampau dan kilat. Dalam projek ini, penangkap lonjakan oksida logam akan digunakan untuk melindungi penebat talian penghantaran dan peralatan sistem kuasa yang dipautkan ke menara penghantaran. Dalam simulasi, sambaran petir akan menjadi strok pada menara penghantaran yang akan memberikan voltan tinggi secara tiba-tiba dalam sistem yang boleh merosakkan peralatan lain. Sebaliknya, sifat dinamik penangkap lonjakan varistor oksida logam telah disimulasikan dalam projek ini dengan menggunakan beberapa model yang dicadangkan iaitu model IEEE, model Pinceti dan model Fernandez. Model-model ini disimulasikan dengan menggunakan perisian simulasi yang dipanggil PSCAD. Talian tunggal 1.5km 275kV dengan 5 menara telah dimodelkan dan disimulasikan dengan perisian PSCAD untuk menjalankan ujian prestasi pelbagai jenis model penahan lonjakan varistor oksida logam yang telah dicadangkan untuk melindungi menara dan talian penghantaran.

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CHAPTER 1

INTRODUCTION

1.1 Background

Lightning is a natural phenomenon which discharge an enormous amount of electrical energy. This situation can be extremely destructive as it carries a lot of energy. With only a single stroke to transmission line, it is adequate to cause a blackout throughout a feeder. In Malaysia, lightning strikes are very common phenomenon as the country's tropical change and location. Malaysia is one of the countries with the highest lightning flash density globally [1]. This statement has proven an online article that disclose Malaysia has one of the world's greatest rates of lightning strikes which 132 deaths were caused over a ten-year period, up until August 2019 [1]. Therefore, Malaysia must be aware of the lightning behaviour that will affect the performance of electric supply industry.

However, lightning is also capable of striking the transmission line at any time. When lightning hits a transmission line, an instantaneous and substantial amount of electricity will flow into the electrical system. Lightning that strikes a power transmission line (or phase) directly causes the voltage to increase by a million volts or more within a millionth of a second on the affected line. A huge amount of the lightning surge is diverted to the tower and then to ground when there is an excessive voltage, which causes one or more of the suspension insulators supporting the afflicted phase to arc over to the grounded tower. Along the transmission line, high-voltage surges also move (in both directions) in the direction of supply and downstream substations. However, this phenomenon can be avoided and protected the transmission line from the surge by implementing the lightning arrester. The transmission line insulations and equipment of the power system that is attached to the transmission tower can be protected by surge arresters of the Metal Oxide Varistor (MOV) type if the transmission line was struck. This protection is possible since the transmission line is linked to the power system. [2].

Metal Oxide Varistor (MOV) surge arresters are often utilised for the purpose of providing protection for systems and equipment operating at medium and high voltages against the effects of lightning and switching overvoltage[3]. Arresters are available in several forms (such as gapped silicon carbide, gapped or non-gapped metal oxide), and they all function in the same way, in which they act as high impedances when they are subjected to typical operating voltages and turn into low impedances when they are subjected to surge circumstances [4], [5]. Although silicon-carbide (SiC) gapped arresters are still used, metal-oxide arresters without gaps with metal-oxide resistors are fitted virtually entirely today. [6]. They function with less power-frequency current leakage than SiC arresters and exhibit exceptionally nonlinear properties [3]. Only the overvoltage-induced current impulse can pass through a MOV arrester; power-frequency propagation is not permitted. This makes it possible to substitute MOV arresters with lesser energy capacities for SiC arresters. [7].

The frequency-dependent characteristic of MOV-type surge arresters is proposed to be represented by the dynamic models of surge arresters, which are crucial for insulation coordination and reliability studies of multiple models in power systems at different voltage levels. IEEE, Fernandez, and Pinceti are the established surge arrester models [2]. These models have been used to simulate the power system which simulation results corresponding to the arrester's actual behaviour.

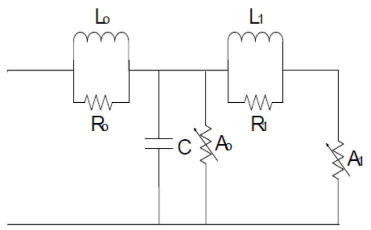

Figure 1.1 IEEE Model [22]

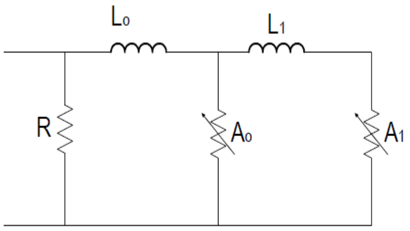

Figure 1.2 The Pianceti – Gianettoni Model [23]

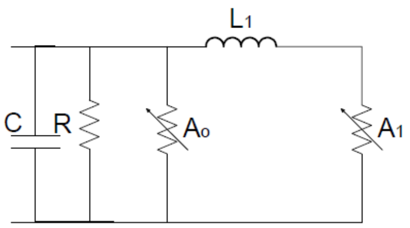

Figure 1.3 The Fernadez – Diaz Model [24]

1.2 Problem Statement

Due to lightning strike and switching overvoltage, the distribution and transmission lines, as well as the electrical equipment that is associated with them, are subjected to a great deal of stress. This halts the normal operating of the electricity systems and causes equipment failure. The placement of wires above ground is the most common method for enhancing lightning performance and decreasing transmission line issues. These wires are designed to deflect lightning strikes that may otherwise damage the phase conductors [8]. The lightning leakage current that passes through the impedance of the tower and tower footing when lightning hits the tower frame or the overhead shield wire results in potential variations throughout the line insulation. When the line's insulator strength is surpassed, a flashover occurs. Additionally, considering that tower voltage highly relies on tower resistance, footing resistance is a crucial factor in assessing lightning performance [9].

Surge arresters are thought to be the most effective defence against this transient overvoltage at locations with a high resistance value and keraunic level, as compared to ground wires. Arresters are used to channel the overvoltage impulse and are placed between the phase and the ground. They are built to be great conductors when line voltage exceeds design standards, allowing the energy of a lightning strike to reach the earth, and to be insulators at normal operating voltage, transporting barely more than a few milliamperes of current. Surge arresters increase the line's lightning performance, but they bear the risk of being destroyed by strong current impulses.

The simulation model used serves as a foundation for the theoretical estimation of the likelihood of surge arrester failure. The dynamic behaviour of metal oxide surge arresters is controlled by the period of peak of the injected impulse current, so that the residual voltage peaks before the maximum of the impulse current and rises with low front timings of the injected impulse current [10]. A variety of techniques are available in the literature to predict the frequency-dependent performance of metal oxide surge arresters. The IEEE model, Pinceti-Gianettoni model, and Fernandez-Diaz model are the most used and well-known models. The next two models employ streamlined versions of the IEEE model. An appropriate computerised system (PSCAD) that provides and analyses the performance test data of each model is used to create and compare the arrester models.

1.3 Objectives

The purposes of the study are:

i. To determine the most suitable types of MOV lightning arrester model implementation in transmission tower and transmission line.
ii. To simulate dynamic properties and evaluate the performance test on the different model of surge arrester for protecting the tower of 275kV transmission line from lightning strike.

1.4 Scope

The scopes for this project are the development of the project. This project will be carried out with the following steps:

i. Research of the journals, articles and other sources

   This project is developed by doing research to prove the objectives. Many research papers, journals, articles and other resources have been studied to undergo this project.

ii. Design of the model system

   This project has been using a software simulator to design a system to utilize the objectives of the project. The software that has been used is PSCAD. Even though this project is only study research regarding the propose of the project, a system must be designed to do a performance test by evaluating and testing the system so that can proof the problem statement with solid evidence with analysis and discussion.

iii. Results and Analysis

   After conducting the performance test of the system, a calculations and analysis will be carried out from the results obtained. By performing the calculations and analysis of the overvoltage in power system during transient states for estimation of expected values of overvoltage, this will give a verification of the project study.

1.5 Project Outline

There are five chapters in the study. A brief description of each chapter is discussed.

1.5.1 Chapter 1: Introduction

The project background, problem statement, objectives, scope, and project plan are all included in Chapter 1.

1.5.2 Chapter 2: Literature Review

Chapter 2 provides an overview of the research required to complete the first aim of the project, which involved the process of evaluating system utilisation. Additionally, a research gap has been developed based on the literature review to compare the methodology, results, and restrictions.

1.5.3 Chapter 3: Methodology

The fundamental methods to accomplish the second objective is provided in Chapter 3. The modelling and analysing the suitable type of lightning arrester for transmission line overvoltage protection is also explained in this chapter, along with the model design and operating mechanism.

1.5.4 Chapter 4: Results and Discussion

In this chapter, the results are recorded and observed. The Results and Discussion section of this report presents a comprehensive analysis of the findings obtained from the study. This section aims to provide a detailed account of the data collected, the statistical analyses performed, and the interpretation of the results in light of the research objectives.

1.5.5 Chapter 5: Conclusion

The overall conclusion and a summary of the accomplishments of the project will be made after the completion of the study are presented in Chapter 5. Future research and recommendations are also included.

1.6 Summary

In conclusion, the modelling and analysis of the suitable type of lightning arrester for transmission line overvoltage protection were studied, analysed, and evaluated to provide evidence of the best type of lightning arrester that should be implemented in transmission line protection. In this study, a model system was constructed in a software simulator to accurately analyse the results.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter summarises research on lightning behaviour. Not only that, but this chapter also reviews how metal oxide surge arresters behaved during lightning strikes. Then, the scientific review focuses on the methodologies employed by various studies to investigate lightning behaviour and lightning protection technologies. A research gap is mentioned at the end of the section.

2.2 Metal Oxide Varistor (MOV) Surge Arrestor

A surge arrester is a safety device designed to safeguard a system from potential damage. The installation of surge arresters is a common practise in the generation system, transmission line, and distribution system. The purpose of incorporating sensitive molecules into structural materials is to effectively redirect high voltage to the ground. The majority of the materials employed in the construction of the Metal Oxide Varistor Surge Arrester (MOV) which also known as MOSA correspond to its structural components. Therefore, surge arrestors play a crucial role in protecting electrical equipment from transient overvoltage, including those caused by lightning discharges and line-switching surges.

One type of surge arrester commonly used in transmission lines is the metal oxide varistor surge arrestor [2]. Metal oxide varistor surge arrestors are designed to absorb electrical energy resulting from temporary overvoltage and convert it into heat, preventing the excessive voltage from damaging the insulation of the transmission line and connected equipment. Metal oxide surge arrestors are essential for maintaining the integrity of medium and high-voltage systems by protecting against overvoltage [26]. Metal oxide surge arrestors are often subjected to high-voltage stresses due to various factors, such as high earth resistance of the grid grounding system, sealing defects and environmental contamination, resonance and switching surges, lightning overvoltage, and repeated transients [26]. These surge arrestors are installed closely to the equipment being protected, allowing them to rapidly divert the surge current away from the sensitive components. The metal oxide varistor surge arrestor model is preferred in transmission line applications due to its high energy absorption capability and highly nonlinear V-I characteristic. The metal oxide surge arrester model used in transmission lines is typically a nonlinear metal oxide arrester without gaps [11]. This model utilizes metal oxide varistors, which are made of a polycrystalline ceramic material, typically doped zinc oxide. This material has unique properties that make it ideal for surge protection, including a high specific energy absorption capacity, reliability, and cost-effectiveness [12]. The metal oxide varistor surge arrestor model is widely chosen for transmission line applications due to its ability to effectively absorb and dissipate electrical energy resulting from temporary overvoltage, lightning strikes, and switching surges. In conclusion, the metal oxide varistor surge arrestor is a vital component in transmission lines for mitigating the damaging effects of transient overvoltage.

Figure 2.1 A ZnO 20kV Surge Arrester (MOSA) [3]

The construction of MOSA is characterised by a straightforward design, consisting of one or several columns of cylindrical blocks known as varistors. Figure 2.3 illustrates a surge arrester with a ZnO (zinc oxide) composition, operating at a voltage of 20kV.

Figure 2.2 shows the resulting voltage in high voltage electrical system where the peak voltage between phases to earth continuously shown in per unit (pu), depending on the length of time it is produced.

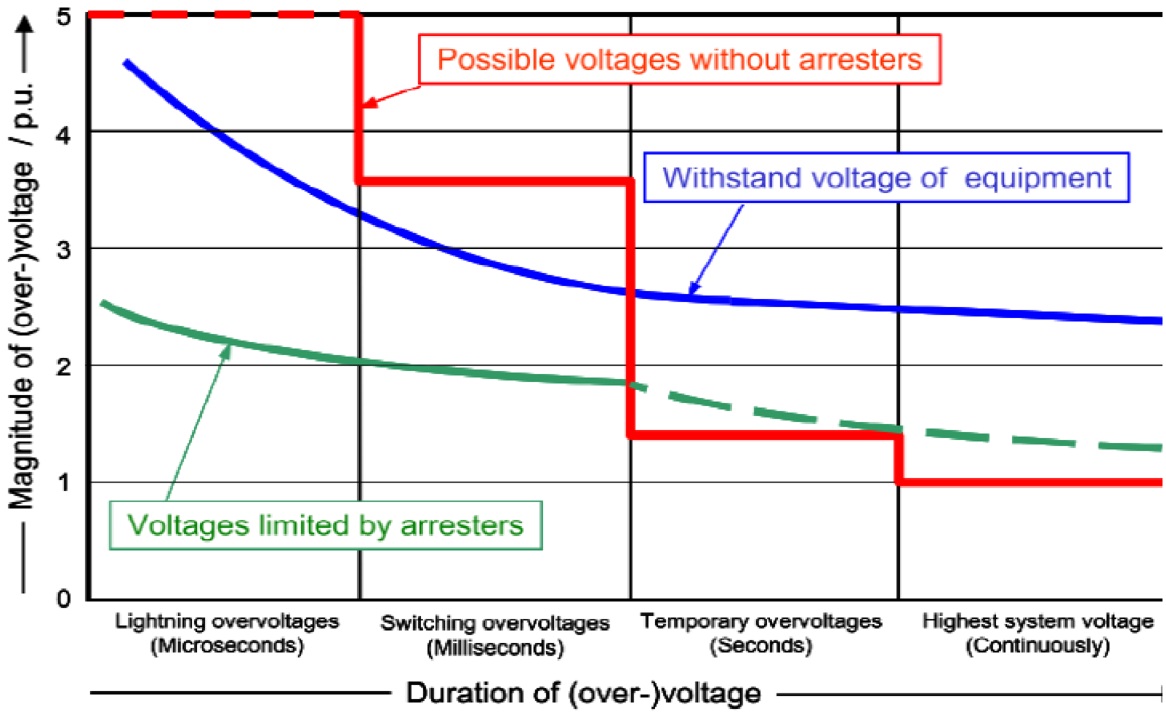

Figure 2.2 Magnitude Of Voltages And Over Voltages In A High Electrical Power System Versus Duration Of Their Appearance [16]

The time axis is partitioned into four distinct zones, specifically the 'Lightning Overvoltage' occurring in microseconds, the Switching Overvoltage occurring in milliseconds, the Temporary Overvoltage occurring in seconds, and the Highest Continuously reflected in the system voltages. As depicted in Figure 2.2, lightning and switching events pose a higher susceptibility to damage and accidents compared to other factors, even when the duration of such events is relatively brief, particularly in the absence of surge arresters. The occurrence of damage is likely to transpire as a result of the low resistance exhibited by low voltage equipment when subjected to overvoltage. Nonetheless, the inclusion of a surge arrester serves the purpose of safeguarding equipment in the event of lightning strikes and switching activities.

The installation of the surge arrester for transmission lines is carried out in parallel with the equipment that is being safeguarded. The observed phenomenon can be attributed to the occurrence of current flow and voltage flash, which does not directly affect the equipment. Instead, it is directed towards the surge arrester via an online route. The primary objective of this process is to safeguard the insulator string by significantly enhancing its ability to withstand lightning strikes. Consequently, this approach leads to a substantial reduction in the rate of lightning-induced trip-outs, thereby achieving the intended goal of lightning protection.

When the tower was struck by lightning, a portion of the lightning current was conducted through the overhead ground wire to the nearby tower, while another portion of the lightning current was conducted through the tower itself and dissipated into the earth. The transient resistance feature of a tower's grounding resistance necessitates the usage of impulse grounding resistance to effectively demonstrate it [27].

When the magnitude of lightning current exceeds a specific threshold, the arrester is capable of diverting the current. The majority of the electrical current generated by lightning is directed through the arrester, thereafter conducted along the lead, and ultimately sent to the next tower. The phenomenon of electromagnetic induction occurs between the leads when there is a flow of lightning current through both the lightning shield line and the leads. This results in the generation of coupling components in both the leads and the lightning shield line. The shunt current of the arrester significantly exceeds the shunt current resulting from the lightning current shunted by the lightning shield line. The presence of shunt leads contributes to the enhancement of lightning protection by reducing the potential difference between the lead and the top of the tower to a level below the flashover voltage of the insulator string. It is possible that flashover does not occur in an insulator. Therefore, the line arrester has a significant capability to effectively hold electrical potential. These are the major qualities of a queue arrester. The protective range of an arrester may be demonstrated to encompass solely the tower on which the arrester is situated, as well as the insulator string associated with the arrester. This holds true for both lightning counterattack and instances of lightning shielding failure [27].

The MO resistor is characterised by its highly nonlinear voltage-current (U-I) characteristic, which eliminates the need for disconnecting the resistors from the line using serial spark-gaps, a feature commonly observed in arresters utilising SiC resistors. Silicon Carbide (SiC) is a material commonly utilised in surge arresters, however its application in this particular model is infrequent. The structure of the device consists of a gap located between arrester