Buletin Ilmiah Sarjana Teknik Elektro
Vol. 5, No. 1, March 2023, pp. 145-155
ISSN: 2685-9572, DOI: 10.12928/biste.v5i1.7569

Analysis of Lightning Strike Impulse Strategies in Electricity Distribution Channels Utilizing Mixed Lines

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ARTICLE INFORMATION

Article History:

Submitted 27 January 2023
Revised 12 March 2023
Accepted 18 March 2023

Keywords:

Impulse Voltage;
20 kV Distribution Channels;
Mixed Lines;
ATP-EMTP

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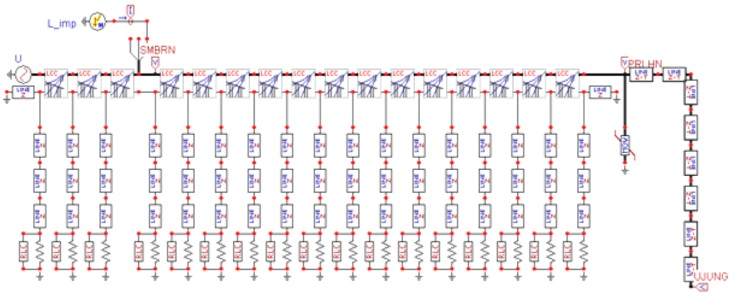
ABSTRACT



To ensure the operational security of these systems and to give higher quality electricity to all users, it is important to assess the transient behavior of electric power transmission and distribution systems when they are challenged to varied forms like lightning discharges, which in this research is focused to determine the effect by utilizing the mixed line configuration on the impulse voltage of lightning strike on the 20 kV distribution line. This experiment was carried out using sources of data through channel documentation on Makassar City Polda Feeders with an airway length (SUTM) of 7.8 km and a cable channel length (SKTM) of 2 km obtained from PT. PLN (Persero) Makassar Branch and then input into the ATP-EMTP simulation process with either a simulation of 20 and 50 kA strikes at distances of 2.5, 4.5 and 6.5 km with lightning impulses of 1.2/50 and 8/20 µs. configuration of lines at the transition point and also the end of the cable channel depending on the magnitude of the lightning current, the location of the strike, and the lightning impulse. Lightning peak current is proportional to the voltage response at the transition point and the end of the cable, and the effect on lightning impulse peak voltage is generated at the transition point and the end of the cable. According to research results of initial research, the use of mixed channel lines can decrease the impulse voltage is 20 kV distribution lines.

Document Citation:

M. I. Burhan and D. A. L. Sari, “Analysis of Lightning Strike Impulse Strategies in Electricity Distribution Channels Utilizing Mixed Lines,” *Buletin Ilmiah Sarjana Teknik Elektro*, vol. 5, no. 1, pp. 145-155, 2023, DOI: 10.12928/biste.v5i1.7569.

1. INTRODUCTION

The advancement of the periods, in addition to current technological advancements, cannot be ignored, and this advancement is accompanied by an increase in the demand for electrical energy [1]. The ability to use electrical energy more efficiently can help the economy flourish. Indonesia's geography, industrialization, and electrical energy consumption always require a dependable and consistent transmission and distribution infrastructure to deliver electrical energy from the source to the load [2]. The system must also meet other requirements connected to economical system operation relating to the interests of energy supply businesses in addition to the technical requirements listed above that are intended for consumers [3]. It cannot be denied that there are still some problems in its distribution, especially in the distribution system, and the most general problem in the distribution sector is disturbances to feeders [4], which occur in the form of technical or natural disturbances such as lightning.

On the medium voltage distribution side, the electric energy distribution system is implemented utilizing Medium Voltage Air Lines (SUTM) shown in Figure 1 [3] and Medium Voltage Cable Channels (SKTM). For distributing electricity on land, air ducts are considered to be more efficient. Amidst the latter, many interruptions take place throughout the procedure, with lightning as one of them [5]. Lightning strikes in power systems can interrupt power supplies and impact power system equipment, along with consumers' home appliances. As a result, they may result in a negative effect on power continuity and quality indicators, as well as cause considerable financial losses [6]. Overvoltages generated by lightning discharges are the most common in electrical power systems and the biggest cause of blackouts in transmission and distribution systems [7]. In addition to overhead lines, cable lines, also widely recognized as Medium Voltage Cable Channels (SKTM), are used to distribute electricity; nevertheless, the installation of these cable lines is much more difficult compared to that of overhead lines because it is performed underground [8]. Voltage can be generated in underground line components by implementing the maximum overvoltage generated by a lightning strike into the grid [9].

Figure 1. SUTM distribution lines

Because each channel possesses both benefits and disadvantages, a mixed-lines connection is established, which is a combination of medium-voltage overhead lines and medium-voltage cable channels [10]. The effects of lightning strike disturbances on overvoltage [11], impulse voltages, flashovers, and other problems, including those related to electric power distribution [12], persists in the interaction between the two (Mixed-Lines SUTM and SKTM).

The goal of this article is to present a broad modeling of a distribution system for the purpose of simulating lightning discharges in an instructional way. The ATP-EMTP had been chosen due to being broadly used in the literature, has appropriate models, and is freely available for academic use. This modeling might be applied to propose methodologies for the identification of Lighting strike disturbances in distribution systems. As a result, it is considered essential to conduct research with objective of determining the peak voltage value at the switching point and at the end of the cable under both increasing and decreasing situations, simulating the effect of flashover on mixed-lines channels with varying strike distance parameters while still providing voltage on the line through the use of ATP-EMTP simulation, and explanation the effect of using mixed-lines lines in reducing overvoltage on the line.

2. METHODS

The research lasted three months, from November 2022 to January 2023, and was conducted at PLN Makassar in the province of South Sulawesi. Through summary, the process executed by the author are illustrated in the flowchart in Figure 2.

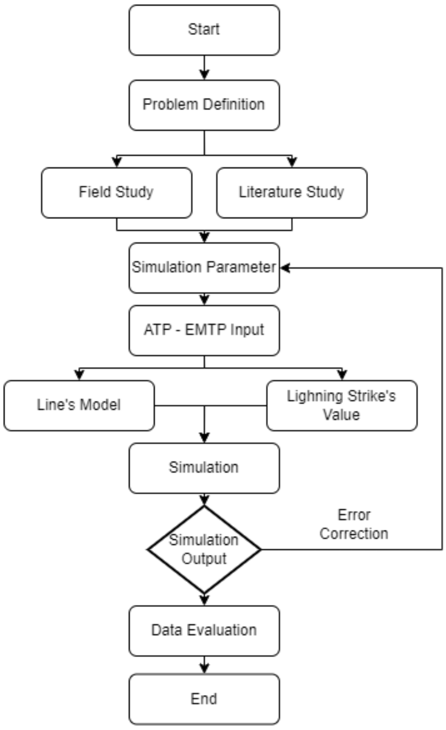
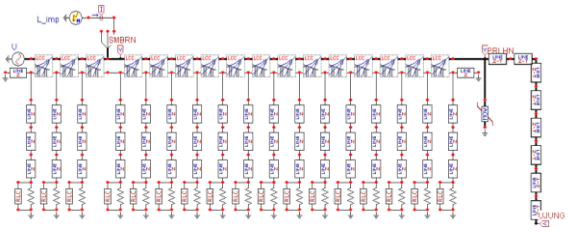


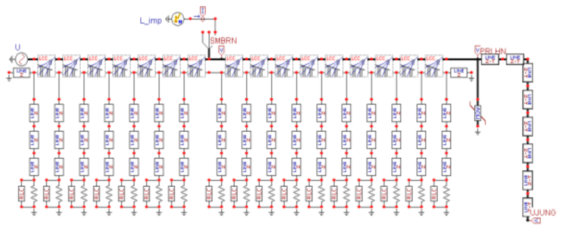
Figure 2. Research flowchart

2.1. System Design

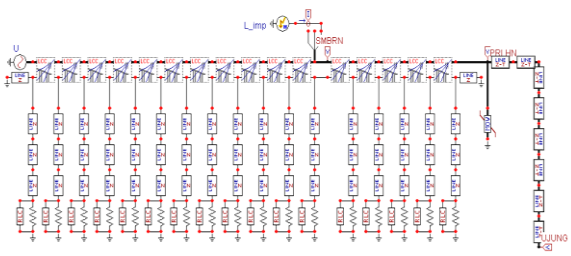
This study focuses on how to generate a simulation that can offer an overview of the effect of the mixed line configuration on the impulse voltage generated by direct lightning strikes from various distances. Figure 3 illustrates the mixed-line simulation modeling with varying strike distances. The distribution channel at Polda Feeder was utilized for modeling, with a length of 8 km SUTM and 2 km SKTM. A3C wire is utilized within the conductor channel [13].



3.a



3.b



3.c

Figure 3. Mixed-line channel modeling with strike distances of 2.5 km (3.a), 4.5 km (3.b) and 6.5 km (3.c)

While cable lines use single core XLPE conductors. Figure 4 illustrates a single line diagram of the Polda feeder. The simulation in this study was conducted on a 20 kV medium voltage line using the Transient Analysis Program (ATP) software. This channel is assessed for lightning resistance, with a peak current of 20 to 50 kA.

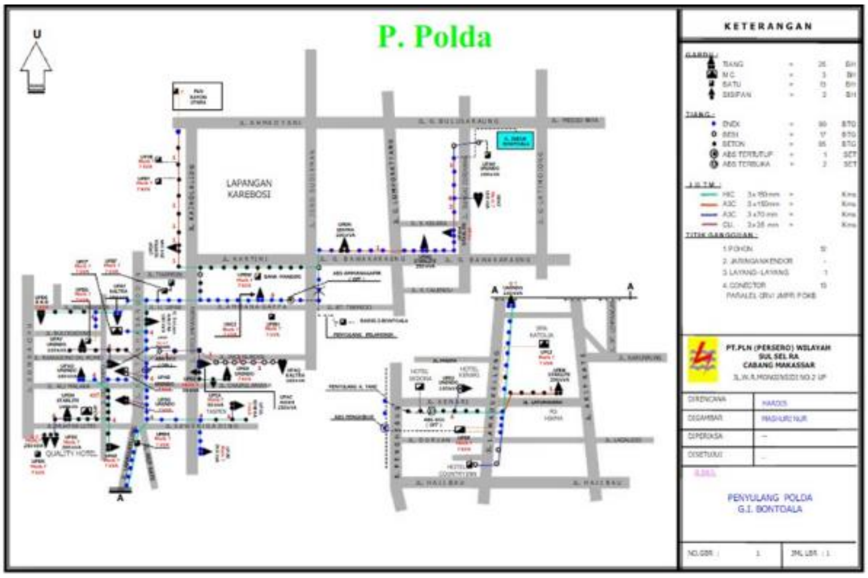


Figure 4. Single line feeder Polda

2.2. EMTP (Electromagnetic Transients Program)

EMTP (Electromagnetic Transients Program) is a computer program package that resolve transient problems in electric power systems utilizing concentrated circuits, distributed circuits, or a combination of both [13]. ATP Draw is a visuals program for Windows ATP version of EMTP [14]. Figure 5 illustrates the ATP Draw main screen.

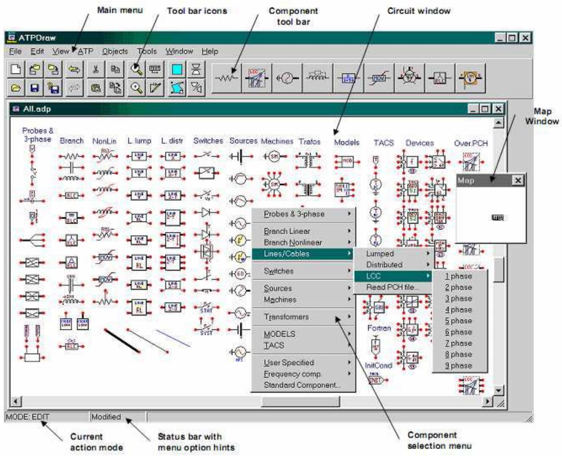


Figure 5. EMTP front page

Lightning strikes directly on the phase line at varying distances from the transition point in the EMTP simulation, for example, and data is collected. For switching impulses, the standard impulse wave is expressed by an identifier as ± Tf x Tt (μ sec), where the sign (±) denotes polarity [15].

3. RESULT AND DISCUSSION

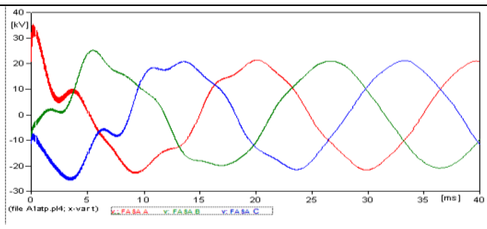
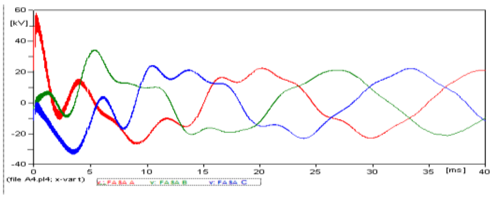
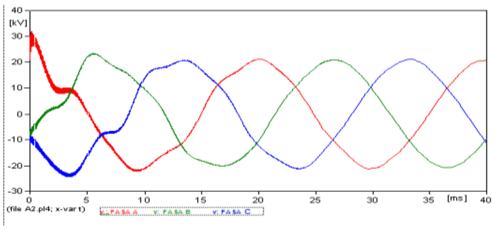
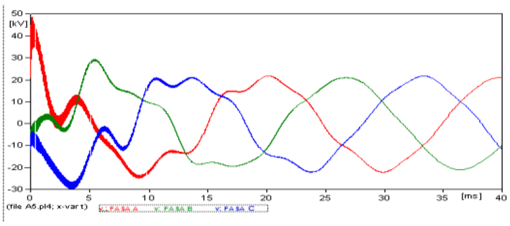
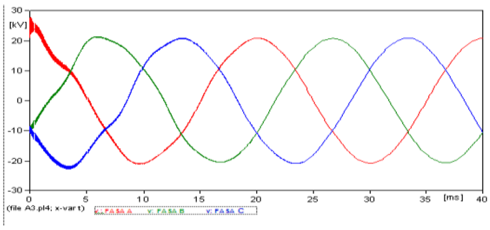
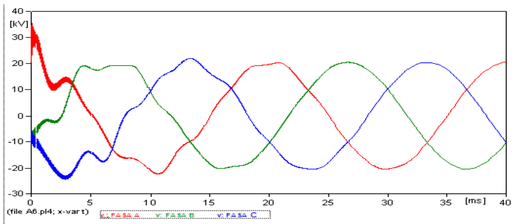
3.1. Result

The simulation was divided into two observations, one located at the mixed lines transition point and another at the end of the cable channel, which in this simulation used multiple metrics of the location of lightning strikes, namely 2.5 km, 4.5 km, and 6.5 km. The peak lightning current used from the transition point between 20 and 50 kA. The simulation's output contains, for instance, phase a (red), that is struck by lightning [16][17], and phases b (green) and c (blue), which are stimulated by voltage from phase a [18].

3.1.1. Switch Point Simulation With 1.2/50 μs Lightning Impulse

Based on the results of the simulations carried out using EMTP program, it is shown that the variation in the distance and peak current at the transition point can be explained in Table 1.

Table 1. Voltage response graph at the switching point with an impulse of 1.2/50 μs

	20kA	50kA
2.5 km		
4.5 km		
6.5 km		

A comparison graph can also be developed from the simulation results between the maximum voltage points with the given distance variations of lightning strike, as shown in Figure 6.

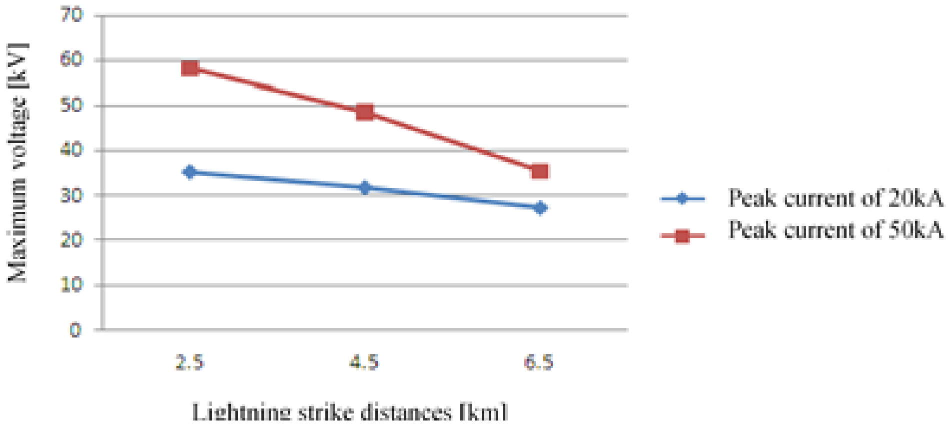
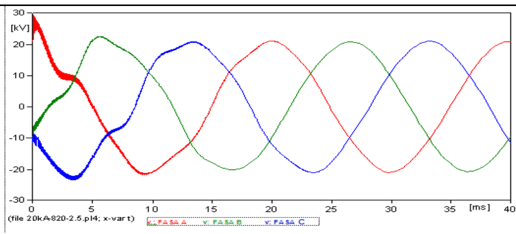
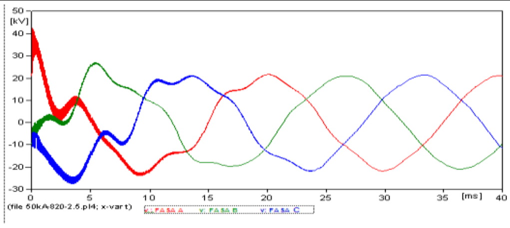
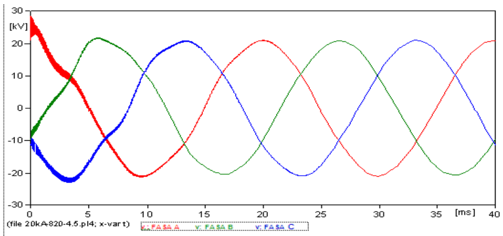
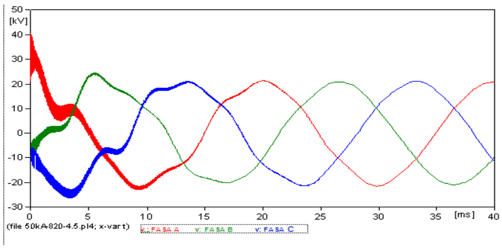
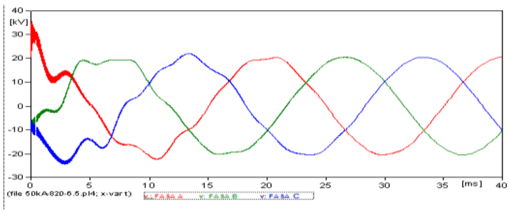
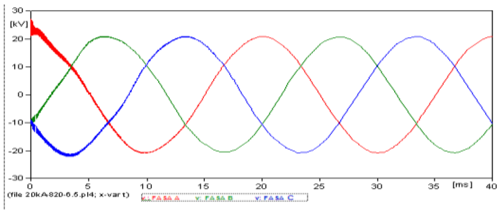


Figure 6. Graph of the peak voltage at the transition point with variations in strike distance and lightning impulse 1.2/50 μs

3.1.2. Switch Point Simulation With 8/20 μs Lightning Impulse

Based on the results of the simulations carried out using EMTP program with parameter of mixed 8/20 μs at the end of the lines, it is shown that the variation in the distance and peak current at the transition point can be explained in Table 2. Same with the previous simulation, a comparison graph can also be developed from the simulation results between the maximum voltage points with the given distance variations of lightning strike, as shown in Figure 7. There some significant difference happened with the second simulation which happened at 6.5 km distance of lightning strike the graph showed there is no fluctuation after phase A (red). Based on previous study this happened because the range was too far away to be felt by mixed lines [19][20].

Table 2. Voltage response graph at the switching point with an impulse of 8/20 μs

	20kA	50kA
2.5 km		
4.5 km		
6.5 km		

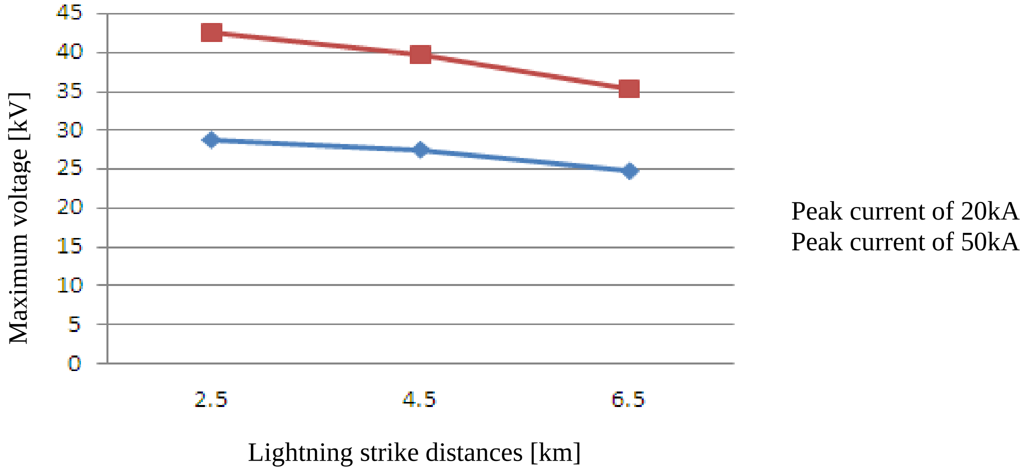
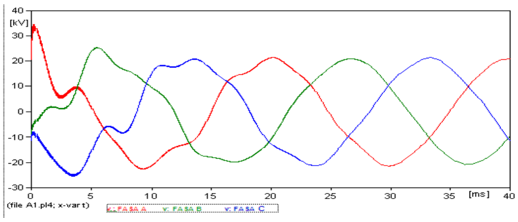
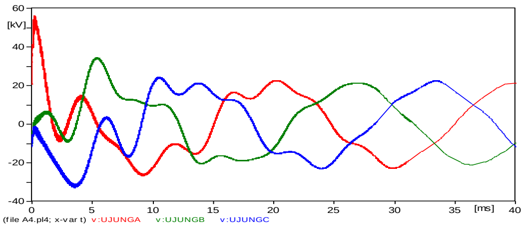
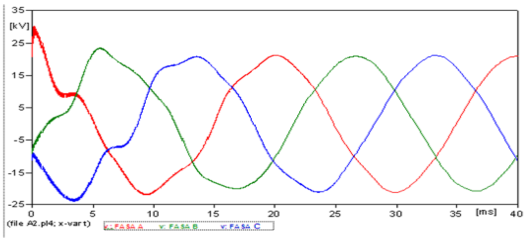
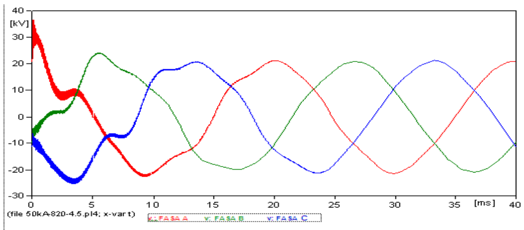
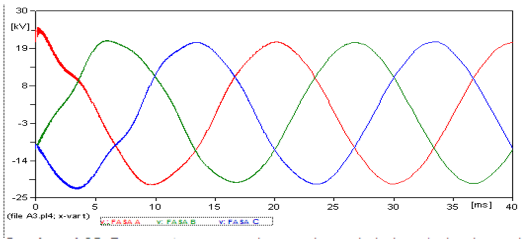
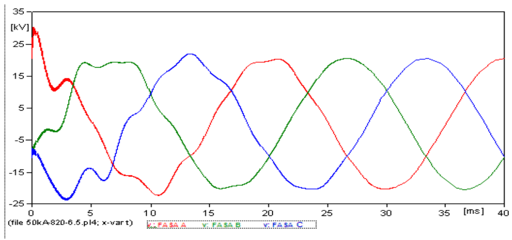


Figure 7. Graph of the peak voltage at the transition point with variations in strike distance and lightning impulse 8/20 μs

3.1.3. Cable Line End Point Simulation With 1.2/50 μs Lightning Impulse

Based on the results of the simulations carried out using EMTP program with parameter of mixed 1.2/50 μs at the end of the lines, it is shown that the variation can be explained in Table 3. A comparison graph can also be developed from the simulation results between the maximum voltage points with the given distance variations of lightning strike, as shown in Figure 8. As showed in Table 3, there is some difference with stimulated line of b (green) and c (blue) at variation of current 50 kA which the result was more stimulated that other simulation which means the lightning strike affects more when the point of simulation was on the end point.

Table 3. Voltage response graph at the switching point with an impulse of 1.2/50 μs

	20kA	50kA
2.5 km		
4.5 km		
6.5 km		

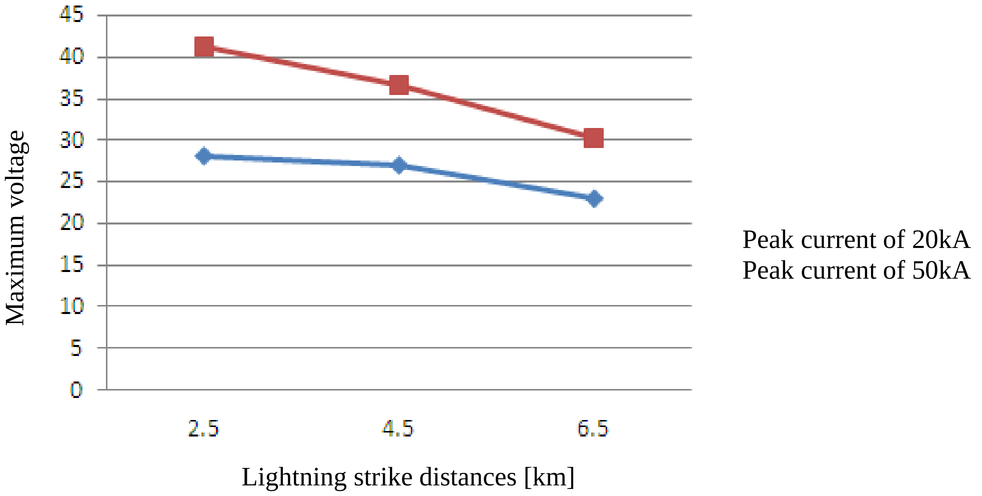
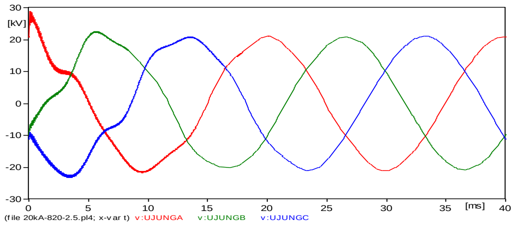
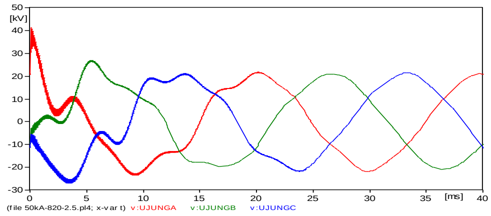
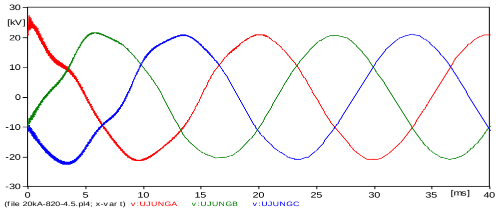
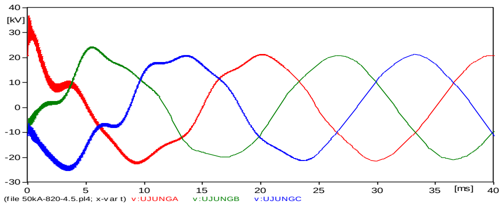
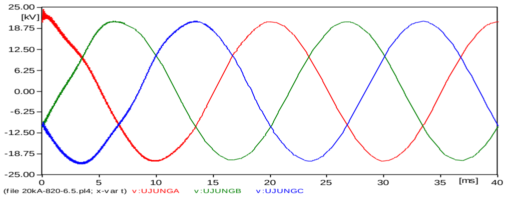
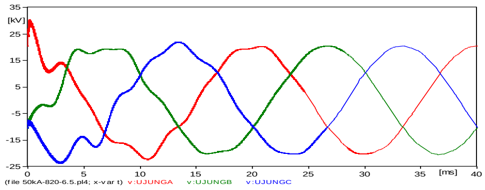


Figure 8. Graph of the peak voltage at the end point with variations in strike distance and lightning impulse 1.2/50 μs

3.1.4. Cable Line End Point Simulation With 8/20 μs Lightning Impulse

The last results of the simulations carried out using EMTP program with parameter of mixed 8/20 μs at the end of the lines, it is shown that the variation can be explained in Table 4. A comparison graph can also be developed from the simulation results between the maximum voltage points with the given distance variations of lightning strike, as shown in Figure 9.

Table 4. Voltage response graph at the switching point with an impulse of 8/20 µs

	20kA	50kA
2.5 km		
4.5 km		
6.5 km		

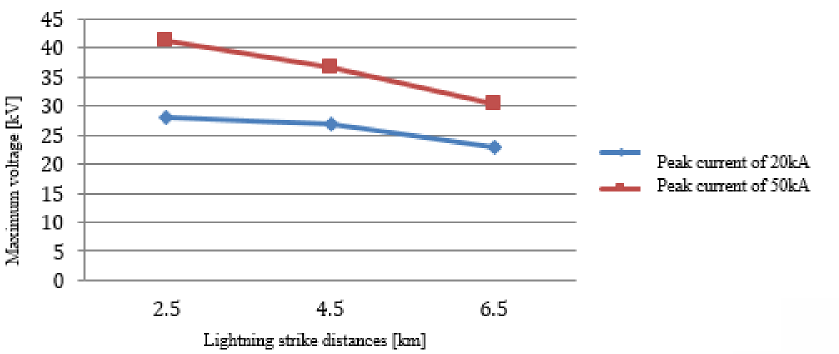


Figure 9. Graph of the peak voltage at the end point with variations in strike distance and lightning impulse 1.2/50 µs

3.2. Discussion

3.2.1. Switch Point Simulation With 1.2/50 µs Lightning Impulse

Table 5 shows the overall simulation results. The table results indicate that the peak voltage value at the switching point increases as the peak current striking and decreases with increasing strike distance. When the distance in between lightning strike and the transition point is 2.5 km and the peak lightning current is 20 Ka, the peak voltage at the transition point is 35.277 kV. The peak voltage at the switching point falls to 31.833 kV as the strike distance increases to 4.5 km. When the peak lightning current is 50 kA, the voltage at the switching point increases to 48.532 kV when the strike distance is 4.5 km.

Table 5. Voltage response graph at the switching point with an impulse of 1.2/50 µs

Peak Current of 20 kA	
Strike Distances (km)	**Peak Voltage Phase wire at the switching point (kV)**
2.5	35.277
4.5	31.833
6.5	27.381
Peak Current of 50 kA	
Strike Distances (km)	**Peak Voltage Phase wire at the switching point (kV)**
2.5	58.202
4.5	48.532
6.5	35.340

3.2.2. Switch Point Simulation With 8/20 µs Lightning Impulse

Table 6 illustrates the overall simulation results. The table results indicate that the peak voltage value at the transition point increases with increasing peak currents of lightning striking and decreases with increasing strike distance. When a lightning strike is 2.5 kilometers away and the peak lightning current is 20 kA, the peak voltage at the transition point is 28.692 kV. when the strike distance is 4.5 km increases to 39.700 kV. From Table 1 it can be seen clearly that the voltage drops at the transition point when the strike distance is farther from the transition point, and also that the peak lightning current increases, which affects the tension value at the transition point.

Table 6. Voltage response graph at the switching point with an impulse of 8/20 µs

Peak Current of 20 kA	
Strike Distances (km)	**Peak Voltage Phase wire at the switching point (kV)**
2.5	28.692
4.5	27.466
6.5	24.764
Peak Current of 50 kA	
Strike Distances (km)	**Peak Voltage Phase wire at the switching point (kV)**
2.5	42.541
4.5	39.700
6.5	35.340

3.2.3. Cable Line End Point Simulation With 1.2/50 µs Lightning Impulse

Table 7 is a simulation results indicate that the peak voltage at the end of the cable increases as the peak lightning current increases in value and decreases as the strike distance increases. When a lightning current of 20 kA strikes at a distance of 2.5 km, the voltage at the end of the cable line is 34.569 kV. When the lightning current attains 50 kA, the voltage at the end of the cable line goes up to 44.896 kV.

Table 7. Voltage response graph at the switching point with an impulse of 1.2/50 µs

Peak Current of 20 kA	
Strike Distances (km)	**Peak Voltage Phase wire at the switching point (kV)**
2.5	34.569
4.5	30.357
6.5	25.289
Peak Current of 50 kA	
Strike Distances (km)	**Peak Voltage Phase wire at the switching point (kV)**
2.5	55.351
4.5	44.896
6.5	30.185

3.2.4. Cable Line End Point Simulation With 8/20 µs Lightning Impulse

Table 8 reveals that the higher the value of the peak lightning current, the greater the voltage generated at the end of the cable line, and the greater the distance of the lightning strike, the lower the voltage value at the end of the cable line. Changes in the lightning impulse with in simulated voltage at the cable line are the same effect as changes in the simulated voltage at the switching point. The lesser the front time value, the faster an impulse reaches its peak, and the higher the tail time value, the longer a lightning impulse is at its peak value, resulting in a large voltage.

Table 8. Voltage response graph at the switching point with an impulse of 8/20 µs

Peak Current of 20 kA	
Strike Distances (km)	**Peak Voltage Phase wire at the switching point (kV)**
2.5	28.143
4.5	27.030
6.5	23.046
Peak Current of 50 kA	
Strike Distances (km)	**Peak Voltage Phase wire at the switching point (kV)**
2.5	41.186
4.5	36.648
6.5	30.275

Following the overall simulation results, namely at the transition point and the end of the cable channel, the voltage at the transition point will decrease in value when passing through the cable channel. This can happen because the conductor has different types of impedance, and the length of the cable line also impacts the voltage drop at the switching point [20]. Furthermore, tower grounding can assist in reducing phase line overvoltage. Compare the voltage values at the switching point and at the end of the cable line for more data.

4. CONCLUSIONS

According to the research findings, it is possible to conclude that the voltage contained in all simulations continues to remain in the reasonable and safe category for safety and equipment in accordance with safety and equipment standards. Whereas the voltage at the transition point and the end of the cable channel decreases with distance, the voltage at the transition point increases with distance, and the voltage at the end of the cable line decreases with distance.

If compared to similar studies [11], [12], and [17], the achieved results where there was interruption with the electricity distribution lines due to lightning strikes around the distribution points were quite similar. In anticipation of a breakout, several studies, such as [11], added ground wire overhead [12]. Provided EMTP simulation results for the addition of the shield wire attribute in anticipation of reducing the effects of lightning strikes [17], simulated a transmission system with an arrester introduced.

In our research we founded that using mixed lines can assist in reducing line overvoltage. In other words, the use of mixed lines can reduce the overvoltage on the line. This can happen because there are different types of impedance in the conductor, and also because the length of the line including the length of the cable line (SKTM) also affects the voltage drop at the transition point and the end of the cable. In addition, grounding can also reduce the overvoltage on the phase line [21]. Therefore, it is suggested that PT. PLN (Persero) especially the Makassar Branch pay more attention to the use of 20 kV Mixed-Lines channels in order to reduce the impact of impulse voltages due to lightning strikes on the 20 kV distribution channel, especially in open areas and prone to lightning strikes, by maximizing cable channel length.

For future research, we can make prediction of which addition of lightning strike's effect reduction method give best result with each area of distribution lines.

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