Evolution in Electrical and Electronic Engineering Vol. 4 No. 2 (2023) 140-147
© Universiti Tun Hussein Onn Malaysia Publisher's Office

EEEE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/eeee
e-ISSN : 2756-8458

Simulation of Lightning Impulse on Surge Protection Device for Low Voltage System

Nur Nadzirah Syazwani Mohd Fauzi[1], Muhammad Saufi Kamarudin[1]*

[1]Department of Electrical Engineering, Faculty of Electrical and Electronics Engineering,
Universiti Tun Hussien Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/eeee.2023.04.02.019
Received 28 June 2023; Accepted 20 August 2023; Available online 30 October 2023

Abstract: Lightning strikes represent a dangerous threat to electrical equipment, especially for low-voltage alternating current (AC) systems. Overvoltage can be described as a condition when the suddenly rising voltage value happens more than the normal level of the protection devices rated. When a voltage rises above a certain level, the insulating system of electrical equipment and wires will flash over. In order to avoid flash over to happen, surge protection devices (SPDs) work as a crucial component for protecting such systems against transient overvoltages caused by lightning strikes to minimize damages or losses. This study focuses on identifying the effect of Metal Oxide Varistor (MOV) based on their type of protection modes; Normal Mode and Common Mode with the use of ATPDraw software. Heidler type of current sources are used to represent the lightning strikes that occur in the system with a standard current value of 8/20 µs. The circuit model constructed in this research was a three-phase low-voltage AC power system that is commonly used in residential areas. The system works by monitoring the lightning impulse transient on the MOV when a 10kA current is injected into the system. The MOV acts as an open circuit during normal conditions and in a short circuit condition when lightning surges occur to discharge the high current to the ground. The output waveform explained how the MOV works when lightning strikes happen and the amount of high current discharged to the ground in order to protect the system. By comparing the output response waveform for both types of protection modes, the normal mode gives more protection to the system compared to the common mode since the MOV is connected line-to-ground which tends to cause the system failure. It can be analyzed in detail for the capability of the MOV in handling the high current to avoid failures happening in the system depending on the burden that exists.

Keywords: Surge Protection Devices, Lightning Impulse, Metal Oxide Varistor, Low Voltage AC Power System

**Corresponding author: saufi@uthm.edu.my*

1. Introduction

Lightning strikes are a major source of disturbance as they generate huge surge voltage and current which occurs when an electrical discharge is carried on by tensions within or between storm clouds and the earth [1]. British Standard International (BSI) Standard explains that the standard of lightning impulse voltage and current is a smooth full lightning impulse having 1.2/50 μs and 8/20 μs [2].

Surge Protective Devices (SPD) are electrical devices that limit the risk of electrical and electronic equipment damage in a building from lightning surges caused by lightning strikes to the connected low-voltage overhead lines [3]. Overvoltage occurs for various reasons as externally generated overvoltage, mainly due to lightning strikes and related phenomena, and overvoltage due to internal causes such as switching and other operations [4]. It is crucial to use surge protective devices (SPDs) with properties specifically tailored to the respective application field if electrical systems or electronic equipment are to be adequately protected against surge voltages and lightning currents [5]. As a result, many SPDs with different properties have been developed and will be developed in the future. When SPDs are connected to low-voltage power systems (LVPS), qualification testing has to take place under conditions that simulate the real operating conditions of the power systems in which they are to be deployed [6]. In this case, the electrical properties of the power system strongly affect the SPD's operation behavior [7].

The SPD was divided into three (3) regions; pre-breakdown region, breakdown region and high current region [8]. These regions provide useful information for understanding the MOV's behavior during voltage surge occurrences and aid in the selection of the right MOV for surge protection applications. V-I characteristic curves are also called resistance curves of varistors and arresters. It is the case that there is an equal or corresponding voltage or current for any given voltage or current. A varistor, also known as a metal oxide varistor (MOV) disk, is a variable resistor whose resistance is strongly dependent on the voltage applied across its terminals [9].

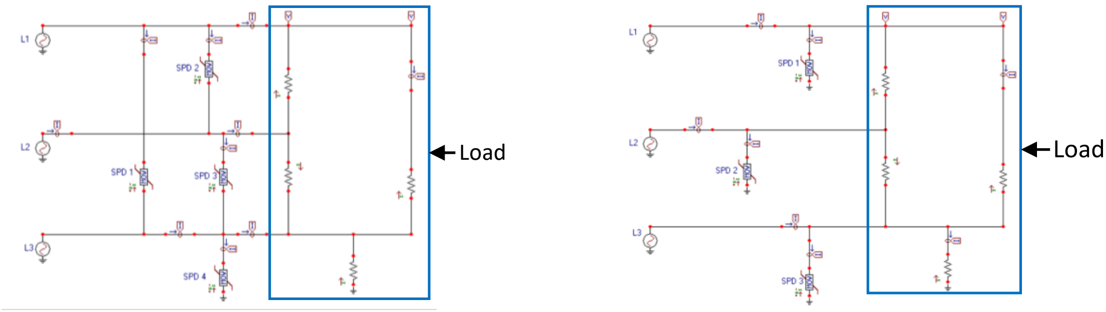
The performance of the MOV is affected by the type of protection mode used for the system; Normal mode or common mode. The difference between these two types of protection modes is the connection of the MOV in the system [10]. In normal mode conditions, the MOV is installed between line-to-line connections [11]. Common mode connected the MOV that is installed between line-to-ground connections [12].

This paper proposed the idea to install additional protection for low-voltage AC systems in residential areas. The comparison effect between both types of protection modes of the MOV in a three-phase AC power system should be done by identifying the lightning impulse that occurs at certain lines of power supply.

2. Materials and Methods

2.1 ATPDraw Simulation Programme

In the simulation, the circuit is constructed in 2 types of protection modes; Normal Mode and Common Mode by comparing the output response based on the location of the MOV. Both types of protection circuits allow monitoring of the effect of the lightning impulse in each line that flows through the MOV. A normal mode protection circuit is when the MOV is located across a line-to-line connection meanwhile common mode protection connects the MOV between the line and the ground. Figures 1(a) and 1(b) show the type of protection modes constructed in the simulation without the Heidler-type component.



(a) (b)

Figure 1: (a) Normal Mode Protection Circuit (b) Common Mode Protection Circuit

Figure 2 shows the Heidler type of source representing the lightning strikes either in voltage or current source. The lightning impulse had been set to 8/20 µs with a peak value of 10kA.

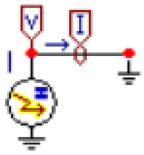


Figure 2: Heidler Type of Source

2.2 MOV Characteristics Selection

The MOV circuit is determined by the operating current and voltage parameter of the application of 10kA current rating. Table 1 shows the MOV V-I Characteristics that were manually filled in the simulation programme.

Table 1: V-I Characteristics of MOV for 10kA Current Rating

Current (A)	Voltage (V)
0.000009	3,595
0.000027	17,976
0.00009	25,167
0.00045	27,863
0.009	28,762
0.9	30,200
9	31,908
112.5	35,413
225	36,492
450	37,750
900	39,907
1350	41,345
2700	43,502
4500	45,660
9000	48,895

3. Results and Discussion

The connection of the MOV in the system affects the protection modes. Surges can transmit in either a Normal Mode (Line-Line) or a Common Mode (Line-Ground) in the distribution system. The resistor with the value of 1M ohm serves as the load connected to the delta connection in both circuits.

A. Normal Mode Protection

The Normal Mode of Protection's MOV arrangement, which consists of four (4) MOV, is depicted in Figure 3. The MOV is connected to the circuit in four different ways: SPD 1 (L1-L3), SPD 2 (L1-L2), SPD 3 (L2-L3), and SPD 4 (L3-Ground).

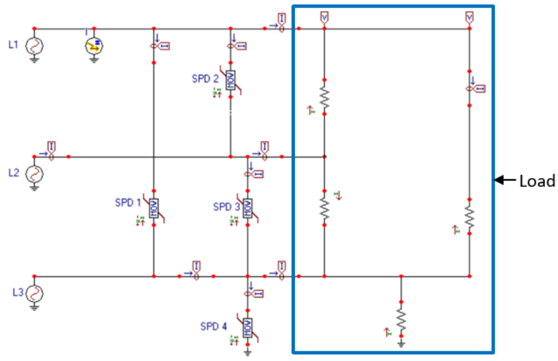


Figure 3: Normal Mode Circuit Diagram

Figure 4 displays the MOV's output response in normal mode when the current was injected at L1. Based on the result obtained, SPD 1 discharges more current than SPD 2 and SPD 3 while SPD 4 discharges the highest value of current when lightning occurs compared to other SPDs. This situation happened because only SPD 4 connected from the line to the ground. SPD 1 discharged 7.9 kA current meanwhile SPD 2 and SPD 3 discharged 3.5 kA current. This process is repeated by changing the location of the lightning strike that occurs on other lines.

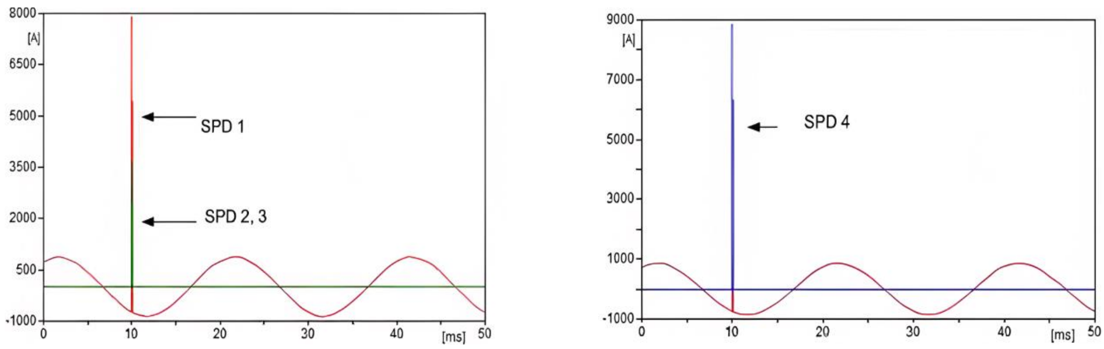


Figure 4: The Output Response of MOV in Normal Mode

The lightning impulse located in the circuit changed from L1 to L2 and L3 to monitor the output response of each line as shown in Figures 5 (a) (b) (c) and Figures 6 (a) (b) (c).

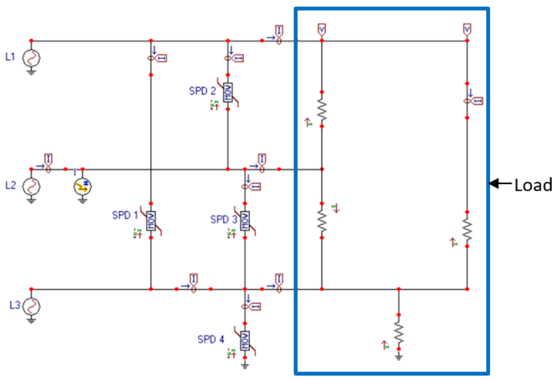


Figure 5 (a): Lightning impulse injected at L2

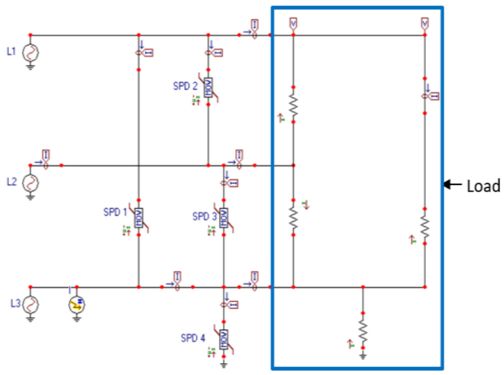


Figure 6 (a): Lightning impulse injected at L3

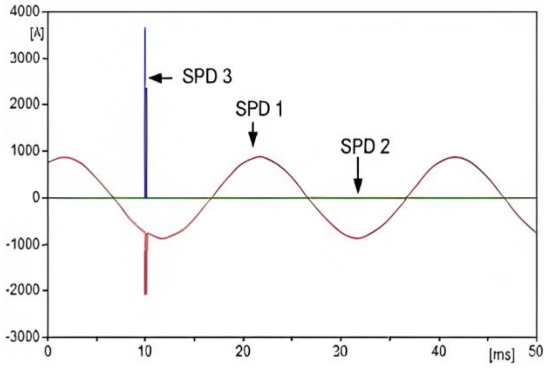


Figure 5 (b): Output Response of SPD 1, SPD 2 and SPD 3 when current injected at L2

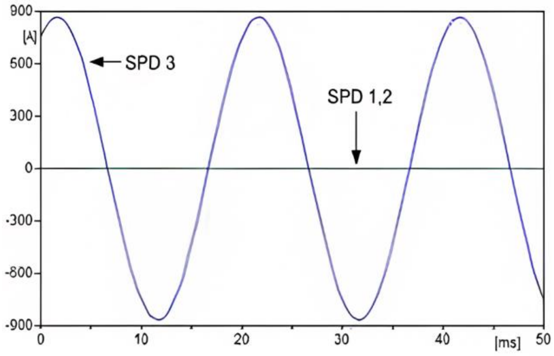


Figure 6 (b): Output Response of SPD 1, SPD 2 and SPD 3 when current injected at L3

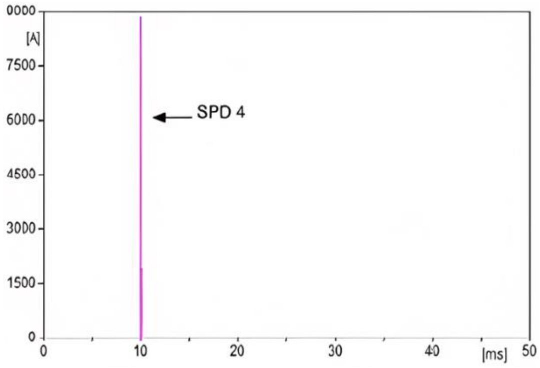


Figure 5 (c): Output Response of SPD 4 when current injected at L2

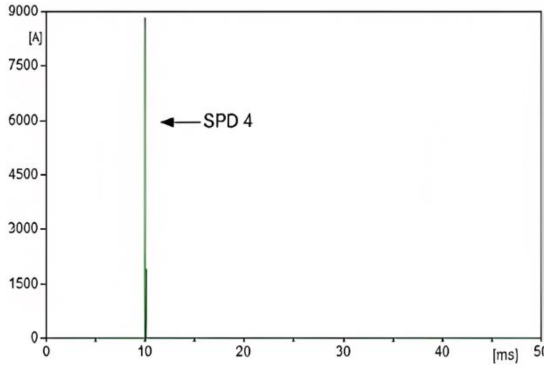


Figure 6 (c): Output Response of SPD 4 when current injected at L3

B. Common Mode Protection

Figure 7 (a) depicts the MOV configuration for the Common Mode of Protection, which consists of three (3) MOVs. A line-to-ground connection is made between the MOV in this circuit's SPD 1 (L1-ground), SPD 2 (L2-ground), and SPD 3 (L3-ground) lines. The output response of the MOV is shown in Figure 7 (b) when the current is injected at L1. SPD 1 discharges the most current compared to SPD 2 and SDP 3. Since each SPD is connected line-to-ground, the current will discharge to the ground in order to protect the system when a lightning strike occurs. This process is repeated by changes in the location of the current injected at L2 and L3. In common mode protection, the MOV works similarly in each line depending on the location of lightning that occurs.

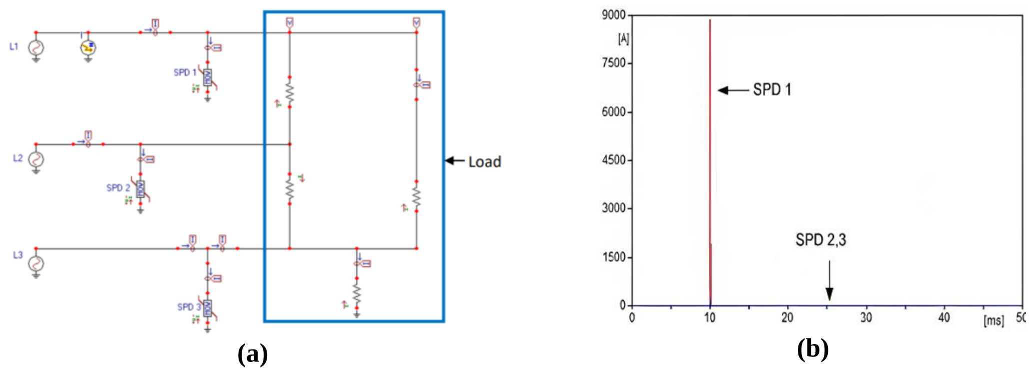


Figure 7: (a) Common Mode Circuit Diagram (b) Output Response of MOV in Common Mode

Figure 8 (a) and Figure 9 (a) show the circuit constructed and the output response for each condition which is when the lightning impulse is located at L2 and L3.

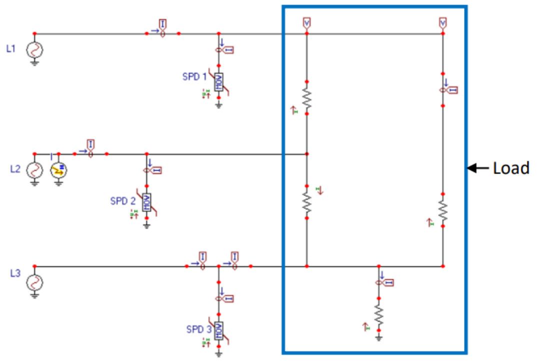


Figure 8 (a): Lightning impulse injected at L2

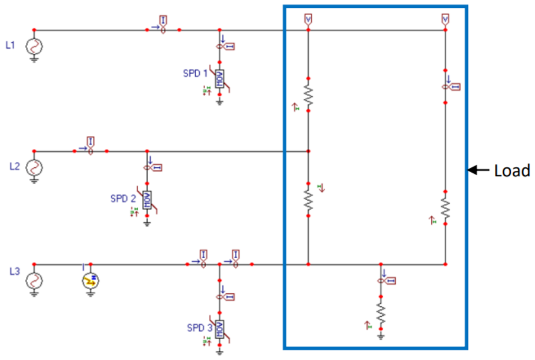


Figure 9 (a): Lightning impulse injected at L3

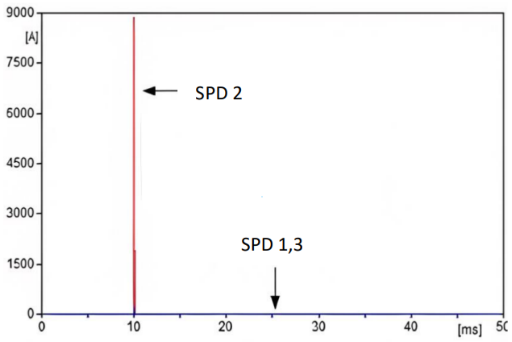


Figure 8 (b): Output Response of SPD 1, SPD 2, and SPD 3 when current injected at L2

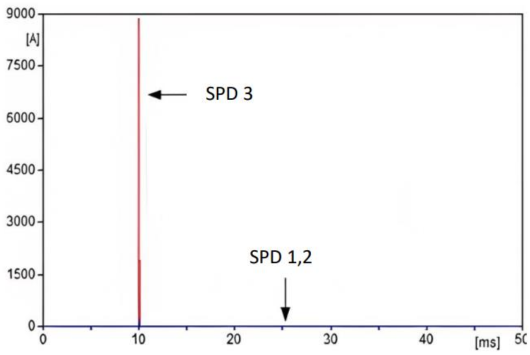


Figure 9 (b): Output Response of SPD 1, SPD 2, and SPD 3 when current injected at L3

C. MOV Effect at L1, L2, L3 in Normal Mode

In this part, the simulation was conducted to monitor the response of the MOV as shown in Figure 10 in Normal mode protection when current is injected into each phase L1, L2 and L3.

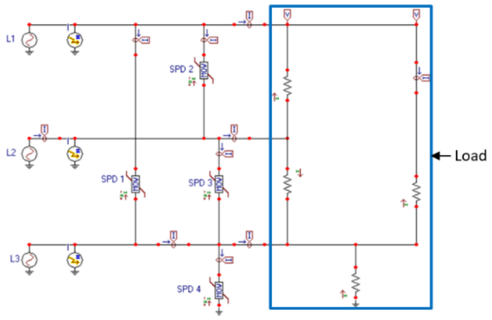


Figure 10: Normal Mode MOV protection circuit with the lightning impulse at L1, L2 and L3

Figure 11 shows the graph generated by each MOV response after the current is injected at 10 kA after 10 ms. Figure 11 shows the output response of the MOV at each line. The current flow through SPD 4 is very high (28 kA) and exceeds the maximum current discharge of the MOV which can cause the failure of the MOV. A higher rating voltage of MOV should be used to prevent MOV failure by the ground fault.

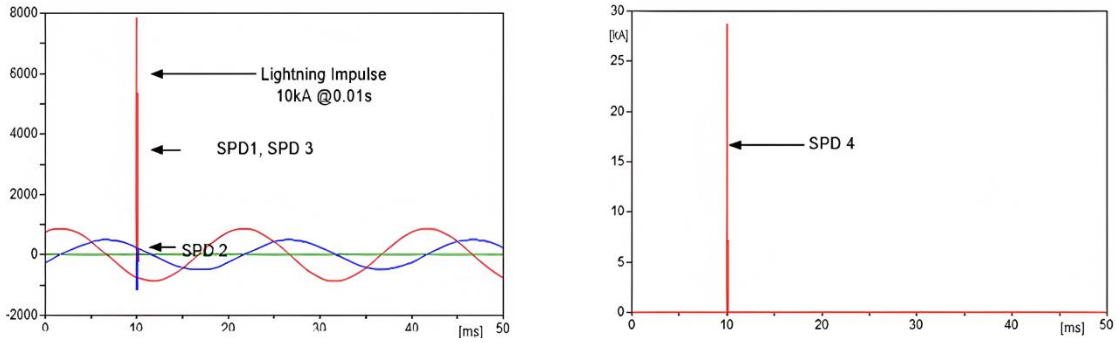
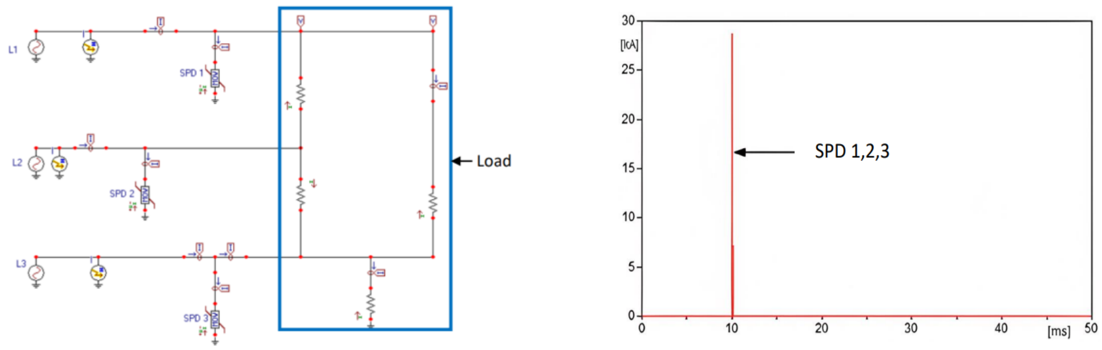


Figure 11: Output Response of the MOVs in Normal Mode at each line

D. MOV Effect at L1, L2, L3 in Common Mode

In common mode protection, the circuit shows as in Figure 12 (a) that the lightning impulse is injected at all phases L1, L2 and L3. In this test, each SPD discharge a similar amount of current to the ground since they work independently to protect each line when a lightning strike occurs without involving other lines as shown in Figure 12 (b).



(a) **(b)**

Figure 12: (a) Common Mode MOV protection circuit with the lightning impulse at L1, L2 and L3 (b) Output Response of the MOVs at each line

4. Conclusion

The ATPDraw simulation programme was used in this project to construct the type of protection mode for a low-voltage ac power system. The analysis through the output response of each MOV works during the lightning strike that occurs in each phase with two types of protection modes; Normal Mode and Common Mode. Normal Mode provides more protection by connecting the SPDs between line-to-line, while Common Mode has three SPDs connected between line-to-ground. However, common mode protection causes current sharing conditions which help to reduce the burden on each SPD. Failure in the Common Mode system was the most common cause of the system failure and each line should be used the higher rating of the varistor in order to prevent the system failures.

Acknowledgement

The authors would also like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

References

[1] Libretexts. 15.3: Lightning and thunder. Geosciences LibreTexts, 2022, from https://geo.libretexts.org/Bookshelves/Meteorology_and_Climate_Science/Practical_Meteorology_(Stull)/15%3A_Thunderstorm_Hazards/15.02%3A_Section_3-

[2] British Standard Institution, Lighting Protection: General Principles, BS 62305-1, 2011

[3] Kisielewicz. T, Piparo. G. B. L, Mazzetti. C, Surge protective devices efficiency for apparatus protection in front of direct flashes to overhead low voltage lines. Electric Power Systems Research, pp 88–96, 2016, from doi: 10.1016/j.epsr.2016.01.008

[4] PPS.R. Murty, Electrical Power Systems Chapter 11 – Overvoltages, pp 229 – 257, 2017.

[5] Finis. G, Wetter. M, Durth. R, Depping. C, Laboratory with highest impulse current and 50 Hz short-current parameters specially designed for the qualification-testing of SPDs, Electric Power System Research, 2016.

[6] Kisielewicz. T, Mazzetti. C, Piparo. G.B L, Flamingo. F, Stress to surge protective devices system due to direct flashes to low voltage lines, Electric Power System Research, Elsevier, 2015.

[7] Uman. M. A, The Art and Science of Lightning Protection, Cambridge University Press 2008.

[8] Jonathan Woodworth, Understanding Arrester Voltage-Current Characteristic Curves Arrester Facts 003, ArresterWorks, March 2019.

[9] Y.C. Cui, Q. L. Wu, H. W. Yang, J. M, Gao, S. Li, C. Y. Shi, Experiments of a 100kV-level pulse generator based on metal-oxide varistor, Scientific Instrument, 2018.

[10] Paul. D, Low Voltage Power System Surge Overvoltage Protection, IEEE, 2000

[11] The Emerald Book, IEEE Recommended Practice for Powering and Grounding Electronic Equipment, 2006, from ISBN: 978-0-7381-7075-6

[12] Electronicsbeliever et al. (2023) Surge Protection Circuit Principle and Design, ElectronicsBeliever. from https://electronicsbeliever.com/surge-protection-circuit-principle-design/ (Accessed: 15 August 2023).