International Journal of Academic Engineering Research (IJAER)
ISSN: 2643-9085
Vol. 9 Issue 11 November - 2025, Pages: 60-66

Impact of Shield Wire failure and Back flashover on String Insulator of a 132 KV Transmission line

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Abstract: *The study examines how lightning stroke, particularly a 100-kA strike, generate over-voltages in a 132 kV transmission line, especially when the lightning directly hits a phase conductor or tower. These strikes create fast-front transient surges that travel along the line and can induce high voltages capable of causing insulator flashover or back flashover. Using the Electric Circuit Simulator (ECS), the research analyzes the behavior of these surges, the resulting tower-top voltages, and the critical conditions that lead to insulation failure. It also evaluates the role of tower footing resistance in dissipating lightning currents to ground under both direct and indirect strokes, and before and after shield wire failure.*

Keywords: Lightning, Flashover, surge, Back flashover

Introduction

Lightning activity remains one of the most significant natural threats to overhead transmission lines, particularly those operating at high voltages such as 132 kV. When a lightning strike occurs, it generates fast-front transient overvoltages capable of severely stressing the insulation system of transmission lines. These overvoltages are typically initiated when a high-magnitude current—often exceeding 100 kA, strikes the shield wire, the tower, or directly impacts the phase conductor [1]. Shield wires are installed primarily to intercept direct lightning strokes and protect phase conductors by channeling lightning currents safely to the ground. However, when a shield wire fails due to improper positioning, degradation, or inadequate lightning performance, the phase conductors become vulnerable to direct lightning impacts [2].

The investigation of the power over voltage in this study of lightning discharges is necessary to determine the selection of the dielectric strength of power equipment connected to the transmission line and lightning over-voltage is one of the major causes of equipment failure in a transmission line up to 500 KV. Therefore, flashover due to lightning discharge is classified into the backflash over rate (BFOR) and the shielding wire failure flashover rate (SEFOR). When a transmission line tower is installed with a shield wire protection measure of High voltage transmission line.

One of the most critical effects of lightning on transmission systems is back flashover, a phenomenon that occurs when the lightning current raises the tower potential above the withstand level of the insulator string. This causes a flashover from the tower to the phase conductor, leading to faults, outages, and possible damage to insulator strings [3]. Back flashover probability is strongly influenced by factors such as tower footing resistance, lightning magnitude, soil resistivity, and the insulation strength of line insulators [4]. High tower footing resistance, in particular, results in elevated tower-top voltage during a lightning event, significantly increasing the likelihood of back flashover [5].

In 132 kV systems, ceramic or composite insulator strings play a critical role in maintaining electrical integrity. However, during shield wire failure, these insulators face direct exposure to lightning-induced surges, placing them at high risk of flashover. The reliability of transmission lines therefore depends on a combination of shielding design, grounding performance, and insulation coordination.

Studies have shown that lightning-related faults constitute a substantial proportion of transmission line outages in tropical regions such as West Africa, where lightning density is high and soil resistivity varies widely [6], [7]. This makes it essential to analyze how shield wire failure and back flashover events affect insulator performance in local environments.

The voltage across the tower crossarms is built up by these multiple reflections. If these voltages are equal or greater than the insulator voltage withstand capability, flashover occurs at that critical voltage. [8]. Therefore, the assessment of lightning performance must account for the random behavior of transmission line parameters, such as the phase angles of power frequency voltages in each phase at the instant of a lightning stroke. The use of an Online Electric Circuit Simulator (OECS) enables the analysis of uncertainties introduced by the stochastic nature of these parameters, allowing for more accurate predictions of lightning performance on transmission lines. In this study, back flashover was investigated using OECS through a simulation model of the insulator breakdown gap, with the 132 kV.

Given these challenges, understanding the interaction between lightning strokes, shield wire performance, tower footing resistance, and insulator flashover behavior is crucial for designing resilient 132 kV transmission systems. This study investigates the impact of shield wire failure and back flashover on string insulators using simulation-based analysis to evaluate lightning performance and propose improved protection measures

2.0 Lightning Strokes on Transmission line.

Understanding the characteristic parameters of lightning strokes is crucial for analyzing cloud-to-ground discharges and their impact on transmission lines and connected equipment. These discharges, whether direct or indirect, can generate transient overvoltages that stress phase conductors and towers [9]. For power system engineers, the key focus is on the lightning flash parameters, which include the peak current of the first and subsequent strokes, the waveform of these currents, and the relationship between these parameters and ground flash density. Critical factors also include the return stroke to the shield wire, particularly when the magnitude of the cloud-to-ground voltage or current exceeds the shield wire's capacity, causing the return stroke to reach the phase conductors. Additionally, bypass strokes from the shield wire are a significant cause of shield wire failure, compromising the protection of phase conductors.

2.1Shielding wire and the failure in a Transmission Line.

Shielding wires are employed to protect high-voltage overhead transmission lines from direct lightning strikes. These wires are installed above the phase conductors and connected to the tower tops, ensuring that lightning current preferentially strikes the shield wire rather than the phase conductors. In the event of shield wire failure, however, the lightning current and voltage may directly impact the phase conductors, splitting into forward and backward components along the line. If the lightning strikes a phase conductor, a short-circuit fault to the ground may occur due to the electrostatic interaction between the conductor and the tower. This can result in widespread power outages caused by back flashover, as the phase conductors are supported by insulators connected to the tower. The protection concept of shield wires is primarily based on the Electro-Geometric Model (EGM), which is used to determine the striking distance of lightning strokes as the downward leader approaches the earth. The model also accounts for the propagation velocity of the lightning leader, which is essential for predicting the point of impact and the effectiveness of shield wires in preventing direct strikes to phase conductors.

The concept of shield wire protection in transmission lines is primarily based on the Electro-Geometric Model (EGM), which is used to determine the striking distance of lightning strokes as the descending leader approaches the earth's surface. The corresponding propagation velocity is expressed as follows:

$$Vt = 0.5\, I\,(t)\ \mathrm{Zp} \qquad (1)$$

Where Zp is the impedance of the phase conductor and it is represented as the surge generated by the lightning discharges from the cloud to ground. t is the time of propagation

$$\mathrm{Zp} = \sqrt{\frac{\mathrm{L}}{\mathrm{C}}} \qquad (2)$$

Where L is the inductance (H/m) and C is the series capacitance to the ground F/m per meters of the phase conductor. The voltage or discharge that occurs across the insulator at the end of the span, along with the shield wire, serves as a protective mechanism for the transmission line against external disturbances, such as lightning-induced over voltages [10].

2.2 Effect Back flashover on 132KV Transmission line.

The transmission line shielding wire, also known as the earth or ground wire, reduces the likelihood and frequency of lightning strokes striking the phase conductors. Most lightning flashes are intercepted by the shield or ground wire, preventing direct strikes to the phases. When the shield wire is struck by lightning, the resulting current propagates along the wire and simultaneously travels downward through the tower structure [11]. Due to the potential difference between the tower and the phase conductors, the current may exceed the critical withstand current of the insulator string, causing the tower voltage to rise sufficiently to trigger a flashover of the line insulators, an event known as back flashover. Consequently, the lightning-induced transient or overvoltage travels down to the phase conductor, where the flashover occurs, as illustrated in Fig. 1.

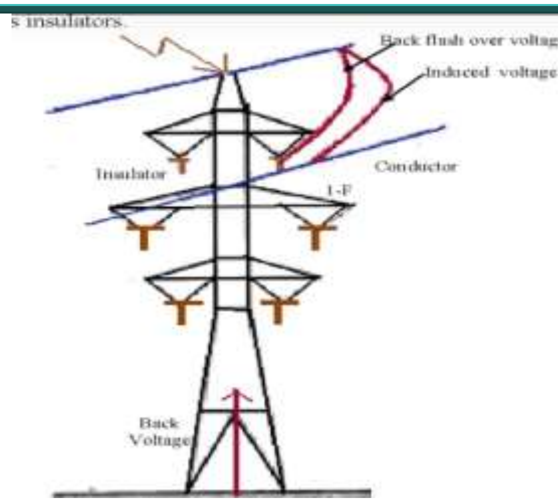

Fig. 1. Back flashover on a transmission line.

3. METHODOLOGY

The study employs a combination of analytical tools, simulation techniques, and transmission line parameters to investigate the effects of shield wire failure that may lead to back flashover on 132 kV insulators. These back flashover events generate over voltages that can be transferred to the phase conductors, and the adopted materials and methods are designed to accurately model, analyze, and interpret these phenomena. The data's used in this study are the parameters of the transmission line, towers, insulators and footing resistance parameters. Which are shown in Table 1 and 2 to investigate the impact of lightning strokes on the 132KV transmission line.

Table. 1: Transmission line parameters

S/N	Parameters	Values	Units
1	Resistance	0.00045	Ω
2	Inductance	4.24	Ω/M
3	Transmission line length	45	Km
4	Tower Height	28	Meters
5	Load resistance	200	Ω

Table 2. Tower Data

S/N	Tower height (m)	Height(h)	Analysis
1	132kv metal steel tower	$h_{4=}$28m,$h_{3=}$25.4 m, $h_{2=21.7m}$,$h_{1=18m}$	Meters
2	Equivalent radius	r_1,r_2, $r_3 r_{4,}$ 0.52m,0.57m, 1.23m, 4.45m	Meters
3	Cross arms	$x_{1,} x_{2,} x_3, x_4$3.0m ,6.4m, 7.8m, 8.2m	Meter

3.2.1 MODELING OF 132KVA TRANSMISSION LINE/TOWER

The transmission line model is developed using the standard circuit line geometry and conductor specifications for a typical 132 kV single-circuit overhead line, as illustrated in Figure 3.1. The line configuration consists of two 490/65 mm² aluminum bare conductors per phase and two 65 mm² ACSR earth wires. The minimum conductor-to-ground clearance is 16.39 meters, and the average span length is 300 meters. A detailed template of the transmission line geometry is presented in Table 1, while Table 2 provides the tower data used for the transmission line simulations.

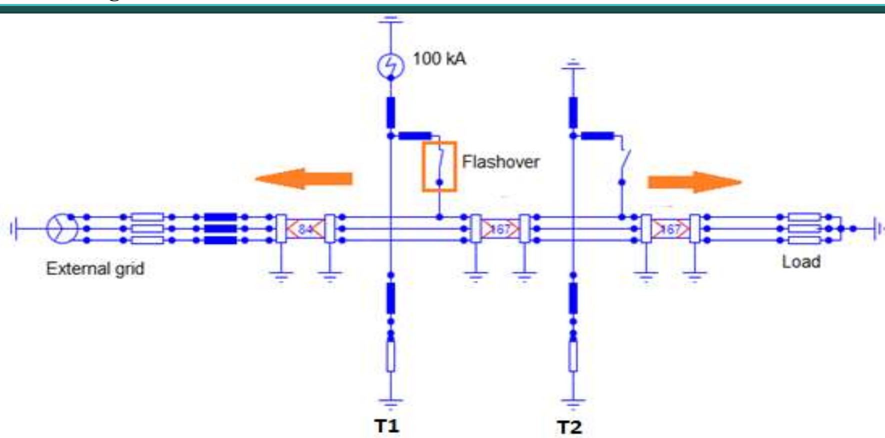

Fig. 3.1. 132 KV Transmission line for the study.

3.2. METHOD OF ANALYSIS

The methods adopted for this investigation into the impact of shield wire failure leading to back flashover on string insulators are as follows:

1. Use of the Electric Circuit Simulator Program (ECSP): ECSP was utilized as an online electric circuit simulation tool for modeling power system transient voltages and stability conditions.
2. Modeling of the 132 kV Transmission Line: A detailed model of the 132 kV line was developed to determine the critical flashover voltage of the insulator string.
3. Simulation of the effect Lightning: The ECSP platform was used to simulate lightning-induced transients on the 132 kV transmission line in-order to assess the performance and failure of the shield wire as a lightning protection mechanism, and to evaluate the resulting back flashover on the line.
4. Analysis of Back flashover Effects: The study examined the behavior of the 132 kV transmission line under conditions with an intact shield wire and after shield wire failure, evaluating the resulting impact on system insulation and overvoltage levels.

4.0 RESULTS AND DISCUSSION

The results obtained from the modeling and simulations conducted in this study provide insights into the effectiveness of various protection systems and help determine the most suitable methods for minimizing lightning-induced overv oltages on the transmission line.

4.1 Behavior of 132 KV transmission line on lightning stroke of 100KA

From Fig. 4.1, the voltage observed on the line under normal operating conditions, without any lightning activity, is 130.88 kV. This value lies within the acceptable operational range for a 132 kV transmission line. However, when the line is subjected to a direct lightning stroke without adequate protection, the lightning's characteristic behavior induces impulse currents and voltages onto the conductors, which can propagate into connected distribution and end-user equipment. Fig. 4.2 illustrates the lightning-stroke current measured on the transmission line in the absence of lightning activity, recorded as 652.81 A, which remains within the normal operating current of the system.

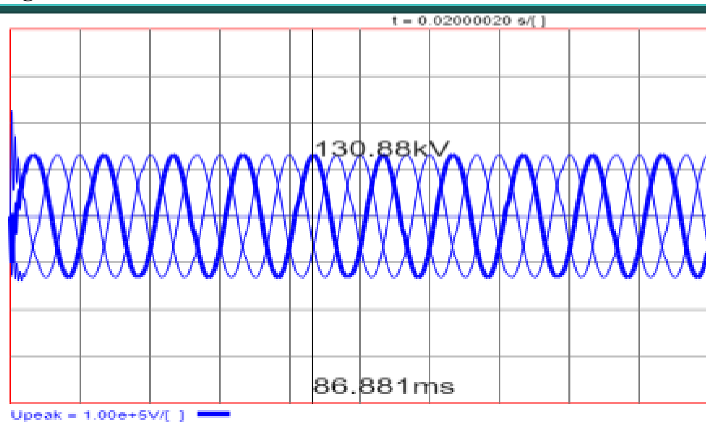

Fig 4.1: voltage with shielding Wire

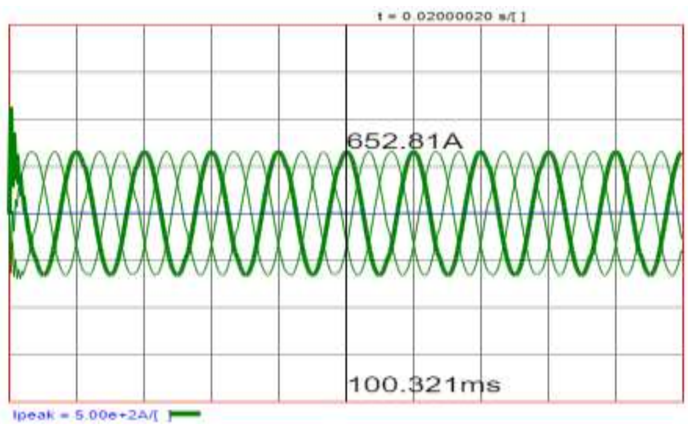

Fig 4.2: Current with Shielding wire

4.2 Behavior of 132KV transmission line on a stroke of 100KA on shield wire failure.

Figures 4.3 and 4.4 show that a 100 kA lightning strike can raise the line voltage to about 1.12 MV, creating severe over voltages that stress and potentially damage insulators and connected equipment. When lightning hits a phase conductor, it generates travelling waves whose magnitude depends on the surge impedance and current, often exceeding insulation limits. The resulting damage is influenced by factors such as surge arrester characteristics, grounding resistance, cable length, and the placement of protection devices. The analysis indicates that longer cable lengths tend to reduce surge magnitude, making the installation position of arresters crucial for effective lightning protection. Increasing the distance between the arrester and the tower can enhance arrester performance, although over voltages may still propagate depending on surge magnitude and system grounding. Figure 4.4 further shows a post-strike current of 5.60 kA flowing through the line following the 100-kA lightning impact.

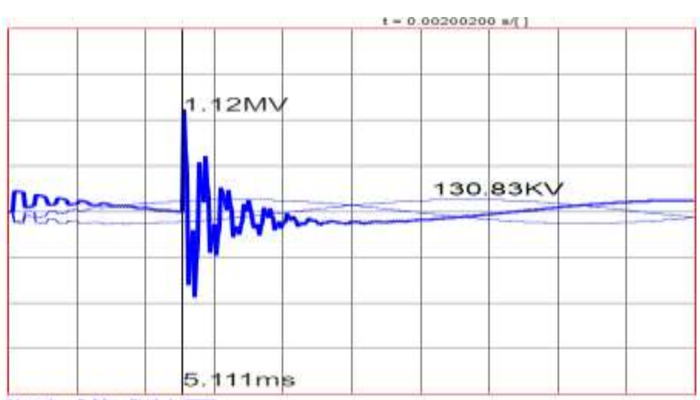

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Fig.4.3. Line voltage after shied wire failure on a 100kA lightning stroke

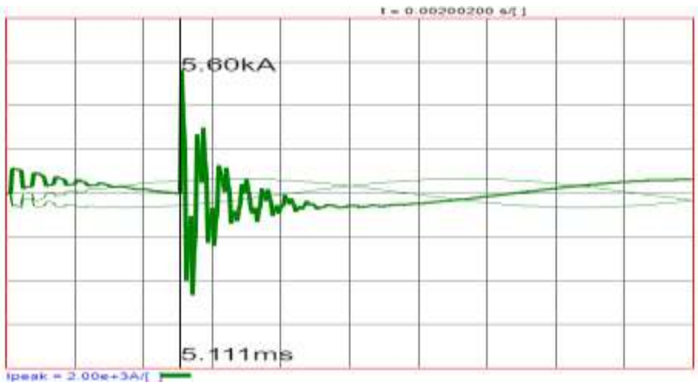

Fig 4.4. Line current after shield wire failure on a100KA lightning stroke.

4.3. Back flashover Effect on 132KV transmission line on during shield wire failure

The back flashover voltage and current arise from the tower-top voltage and current generated during a lightning strike. Figures 4.5 and 4.6 illustrate the critical voltage and current levels that can initiate flashover at the string insulators when a 100-kA lightning stroke strikes the tower. Figure 4.6 shows a maximum insulator string voltage of approximately 916.55 kV, which exceeds the insulator's operating withstand voltage of 750 kV. When this threshold is surpassed, flashover occurs, creating a potential difference between the tower and the phase conductor. Additionally, a critical insulator current of 67.80 kA was observed, flowing through the insulator string. This current contributes to the flashover process and subsequently propagates along both directions of the transmission line.

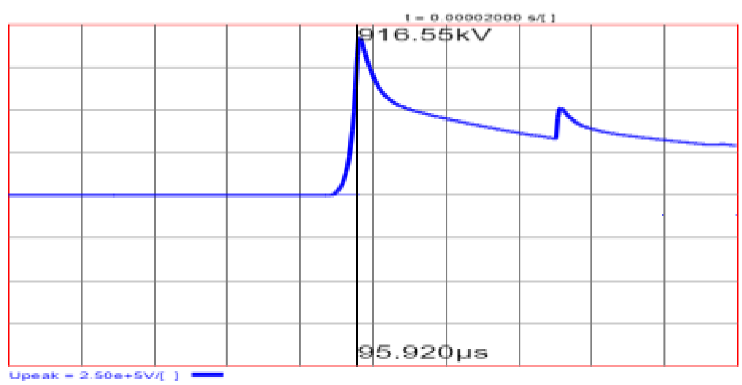

Fig.4.5. The critical voltage after flashover with a stroke of 100KA on tower top.

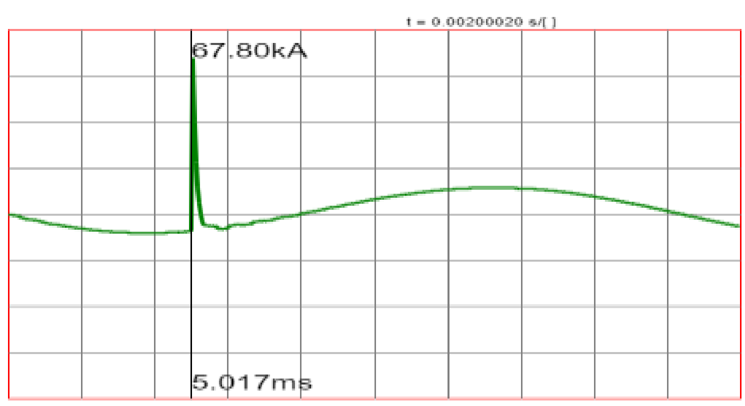

Fig. 4.6. The critical current after flashover with a stroke of 100KA on tower top.

Conclusion

This study investigated the effects of shield wire failure and back flashover on 132 kV transmission line insulators under high-magnitude lightning strokes using an Electric Circuit Simulator Program (ECSP). The modeling and simulation results demonstrated that lightning strokes, particularly those with peak currents around 100 kA, generate significant transient over voltages capable of exceeding the insulation withstand limits of overhead line components. When the shield wire fails or is unable to intercept the stroke, the resulting direct impact on the phase conductor or tower top produces travelling waves that can elevate the line voltage to levels as high as 1.12 MV—far above the safe operating range.

The findings revealed that tower-top voltages and the induced currents during lightning strikes play a critical role in initiating back flashover. The simulated maximum insulator voltage of approximately 916 kV and flashover current of 67.80 kA exceeded the rated withstand capabilities of the insulator string, confirming the likelihood of flashover when lightning protection is inadequate. Furthermore, the study established that factors such as tower footing resistance, lightning current magnitude, surge impedance, cable length, and the location of surge arresters significantly influence lightning performance on transmission lines.

The analysis also highlighted the importance of proper shielding design, arrester placement, and grounding systems in mitigating lightning-induced over voltages. Longer span lengths were observed to attenuate surge magnitude, while optimal positioning of surge arresters improved protection efficiency. Overall, the results underscore the need for improved lightning protection strategies, particularly in regions with high ground flash density.

Shield wire integrity, surge arrester coordination, and grounding performance are essential to preventing back flashover and ensuring the reliable operation of 132 kV transmission lines. The study provides valuable insights that can guide engineers in designing more resilient transmission systems capable of withstanding severe lightning events.

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