American Journal of Applied Sciences and Engineering | *ISSN 2766-7596*
Published by AIR JOURNALS | *https://airjournal.org/ajase*
12011 WestBrae Pkwy, Houston, TX 77031, United States
airjournals@gmail.com; enquiry@airjournal.org

Research Article

Effect of Tower Footing Resistance on Back Flash over across Insulator in a 132 Kv Transmission Line

Ainah, P. K.[1] & Ugemuge, S.[2]

[1]Department of Electrical and Electronic Engineering, Niger Delta University, Wilberforce Island, Amassoma, Bayelsa State, Nigeria
[2]Department of Works and Physical Planning, Federal University Otuoke, Bayelsa State, Nigeria

Abstract

This study conducts a thorough evaluation of the influence of tower footing resistance on the estimation of over voltages across the insulator caused by lightning strikes. The paper employed the Electric circuit simulator programme (ECSP) to examine the effect of footing resistance and lightning stroke on back flashover on the insulator of a 132 kV transmission line. The study assumes an insulator withstand voltage of 750 kV, lightning strikes of 10 kA, 20 kA, 30 kA, 40 kA, 50 kA, and 100 kA, and a footing resistance range of 5 Ω to 90 Ω. The findings reveal that as the amplitude of the lightning stroke grows, so does the voltage across the insulator, while the tower footing resistance decreases. A good tower footing resistance only helps grounding at 50 Hz, and it is also critical to keep the tower footing resistance and inductance low to ground high frequency lightning surges. This highlights the importance of considering both lightning stroke characteristics and tower grounding conditions in the design and analysis of transmission line systems.

Keywords	*Tower Footing Resistance; Back Flashover; Electric Circuit Simulator Programme (ECSP); Footing Resistance; Lightning Stroke*
Citation	Ainah, P. K. & Ugemuge, S. (2024). Effect of Tower Footing Resistance on Back Flash over across Insulator in a 132 Kv Transmission Line. *American Journal of Applied Sciences and Engineering, 5(1) 10-17.* https://doi.org/10.5281/zenodo.10962815

Introduction

Lighting discharges is one of the causes of failures of high-voltage in power systems or equipment (Hussain, et al., 2023). It has been identified as the cause of transmission lines trip out. About 50% of the fault that happens in transmission line is attributed to lighting discharge to the phase conductor. The reliable transmission of electrical power through high-voltage transmission lines is crucial for ensuring continuous supply to consumers. However, these systems are susceptible to various electrical phenomena, one of which is back flashover. Back flashover occurs when the insulation strength of the transmission line is exceeded, leading to a flashover event that can disrupt power flow and damage equipment (Yadee & Premrudeepreechacharn, 2007; Mohajeryami & Doostan, 2016). The impact of tower footing resistance on back flashover is an extremely important topic. Tower footing resistance refers to the resistance encountered by electrical current when it travels through the grounding system of transmission towers.

It plays a crucial role in determining the effectiveness of the grounding system in dissipating lightning-induced currents and preventing back flashover events. This resistance is influenced by factors such as soil composition surrounding the tower footing, moisture in the soil, the depth of the grounding electrodes and conductors installed around the tower footing, and the design of the tower foundation, including the materials used and the configuration of grounding components (Wang et al., 2021). Understanding how tower footing resistance impacts back flashover is essential for engineers and operators tasked with designing, maintaining, and operating high-voltage transmission systems. By delving into this subject, we can explore the mechanisms behind back flashover incidents and develop effective mitigation strategies to enhance system reliability and performance. Environmental conditions such as temperature variations and seasonal changes can impact soil conductivity and, consequently, tower footing resistance (Wang et al., 2021). These factors must be considered during the design and maintenance of transmission line grounding systems. In a low footing resistance state, the current from a lightning strike is effectively dissipated through the tower footing resistance. This helps in keeping the transient overvoltage across the insulator string at a relatively low level. By providing a path for the lightning-induced current to flow into the ground, the tower footing resistance helps in reducing the stress on the insulation (Yadav, et al., 2021). Understanding the complex interplay of these factors is essential for engineers and technicians involved in the planning, installation, and maintenance of tower grounding systems. By optimizing tower footing resistance, it is possible to improve the overall performance and reliability of high-voltage transmission lines, reducing the risk of back flashover and other electrical disturbances. Understanding and addressing the impact of tower footing resistance on back flashover is essential for ensuring the safe and reliable operation of 132 kV transmission lines. Numerous researchers have investigated the influence of footing resistance, magnitude of lightning stroke and back flashover the insulation using different simulation tools (Warmi, et al., 2023; Anekthanasuwan, et al., 2015; Moselhy, et al., 2020; Talib, et al., 2012). In this paper, Electric circuit simulator programme environment is used to investigate and analyse the impact of the footing resistance and the magnitude of lightning stroke on the voltage across the insulator that will cause back flashover.

Back Flashover

Back flashover poses a significant risk in high-voltage transmission systems such as 132 kV lines. This phenomenon arises when the insulation of the transmission line is unable to handle the electrical stress, resulting in a flashover event. The consequences can be severe, including equipment damage and disruptions in power transmission. One crucial factor influencing back flashover is the tower footing resistance. This resistance level plays a vital role in determining when and how severe back flashover incidents occur. It affects various aspects of the system, leading to complexities in understanding and managing this phenomenon. Uneven voltage distribution is one consequence of inadequate tower footing resistance. This can create hotspots along the transmission line, increasing the risk of flashovers. Additionally, inadequate resistance can subject the insulation to higher stress levels, potentially compromising its effectiveness over time.

The volt-time characteristic of insulators provides insight into their ability to withstand transient voltages. While insulators may fail under prolonged exposure to lower voltages, they can withstand short-duration high transient voltages. Understanding these characteristics is essential for designing resilient transmission systems that can withstand electrical stress and prevent back flashover incidents. The insulator voltage withstand capability can be estimated as;

$$V_o = 0.9 * \left(400 + \frac{710}{t^{0.75}}\right) d \qquad 3.$$

Where, d is the length of gap between gap horn (m), t is the time elapse after lightning (µs) and V_o is the flashover voltage (kV).

Tower Footing Resistance Model

Tower footing resistance is influenced by factors such as soil composition, moisture levels, depth of the grounding system, and the design of the tower foundation. Higher tower footing resistance can cause uneven voltage distribution along the transmission line, creating areas with higher electric field strength that are more prone to back flashover (Naidoo, 2019). Conversely, lower tower footing resistance facilitates effective dissipation of lightning and earth fault currents, reducing the risk of flashovers across the transmission tower insulator. However, high tower footing resistance leads to increased transient over voltages during switching operations or lightning strikes. These over voltages stress the insulation of the transmission line, weakening its ability to withstand flashover events and increasing the chances of back flashovers.

To approximate variable grounding resistance, especially under surge, current conditions, a surge current-dependent equation can be applied using equation 1.

$$R_T = \frac{R_g}{\sqrt{1+\frac{I}{I_g}}} \qquad 1$$

Where R_T is the footing resistance, R_g is the tower resistance at low current and frequency, I is the surge current into the ground and I_g is the limiting current initiating soil ionization (KA) while the limiting current aiding ionization is given equation 2.

$$I_g = \frac{1}{2\pi}\left(\frac{E_O \rho_O}{R_G^2}\right) \qquad 2$$

Where Ro is the total grounding impedance's low current at a reduced frequency ratio in equation. Eo is the soil ionization gradient (about 300 kV/m), ρ_O is soil resistivity. Ig is the limiting current. Ig is proportional to soil resistivity ρo.

Methodology

System Description

The transmission tower is modelled with a single-phase conductor and an insulator. The transmission line ohmic resistance, surge impedance, inductivity per meter, capacity per meter line length per meter and line length are 0.00004 Ω/m, 18 Ω, 0.06µH, 185.313 pF, 100/m and 46km respectively. The tower's height is measured using inductance, with the arm having an inductance of 6.4 mH. The inductances from the tower foot to the arm and from the arm to the top are 25 mH and 3 mH, respectively. These details offer a comprehensive view of the transmission line and tower configuration, which is crucial for understanding the electrical behaviour of the system. Additionally, the insulator's Basic Impulse Insulation Level (BIL) is assumed to be 750 kV, indicating its capability to withstand lightning-induced over voltages

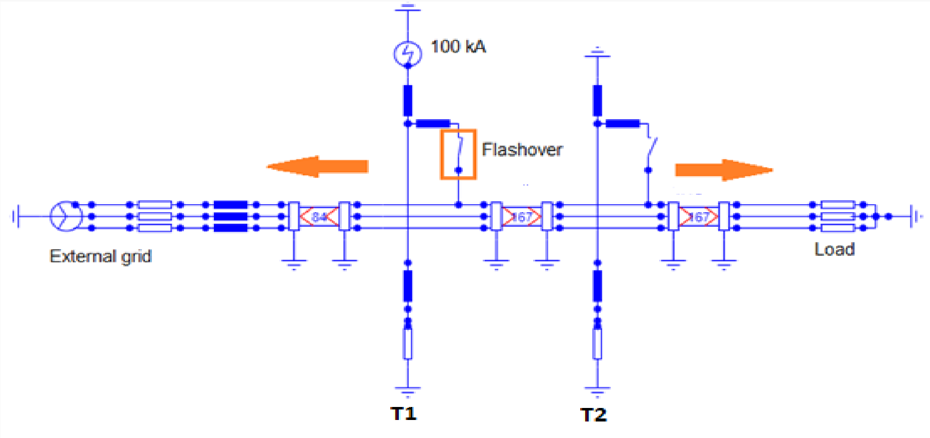

Fig 3: 132kV transmission line showing two tower with one arm and insulator

Method of Analysis

The paper utilized the Online Electric Circuit Software Program (ECSP) to conduct an in-depth analysis of the impact of tower footing resistance on back flashover across the insulator. ECSP is an integral component of the Electric Circuit Simulator (ECS) software, designed as an online tool for modelling and studying various aspects of electrical power circuits and transient events. ECS encompasses a broad spectrum of electrical engineering problems, including transmission line modelling, optimal power flow analysis, short circuit analysis, and transient stability assessment, relay coordination, load flow calculations, cable capacity evaluation, and more. ECS's versatility and modular adaptability make it suitable for organizations of any size, offering a comprehensive solution for power system design, simulation, operation, monitoring, and automation. Its capabilities extend to addressing critical issues such as mitigating back flashover in transmission systems, thereby contributing significantly to the reliability and performance optimization of electrical power networks.

The analysis was done following the steps below;

1. Modelling and simulation of the 132kV transmission line with the insulator using ECSP.
2. Simulation of the effect of the footing resistance on the insulator withstand voltage by varying the footing resistance (from 5Ω to 90 Ω)
3. Analysing the effect of the footing resistance on the back flashover of the insulator.

Results and Discussion

Impact of Different Tower Footing Resistance on the Voltage across the Insulator with a 10 KA Lightning Stroke

Figure 1 shows how tower footing resistance affects the voltage across the insulator after a 10-kA lightning strike. The research comprised altering the tower footing resistance and seeing how it affected the insulator voltage. Figure 1 depicts a gradual increase in insulator voltage as the tower footing resistance increases. The voltage across the insulator was measured at 44.79 kV, 87.85 kV, 173.96 kV, 2060.06 kV, 346.2 kV, 432.31 kV, 561.65 kV, and 690.66 kV as the tower footing resistance was increased from 5 Ω to 80 Ω, before reaching a back flashover condition. The back flashover event occurred when the tower footing resistance reached 90 Ω, causing the voltage across the insulator to drop to zero, as depicted in Figure 1 (f). This abrupt drop in voltage can potentially lead to a lightning-induced earth fault. The back flashover was attributed to the insulator voltage surpassing its BIL (Basic Impulse Insulation Level) or withstand voltage limit of 750 kV, highlighting the critical role of tower footing resistance in mitigating back flashover incidents.

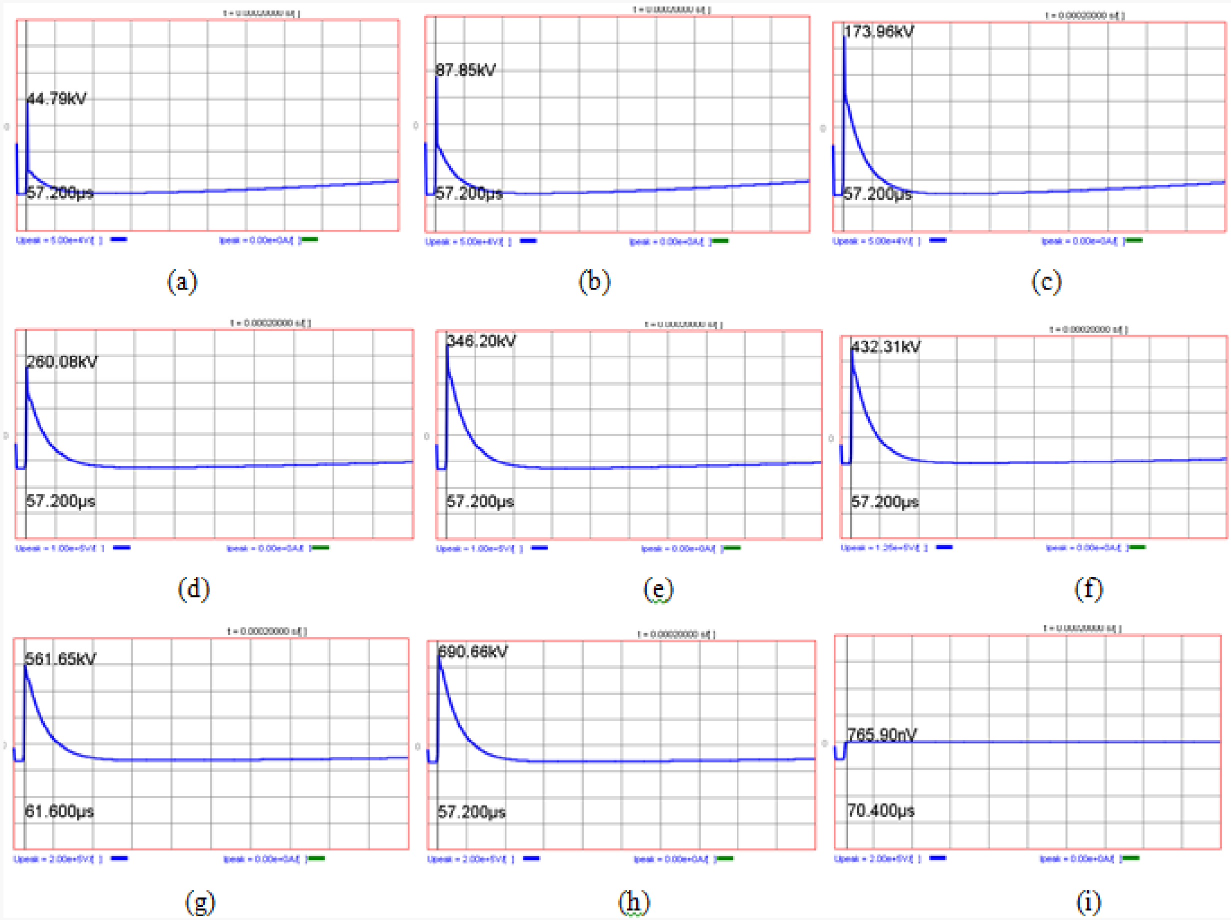

Fig 1: Insulator voltage at 10 KA lightning stroke (a) 5Ω (b) 10Ω (c) 20Ω (d) 30Ω (e) 40Ω (f) 50Ω (g) 70 (h) 80 (i) 90Ω

Impact of Tower Footing Resistance on the Voltage across the Insulator with a Lightning Stroke of 20 KA, 30KA, 40 KA and 50 KA.

Figure 2 provides insights into the behaviour of the voltage across the insulator during a lightning stroke of 20 kA. It illustrates the progressive increase in insulator voltage as the footing resistance varies. Specifically, at 5 Ω, 10 Ω, and 20 Ω footing resistances, the voltage across the insulator measured 220.51 kV, 306.63 kV, and 651.09 kV, respectively, highlighting the impact of footing resistance on voltage levels during a 20 kA lightning stroke. The back flashover event occurs at a footing resistance of 40 Ω in this scenario. This condition causes the voltage across the insulator to plummet to zero, a situation attributed to the significant magnitude of the lightning stroke, as depicted in Figure 2 (d). As the lightning stroke magnitude increases to 30 kA, back flashover is observed at a lower footing resistance of 20 Ω, as seen in Figure 3 (c). Figures 4 and 5 further explore the relationship between footing resistance, lightning stroke magnitude, and back flashover. At 40 kA and 50 kA lightning strokes, back flashover occurs at 10 Ω and 5 Ω footing resistances, respectively. Notably, for, lightning strokes exceeding 50 kA, back flashover is observed even at 5 Ω footing resistance, as demonstrated in Figure 6. These simulation results emphasize that the magnitude of the lightning stroke influences the footing resistance threshold for back flashover. Generally, smaller footing resistances are more prone to causing back flashover during high-magnitude lightning strokes.

Volume 5, Number 1 | 2024 | 10-17 | DOI: https://doi.org/10.5281/zenodo.10962815

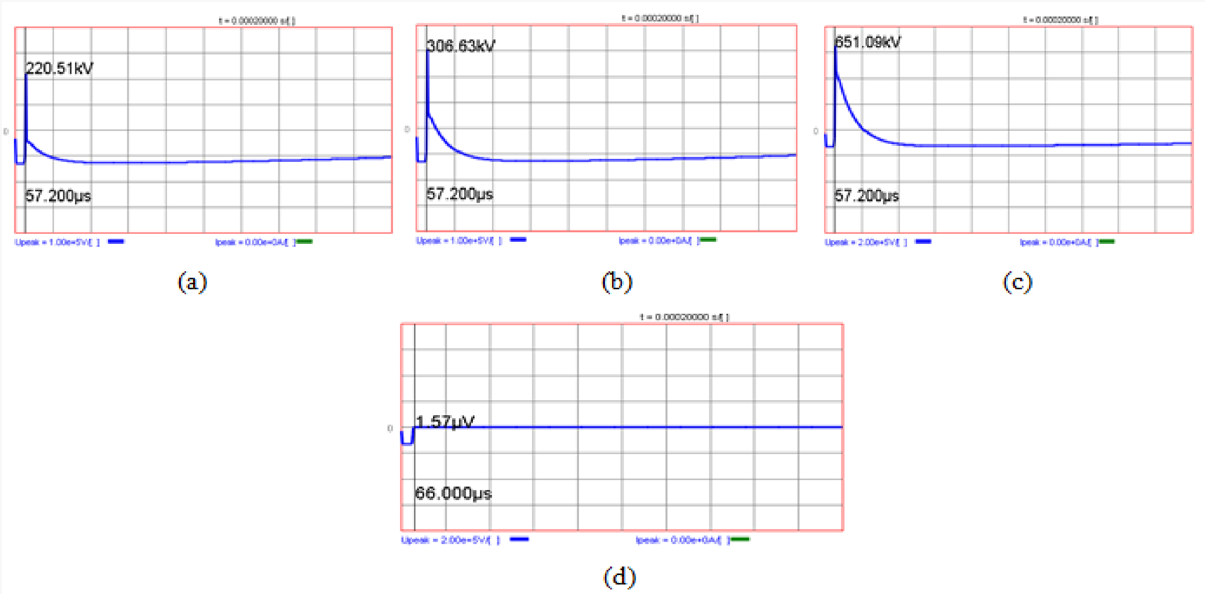

Fig 2: Insulator voltage at 20KA lightning stroke (a) 5Ω (b) 10Ω (c) 20 Ω (d) 40 Ω

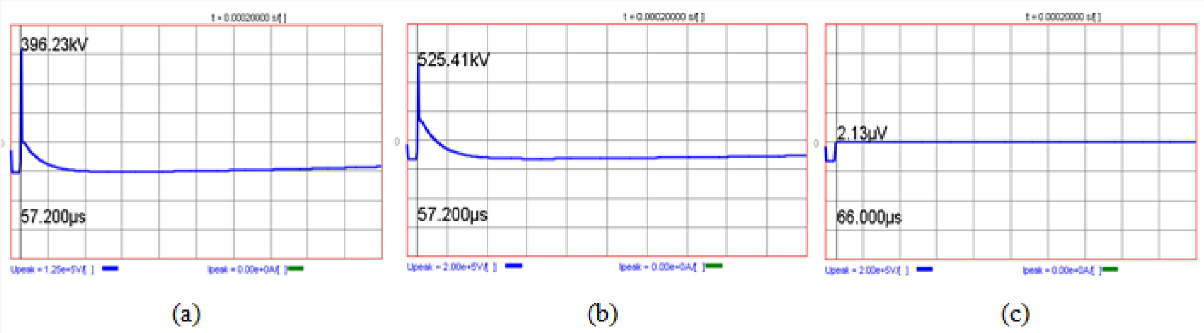

Fig 3: Insulator voltage at 30KA lightning stroke (a) 5Ω (b) 10Ω (c) 20 Ω

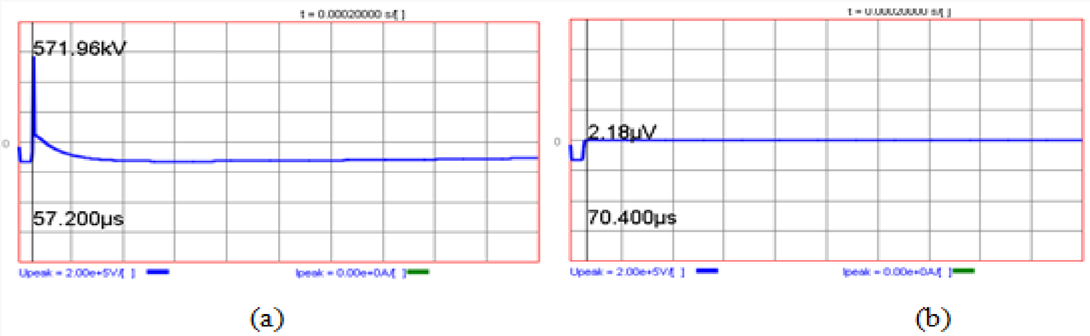

Fig 4: Insulator voltage at 40KA lightning stroke (a) 5Ω (b) 10Ω

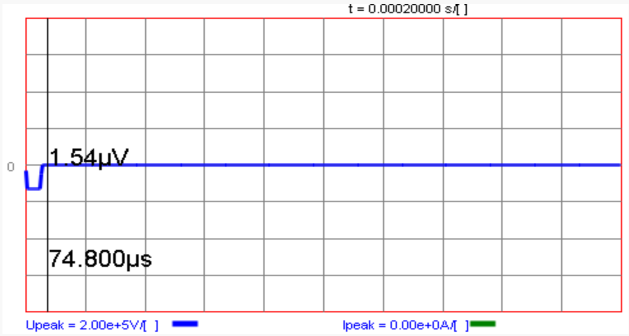

Fig 5: Insulator voltage at 50 KA lightning stroke with a footing resistance of 5Ω

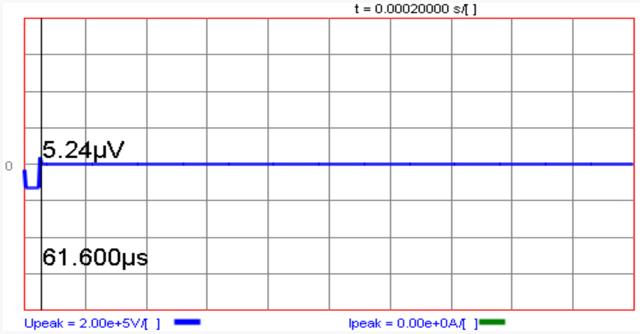

Fig 6: Insulator voltage at 100 KA lightning stroke with a footing resistance of 5Ω

Conclusion

The paper conducted an investigation and analysis on the impact of tower footing resistance on the voltage across the insulator. The simulation results revealed a clear trend: higher magnitudes of lightning strokes and smaller tower footing resistances leads to increased voltage across the insulator. Conversely, smaller lightning strokes and higher tower footing resistances result in higher insulator voltages, potentially causing back flashover. Maintaining a low tower footing resistance is crucial as it allows lightning and earth fault currents to dissipate effectively through the path of least resistance to earth, thereby preventing flashovers across transmission tower insulators. On the other hand, higher tower footing resistance can trigger back flashovers, converting lightning events into earth faults. Additionally, elevated tower footing resistance may delay the clearance of an earth fault, further underscoring the importance of managing footing resistance levels in power transmission systems to ensure operational safety and reliability.

References

Anekthanasuwan, W., Jumrain, P., Junpradit, T., & Petcharaks, N. (2015). Analysis of a back flashover across insulator strings on a 115 kV transmission line tower by PSCAD. *Engineering and Applied Science Research, 42*(3), 226–234.

Hussain, G. A., Hassan, W., Mahmood, F., Shafiq, M., Rehman, H., & Kay, J. A. (2023). Review on partial discharge diagnostic techniques for high voltage equipment in power systems. *IEEE Access*.

Mohajeryami, S., & Doostan, M. (2016, May). Including surge arresters in the lightning performance analysis of 132kV transmission line. In *2016 IEEE/PES Transmission and Distribution Conference and Exposition (T&D)* (pp. 1–5). IEEE.

Moselhy, A. H., Abdel-Aziz, A. M., Gilany, M., & Emam, A. (2020). Impact of first tower earthing resistance on fast front back-flashover in a 66 kV transmission system. *Energies, 13*(18), 4663.

Naidoo, N. (2019). Improving lightning performance on high voltage overhead shielded networks by reducing tower footing earthing resistance [Doctoral dissertation, University of Kwazulu-Natal].

Volume 5, Number 1 | 2024 | 10-17 | *DOI: https://doi.org/10.5281/zenodo.10962815*

Talib, D. N. A. A., Bakar, A. H. A., & Mokhlis, H. (2012, December). Parameters affecting lightning backflashover pattern at 132kV double circuit transmission lines. In *2012 IEEE International Conference on Power and Energy (PECon)* (pp. 808–812). IEEE.

Wang, C., Liang, X., Adajar, E. P., & Loewen, P. (2021). Investigation of seasonal variations of tower footing impedance in transmission line grounding systems. *IEEE Transactions on Industry Applications, 57*(3), 2274–2284.

Warmi, Y., Zulkarnaini, A. R., Yuanisa, C., Elyas, R. O., Putra, A. M. N., & Anthony, Z. (2023). Proposal of analysis method to reduce back-flashover rate taking account of tower footing resistance. *International Journal of Electrical and Computer Engineering, 13*(1), 94–106.

Yadav, V. P., Pauly, J. P., Sreedevi, J., & Prabhakar, C. (2023, January). Impact of tower footing resistance on back flashover in 220 kV transmission system. In *International Conference on Latest Trends & Innovations in Insulated Cables and Overhead Lines*, New Delhi.

Yadee, P., & Premrudeepreechacharn, S. (2007, June). Analysis of tower footing resistance affected back flashover across insulator in a transmission system. In *International Conference on Power Systems Transients* (pp. 4–7).