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MODELING AND SIMULATION OF GROUNDING PROTECTION FOR PROTECTING HIGH VOLTAGE DIRECT CURRENT (HVDC) TRANSMISSION LINES FROM LIGHTNING

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Bachelor of Engineering

Electrical and Electronics Engineering with Honours

2023

MODELING AND SIMULATION OF GROUNDING PROTECTION FOR PROTECTING HIGH VOLTAGE DIRECT CURRENT (HVDC) TRANSMISSION LINE FROM LIGHTNING

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A dissertation submitted in partial fulfilment

of the requirement for the degree of

Bachelor of Engineering

Electrical and Electronics Engineering with Honours

Faculty of Engineering

University Malaysia Sarawak

2023

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To my beloved family and friends.

ACKNOWLEDGEMENT

First and foremost, I would like to express my utmost gratitude to my supervisor, Puan Shirley anak Rufus for her supervision throughout the year. I am also eternally grateful to be offered to do my Final Year Project entitled modeling and simulation of grounding protection for protecting high voltage direct current (HVDC) Transmission line from lightning under her supervision. She has been a great support as well as an excellent lecturer in guiding me to complete this project. This project could not have been completed without his assistance.

Besides, words cannot be expressed how grateful I am to my family members for their unwavering moral support while I am conducting and completing this project. Lastly, I will never forget the heartfelt wishes of my classmates, who are always there for me whenever I need them. You have my sincerest gratitude. Once again, I cannot appreciate everyone enough for the love and support they have shown me, and I wish them nothing but happiness and success in life.

ABSTRACT

A very long-distance transmission lines has a high potential of the electrical losses. High Voltage Direct Current (HVDC) transmission systems are considered as an outstanding solution for this problem. However, HVDC transmission lines are vulnerable to lightning strikes. A lightning strike injects electricity into the transmission lines at the location of the contact. Without the used of simulation programmes, understanding lightning performance might be challenging. PSCAD, a capable programme, was used to generate the necessary data to explore this phenomenon. In this study, a 500kV HVDC transmission system is used as a case study to evaluate the impact of lightning strikes on the HVDC transmission tower. A 500kV HVDC transmission system was constructed using the PSCAD software by considering the real parameters of shielding wire and the tower conductors. A complete 500kV HVDC transmission system model consists of tower model, tower grounding resistance, insulator model, back flashover model and transmission lines. A thorough evaluation of the 500kV HVDC transmission line transient performance during lightning strikes is carried out, taking into consideration various technical parameters. In this study, two scenarios are selected for studying the influence of the lightning strikes on the transmission tower. Double exponential model of lightning strike was constructed using the PSCAD software to produce the lightning waveforms. As for the first scenario, the lightning strike was injected to the shielding wire and the impact of changing the tower grounding resistance was investigated on the insulator flashover occurrences. The second scenario where the lightning strike was injected to the phase conductor (A). The insulator flashover occurrences were investigated by changing the values of tower grounding resistance. From the simulation result, increasing the tower grounding resistance results in higher induced voltage across the insulator for both scenarios. This will result in a higher change of the occurrences of the insulator flashover.

Keywords: HVDC transmission system, lightning model, lightning strikes, insulator flashover.

ABSTRAK

Talian penghantaran jarak yang sangat jauh mempunyai potensi kehilangan elektrik yang tinggi. Sistem penghantaran Arus Terus Voltan Tinggi (HVDC) dianggap sebagai penyelesaian terbaik untuk masalah ini. Walau bagaimanapun, talian penghantaran HVDC terdedah kepada kilat. Kilat menyuntik elektrik ke dalam talian penghantaran di lokasi sentuhan. Tanpa penggunaan program simulasi, memahami prestasi kilat mungkin mencabar. PSCAD, sebuah program yang berkebolehan, telah digunakan untuk menjana data yang diperlukan untuk meneroka fenomena ini. Dalam kajian ini, sistem penghantaran HVDC 500kV digunakan sebagai kajian kes untuk menilai kesan sambaran petir ke atas menara penghantaran HVDC. Sistem penghantaran HVDC 500kV telah dibina menggunakan perisian PSCAD dengan mempertimbangkan parameter sebenar wayar pelindung dan konduktor menara. Model sistem penghantaran HVDC 500kV yang lengkap terdiri daripada model menara, rintangan pembumian menara, model penebat, model lampu kilat belakang dan talian penghantaran. Penilaian menyeluruh ke atas prestasi sementara talian penghantaran HVDC 500kV semasa panahan kilat dijalankan, dengan mengambil kira pelbagai parameter teknikal. Dalam kajian ini, dua senario dipilih untuk mengkaji pengaruh kilat pada menara penghantaran. Model eksponen berganda bagi sambaran kilat telah dibina menggunakan perisian PSCAD untuk menghasilkan bentuk gelombang kilat. Bagi senario pertama, sambaran petir telah disuntik ke wayar perisai dan kesan menukar rintangan pembumian menara telah disiasat ke atas kejadian kilat overlay penebat. Senario kedua di mana sambaran petir disuntik ke konduktor fasa (A). Kejadian flashover penebat telah disiasat dengan menukar nilai rintangan pembumian menara. Daripada hasil simulasi, meningkatkan rintangan pembumian menara menghasilkan voltan teraruh yang lebih tinggi merentasi penebat untuk kedua-dua senario. Ini akan mengakibatkan perubahan yang lebih tinggi bagi kejadian kilat overlay penebat.

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LIST OF ABBREVIATIONS

HVDC – High Voltage Direct Current

UHVDC – Ultra High Voltage Direct Current

DC – Direct Current

GR – Grounding Resistance

HVAC – High Voltage Alternating Current

CEEMD – Complementary Ensemble Empirical Mode Decomposition

DC-TL – Direct Current Transmission Line

PSCAD – Power Systems Computer-Aided Design

EMTDC – Electromagnetic Transient Simulation Engine

TLA – Transmission Lines Arresters

CHAPTER 1

INTRODUCTION

1.1 Introduction

The two current transmission lines that are used for bulk power transmission are high voltage direct current (HVDC) and ultra-high voltage direct current (UHVDC) transmission lines [1]. The benefits of UHVDC transmission system include longer transmission distance, higher voltage levels and higher current transmission capacity. Power transmission lines that operate at voltages more than 800kV are known as UHVDC transmission line [2]. HVDC transmission lines, which usually run at voltages of 500kV or more, are an ideal transmission lines for long-distance power transmission. Currently, HVDC systems are being used as an affordable method of connecting two unique networks via water (sea), as well as two alternating current networks with two different frequencies and alternating current networks powered by renewable energy sources [3][4].

The 500kV HVDC transmission lines that connected Gurun, Kedah in the north along the west coast, Kapar, in the central region, and Pasir Gudang to Yong Peng in the south of Peninsular Malaysia are the largest transmission system that ever been built in Malaysia [5]. The 500kV transmission lines cover a total of 522 kilometers and the 275kV portion is 73 kilometers [5]. Other than that, the Malaysia-Thailand HVDC interconnection was created to improve efficiency and power efficiency and power transmission capacity between the two nations [6]. A full-length neutral conductor is included in the 120km, 300kV HVDC transmission line that links converter stations in southern Thailand and northern Malaysia [6]. The largest UHVDC transmission lines in the world are Jinpin – Sunan East China UHVDC transmission lines with 800kV DC voltage and 2100km length [7]

As the DC transmission lines have complex geographic locations and meteorological conditions along them, there is a high chance that lightning will strike the wire. One of the natural sources of transmission line problems is the lightning flash. Lightning overvoltage has caused a lot of problems to the power grid. These issues may result in power supply outages, equipment failure and malfunctions. There are two types of lightning strikes which are direct and indirect strikes. Back striking refers to transmission line flashovers brought on by lightning striking a tower or grounding wire. Due to the lightning current travelling along the tower and ground wire into the earth, the electrical potential on top of the tower will significantly rise. Other than that, the surge impedance of the tower and ground wire and the grounding resistance can also cause the rises in the electrical potential on top of the tower [8], [9]. There will be a flashover on the line if the difference between the voltage in the insulator string's two ends is greater than the tolerance voltage. Lightning overvoltage occurred when the lightning current crosses the ground wire and strikes a transmission line directly.

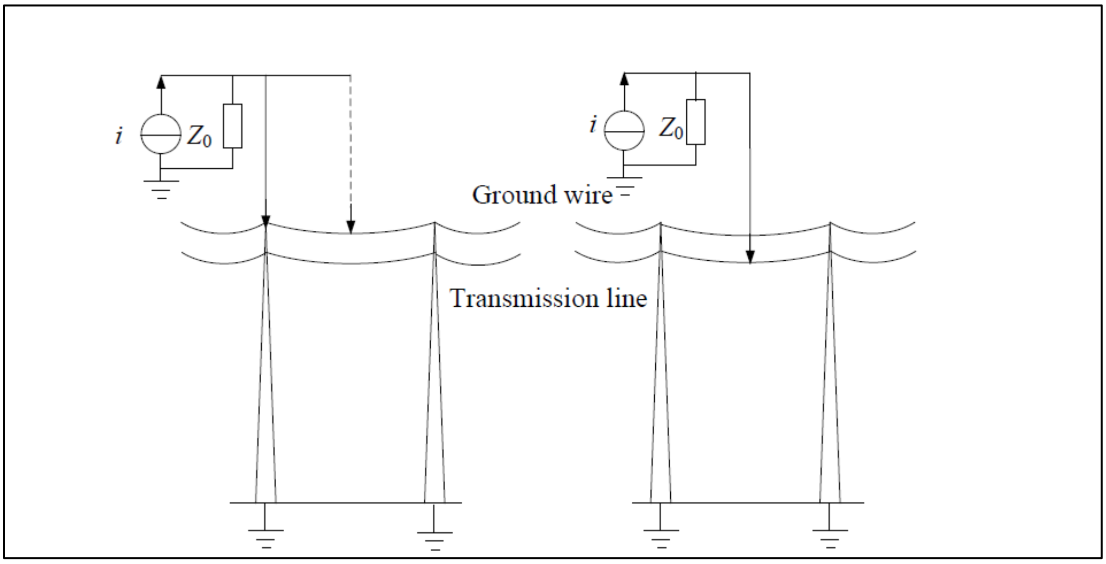

Figure 1.1: Back striking and shielding failure [10]

Transporting a large amount of power over long distance (500km) causes issues such as reduced power transfer, reactive power generation and voltage profile variation [8]. It is important to create a detailed lightning model to study the characterization of lightning shock more thoroughly and effectively. Grounding protection or the installation of ground wires is the basic method for lightning protection of HVDV transmission line. In this research, a simulation model of grounding protection for HVDC transmission lines will be built using PSCAD software [8] This paper mainly focusing on the lightning strike on the HVDC transmission line.

Other benefits of HVDC transmission system include the ability to connect the asynchronous AC systems, enhancing system stability, and having less expensive transmission lines which results to an increase in the HVDC application globally [8]. In 1945, Sweden constructed the first HVDC transmission lines project with a 500kV voltage [8]. Then, China also installed several HVDC transmission projects in the country. The range of the voltages was starting from ±400kV, ±500kV, ±660kV, ±800kV to ±1100kV. Large number of voltages is needed to transport huge distances of electrical energy from wind farms and major hydropower units. The entire global transmission capacity utilising HVDC technology is roughly 80GW [8].

1.2 Problem Statement

Lightning strikes are a common cause of transient overvoltage which can lead to faults. Due to the high electrical losses caused by long-distance transmission, HVDC transmission systems are an excellent solution. Large amounts of electricity must be transported over long distances, which creates issues like reduction of power transmission, reactive power generation, and voltage profile change. In order to connect a very large-scale offshore renewable energy sources, such as wind farms to power grids and to connect distance generation sources load centers, a reliable transmission line must be uses. Therefore, HVDC transmission lines are seen to be the best alternative [8] However, HVDC transmission lines are vulnerable to lightning strikes [8]. Insulation failure such as back flashover can occur when the HVDC transmission lines are strike by the lightning.

About 60% of all transmission line trips in China are caused by lightning, which is strongly correlated with both season and geography [11]The lightning withstand level and lightning related tripping rate are two indices that can be used to assess how well a system protects against lightning. The previous studied shows that the highest lightning current amplitude which measured in kA that a line may withstand before insulation flashover occurs because of a direct lightning strike. The line's lightning performance will improve as the value rises [11] It has been widely believed that lightning-related tripping on lines of 110kV and higher were mostly caused by back flashover and that the incidence of shielding failure was lower because shield wire is installed along the whole length of these lines [11] A few years ago, there were 865 lightning-related trips on the State Grid Corporation's lines, of which 592 (68.4%) were brought on by shielding failure, 269 by back flashover and another four cases caused by unrelated factors [11].

HVDC transmission lines must be able to operate correctly and safely, hence a reliable grounding system is a basic method for transmission lines protection. Therefore, in this paper, a lightning model of grounding protection of HVDC transmission line from lightning will be simulate using PSCAD to study the importance of this type of protection. The problem statement of this study has been simplified in Figure 1.2.

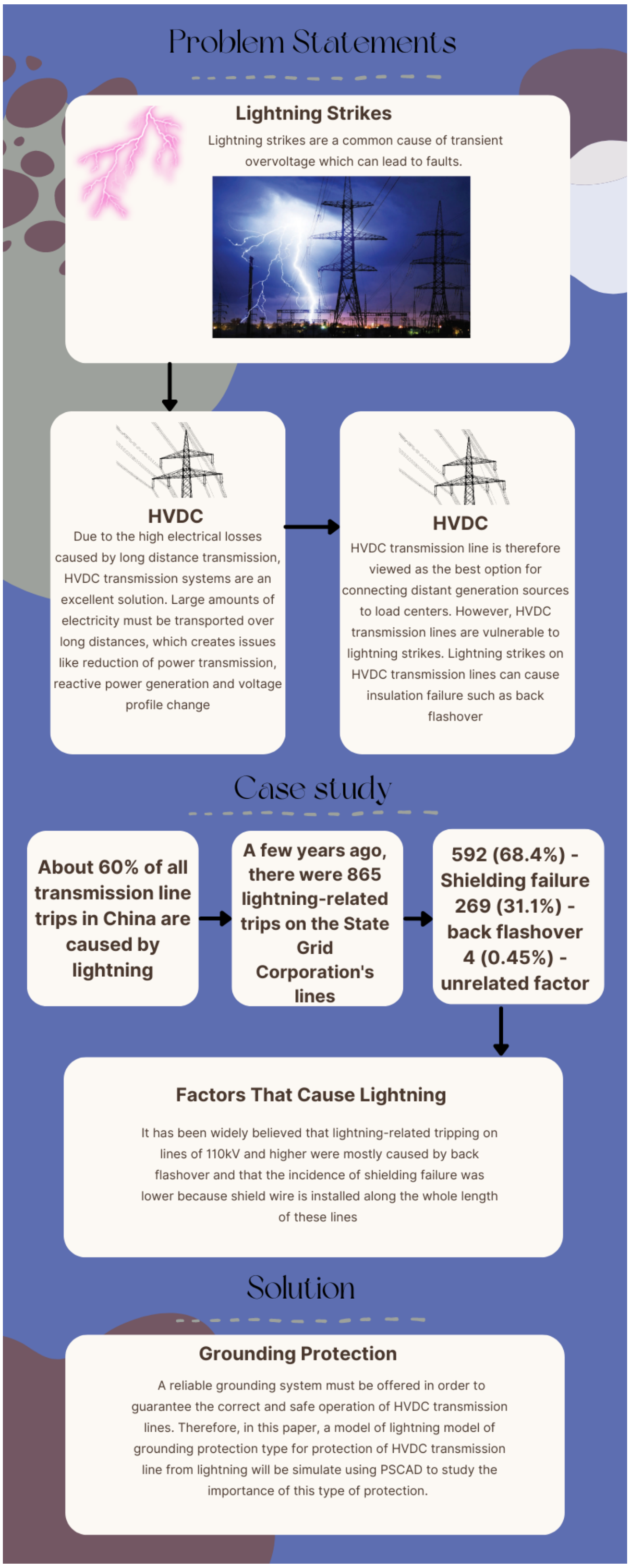

Figure 1.2: Infographic of problem statement

1.3 Objectives

The purposed objectives of this project are:

1. To study and create a lightning model of grounding protection of HVDC transmission line by using PSCAD software.
2. To study the insulator flashover by changing the tower grounding resistance (GR).

1.4 Project Outline

This paper primarily consists of five chapters. The brief descriptions of each of the chapter have been explained in this section.

1.4.1 Chapter 1: Introduction

Chapter 1 includes the introduction of the project including brief description of UHVDC transmission lines, HVDC transmission lines and grounding protection systems. Chapter 1 also consists of the problem statement of the project, the objective of the project, the scope of the research, and the project outline.

1.4.2 Chapter 2: Literature Review

Chapter 2 provides an overview of the studies related to the project that are needed to fulfill the first objective which involved the process of investigating the grounding protection system types and the lightning behavior. A research gap has also been created to compare the transmission lines, software tools used, lightning model, methodology and research outcome based on the literature review.

1.4.3 Chapter 3: Methodology

Chapter 3 contains the necessary methodology to achieve all the objectives. This chapter also explains the lightning simulation model and the transmission tower model that will be used to complete the project. The parameters of all components that will be used have also been stated in this chapter.

1.4.4 Chapter 4: Results and Discussion

Chapter 4 describes the outcomes of the project which include the completed simulation model of transmission line and lightning model. The results from the simulation are displayed in this chapter.

1.4.5 Chapter 5: Conclusion and Recommendations

Chapter 5 concludes the overall project and summarizes the achievement made once the project was finalized. Furthermore, it also contains recommendations and future studies.