IUST Iran University of Science and Technology

Iranian Journal of Electrical and Electronic Engineering

Journal Homepage: ijeee.iust.ac.ir

Back Flashover Voltage on Transmission Tower of 275 KV Extra High Voltage Line (Case Study: Galang-Binjai)

Surya Hardi*(C.A.), Ferry R. A. Bukit*, Irfan Nofri**, Riza R. Wirasari***, Muhd Hafizi Idris****, Muzamir Isa****

Abstract: Overvoltage at the insulator terminal caused by a lightning strike can occur in two ways, i.e., a direct lightning strike on the phase line and ground wire. The insulator can be exposed to the phenomenon of back flashover (BFO) if the terminal voltage of the insulator is higher than its insulator critical voltage The lightning current characteristics are distinguished by the maximum current and the steepness. Differences in the characteristics in this study are identified as International Electrical Commission (IEC) and Conseil International des Grands Reseaux Electriques (CIGRE) impulse waveform standards. The footing-tower grounding system comes in different configurations, such as horizontal, vertical, and grid. Alternative transient program (ATP) software was used for simulating lightning strikes on ground wire and phase lines. The results exhibit that the highest critical voltage of the insulators on the footing tower through grid grounding when the surge current strikes ground wire (3308kV – 3395 kV), with the magnitude of the lightning current ranging from (48 kA – 3395 kA). For lightning direct stroke on the phase line, the critical voltage on vertical grounding is highest on (2938 kV -3021 kV). The surge current flow footing-tower is highest on the grid. The currents magnitude flow in footing tower were influenced by impedance of grounding.

Keywords: Back flashover voltage, Lightning current, String insulator, footing-tower grounding and ATP software.

1 Introduction

GENERATION stations are commonly located far from the center of loads. For transmitting energy produced by the generation to the loads, an overhead long transmission line. The lines are susceptible to lightning strikes caused by their high and widespread. A study, documented in [1], shows that permanent damage to electric apparatus due to lightning strikes ranges from 5% to 10%. Therefore, in an effort to protect the lines against lightning, one of them is ground wire. One or two wires are above the phase line, and it depends on the tower design type. On the other hand, to decrease the effect of the lightning, the tower is also equipped with a grounding system at the tower's foot, which is to provide a path of lightning current to the ground

The lightning stroke on the transmission line injects an impulse current wave, which it propagates to all impedances connected to it and transmits or reflects when the impedance is different. The current wave arrives at a string insulator terminal exposed to overvoltage (OV). If the terminal voltage of the insulator is higher than the critical flashover (CFO) voltage, it can cause the isolator to flashover, even at the higher voltage, the string insulator will break down and then short circuit fault to ground. The function of the insulator is to isolate the voltage (phase-line) and non-voltage parts (transmission tower), whereas ground wire is directly connected to the tower. If the ground wire or tower structure gets a direct lightning stroke, it will result in high induce voltage at the tower, and the voltage also comes up at the grounding system, so the total voltage can cause back flashover (BFO). The BFO can result from the direct lightning strike on phase lines when the ground wire failed to provide protection [2].

Iranian Journal of Electrical & Electronic Engineering, 2025.
Paper first received 23 Dec. 2024 and accepted 22 Feb. 2025.
* The author is with the Electrical Engineering Department, Universitas Sumatera Utara, Medan-Indonesia.
** The author is with the Universitas Muhammadiyah Sumatera Utara, Medan- Indonesia.
*** The author is with the Universitas Alwasliyah (Univa) Medan, Medan-Indonesia.
**** The author is with the Centre of Excellence for Renewable Energy (CERE), Faculty of Electrical Engineering & Technology, Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia.
Corresponding author: Surya Hardi
E-mail: surya.hardi@usu.ac.id.

Some papers published use software to simulate transmission line performance due to lightning strikes. ATP-EMTP software was used to estimate the lightning performance using the Monte Carlo method, as documented in [6]. Other papers analyze back flashover related to the insulation coordination of a substation transformer [7, 8]. The influence of front and tail waves of lightning current against lightning protection performance was investigated. Simulation is direct injection on shield wire with a crest voltage 10 MV

The effect of a lightning strike on a distinct lightning current wave on string insulators was investigated. Back flashover on the transmission lines is considering amplitude, and shape, as well as striking distance using ATP [9 - 11]. PSCAD/EMTDC was used to simulate back flashover on 115 kV [12]. Transmission line systems were modelled to include a transmission tower, an insulator, and footing resistance for distinct soil resistivity. The crest current between (30-200) kA and the waveform of (8/20) µs is constant. Studying the insulator back flashover is important to design transmission line systems for lightning strikes. The previous study stated that the lightning characteristics have a significant effect on the insulator's flashover. The previous research did not consider grounding types and time flashovers.

This paper discusses the determination of critical back flashover voltage on a string insulator and current waveform performance caused by lightning strikes in using ATP software. The lightning stroke was simulated on the conductor phase line and tower/ground wire. The current waveform lightning surge characteristics of the IEC and CIGRE standards were used with a varied a varied crest current. Grounding of the footing tower in a horizontal, vertical, and small grounding grid. Different footing grounding systems were used to analyze. The voltage and the current in the footing-tower grounding were observed. The study was carried out by implementing one of the real transmission line towers at 275 kV (Galang – Binjai), North Sumatra Province, Indonesia. The transmission is a part of extra high voltage an interconnection system owned by the state electricity company in the North Sumatra.

2 Methodology

2.1 Lightning current characteristic

Two lightning characteristics that have a great influence on the insulator flashover are the crest of the lightning current and the current wave steepness. The waveform includes wave front and wave tail, which are denoted as T_f and T_t, respectively. The wave front has a steep shape, while the wave tail is more sloping. The impulse waveform is illustrated in Figu. 1. The lightning characteristics data are not available in all locations in Indonesia. The measurement result carried out by Zoro at Tangkuban-Perahu Mountain, Indonesia, was documented in [2]. Indonesia is categorized as climate tropic, which it has high relative lightning density. The lightning current crest with a magnitude probability of 50% is 40 kA, with a steepness of 25 kA/µsec.

Several boards have produced standards about impulse waveforms, as documented in [15]. Among them are the International Electrical Commission (IEC), whose waveform with ratio Tf/Tt is (1.2/50) µsec, and the Conseil International des Grands Reseaux Electriques (CIGRE), whose waveform with ratio Tf/Tt is (3.3/77.3) µs, which was used in this study.

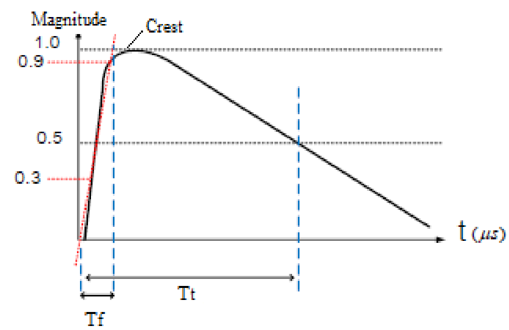


Fig 1. Standard Impulse waveform

2.2 Transmission line parameter

The transmission line is supported by the tower, which is electrically isolated by the insulator. In the tower were some important electrical components, such as insulators with arms and the resistance of the footing tower. This part discusses one of the transmission tower parameters that has been using 275 kV transmission near the Galang substation location. The 275 kV transmission lines from Galang to Binjai are double circuit and 52.1 m high. The transmission has two shield wires, as illustrated in Fig. 2.

Phase lines are using ACSR The zebra conductor type has a reactance of 0.0674 Ω, the inductance of 0.222. Ground wires/shielding wire is galvanized steel with a reactance of 0.364 Ω, the footing tower resistance is Rg (Ω), tower inductance is L_{ind} (H), and V_L (volt) is the voltage system. When the tower gets lightning striking with crest surge current I_S and the steepness current is di/dt. The tower voltage (volt) [2],

$$V_t = I_S R_g + L_{ind} \frac{di}{dt} + V_L \tag{1}$$

Equation (1), it is observed that the tower voltage magnitude is influenced by grounding resistance, the steepness of the current, and tower inductance. Resistance grounding has an effect on high transmission line performance (12,13).

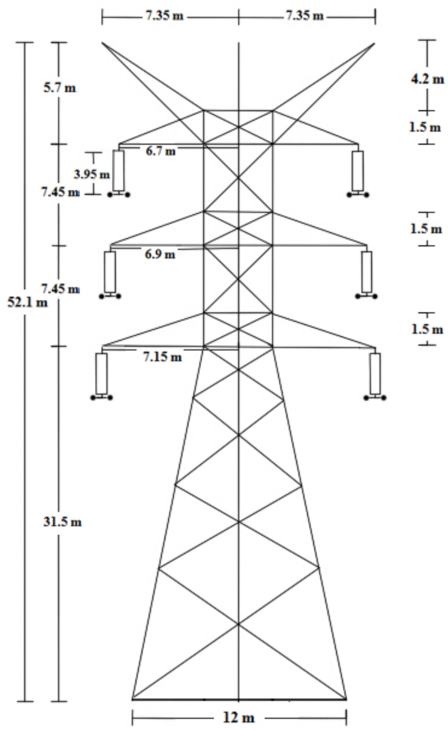


Fig 2. View of simulated tower geometry

There is some grounding of the footing tower which has been used in transmission systems, such as vertical grounding, horizontal grounding, grid grounding, etc. The existing tower grounding system has four legs of the tower vertically. In this study, alternative types of horizontal and grid grounding are considered. The grounding system shapes are shown in Fig. 3 to Fig. 5. The soil resistivity (Ω-m), the length of the electrode rod L (m) meter, the radius of the electrode rod a (m), and d is the depth of burial of the horizontal rod (m).

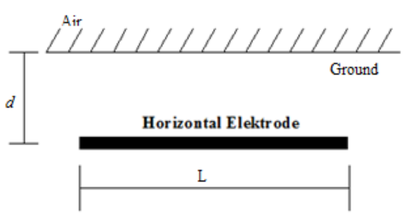


Fig 3. Vertical grounding

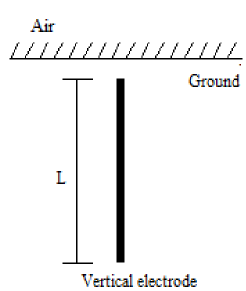


Fig 4. Vertical grounding

Horizontal and vertical grounding resistance, Rg can be written by equations (2) to (3), respectively [16].

$$R_g = \frac{\rho}{\pi L}\left(\ln\left(\frac{2L}{\sqrt{ad}}\right)-1\right) \quad (2)$$

$$R_g = \frac{\rho}{2\pi L}\left(ln\left(\frac{4L}{a}\right)-1\right) \quad (3)$$

The footing-tower has capacitance C (F) and inductance L_{ind} (H). If the tower with is soil resistivity (Ω-m), soil permittivity (F/m), permeability (H/m) and length of embedded rod L (m) can be designated as Equations (4) and (5) [14],

$$C = \frac{\rho\varepsilon}{R_g} \quad (4)$$

This Equation (4) is used for calculating for all capacitance of the grounding system.

$$L_{ind} = \frac{\mu L}{2\pi}\left(\ln\left(\frac{2L}{a}\right)-1\right) \quad (5)$$

Grid grounding consists of four meshes with grid area A (m^2), the grid is stretched out as deep h (m), total length is L (m) in soil resistivity (Ω -m) is shown in Figure 5

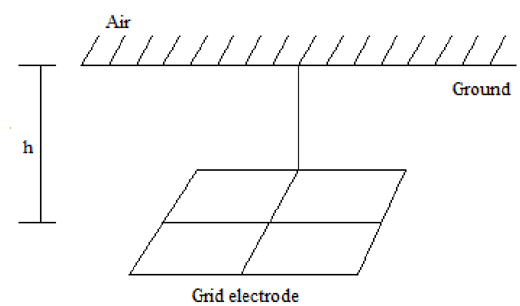


Fig 5. Grid Grounding

The grid grounding resistance can be written as [16],

$$R_g = \rho\left[\frac{1}{L}+\frac{1}{\sqrt{20A}}\left(1+\frac{1}{1+h\sqrt{20/A}}\right)\right] \quad (6)$$

The inductance L_{ind} (H), [15].

$$L_{ind} = 2.05L\left(\ln\left(\frac{2L}{a}\right)-0.69\right)x10^{-7} \quad (7)$$

Insulators are composed of several string insulators made of ceramic with a total length of 3.95 m. The critical flashover voltage on insulator V (volt) can be obtained from the relationship between the total length of insulator L (m) and time to flashover t (second) [3].

$$V = \left(400+\frac{710}{t^{0.75}}\right)\times L \quad (8)$$

A volt-time curve of the 275 KV string insulators with total length of 3.95 m is presented in Fig.6.

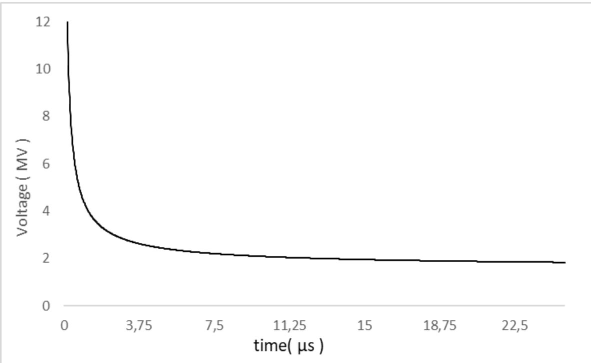


Fig 6. Volt–time curve of the string insulator of the 275 kV

2.3 The 275 kV transmission system modeling

Components modeling considered in this study are presented in Fig.7. It includes source of voltage system, lightning current, phase lines, ground wires, insulators, tower and footing grounding.

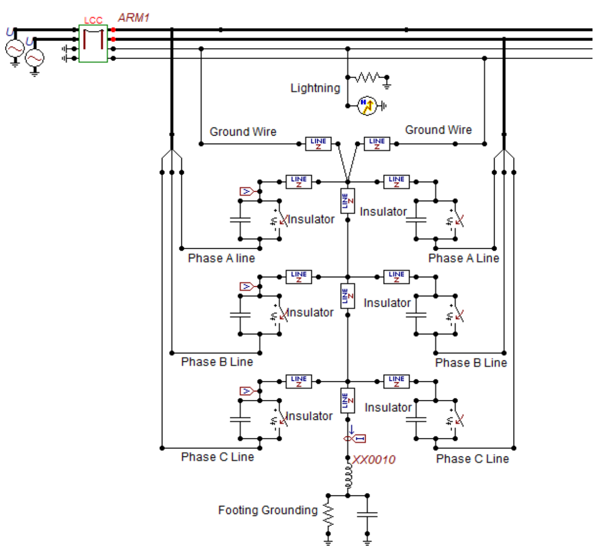


Fig 7. Transmission system modeling

The simulation was carried out by injecting a lightning surge current that varies from 40 kA to 60 kA for a lightning strike on the ground wire and 25 kA to 40 kA for a lightning strike on the line phase increased by multiples of 5 kA. The impedance of tower footing transmission varies based on the grounding system was calculated using equations (3) to (8), while the impedance of the tower is 150.6 Ω constant. The values are shown in Table 1. Different lightning characteristics were modelled as wave front, Tf and wave tail Tt according to IEC and CIGRE standards. If a black flashover occurs at a certain value, the simulation is repeated to obtain the minimum surge current value. The BFO critical of the insulator in simulation is shown at the intersection of the volt-time curves of insulators with lightning impulses.

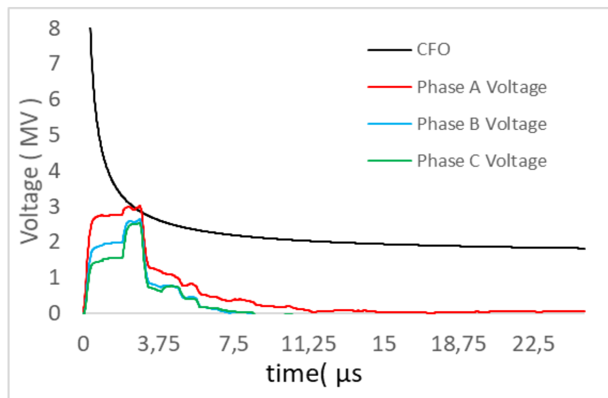
Table 1 Values of tower footing impedances

Grounding type	Resistance (Ω)	Inductance (H)	Capacitance (F)
Horizontal	28.73	64.2×10^{-7}	37.59×10^{-9}
Vertical	54.49	22×10^{-7}	18.15×10^{-9}
Grid	6.48	1.133×10^{-7}	1.47×10^{-9}

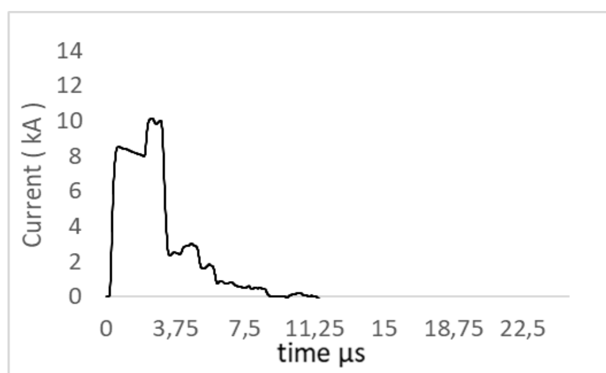
3 Results and Discussion

3.1 Lightning striking to the ground wire

Fig. 8 and Fig. 9 (horizontal grounding presented only) are lightning current waveforms of the IEC and the CIGRE that cause the string insulator to be flashover.

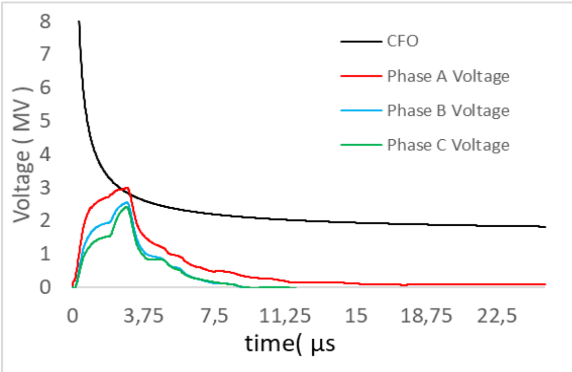


(a) Back flashover voltages

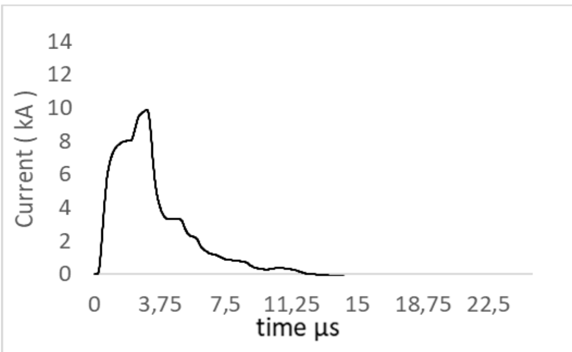


(b) Current waveform

Fig 8. Back flashover voltages and current flows in Horizontal footing waveform caused by the lightning strikes of the IEC impulse current to ground wire



(a) Back flashover voltages



(b) Current waveform

Fig 9. Back flashover voltages and current flows in

Horizontal footing grounding waveform caused by the lightning strike of the CIGRE impulse current waveform to ground wire.

The figures show the insulator volt-time curve and the flashover voltage for each phase at the insulator terminal due to lightning striking to the ground wire in distinct footing grounding systems and standard waveforms. The waveforms in phase-A, phase-B and phase-C are shown in red-line color, blue-line color and green-line blue, respectively. The BFO of the insulator in simulation is shown at the intersection of the volt-time curves of insulators with lightning impulses.

It can be observed that in Fig. 8, the waveforms resulted from injecting impulse currents of the IEC in horizontal grounding only. The footing current waveform produced is dropping drastically at the wave tail. The voltage waveform patterns of lightning produced are not significantly different for different grounding systems. But the BFOs that resulted are slightly different. Insulators BFO in phase-A were recorded at 3360 kV, 3373 kV, and 3395 kV respectively, for the grounding system horizontal, vertical, and grid, as shown in Table 2. The BFO voltage of the horizontal grounding is larger than two others grounding systems. As well for the current that flows in footing tower is higher, as shown in Table 2. Even though in Table 1, the vertical grounding resistance is higher than the horizontal and the grid grounding. The current did not fully depend on the resistance; there is another factor, viz., inductance and capacitance. This is according to equation (2).

The voltage waveform of impulse in Fig. 9 shows the voltage resulted from the CIGRE, and the same pattern for all grounding systems also. There is no difference significantly if is compared with the voltage resulted from the CIGRE and the EIC actually in the currents waveform flow in the footing grounding. If is observed the difference occurred on the way of the crest and as wheel as wave tail which is decreasing exponentially. This difference is caused by different lightning waveforms injected into the wire.

Table 2 presents the BFO insulator in instant conditions, including the minimum surge current, the critical voltage, and the time to flashover in phase A. The surge currents result in the BFO insulator ranging from 47.4 kA to 49.0 kA. The footing grounding system through the horizontal is the one that lowest current (47.4 A) cause the BFO insulator at the magnitude of 3360 kV when subjected to the IEC current standard. The critical terminal voltages of the insulator are highest for grounding grid. The times to the insulator's flashover are distinct, and the longest is the horizontal grounding type when it injects the CIGRE waveform. Different waveforms and grounding systems result in flashover times that are not similar. The time to flashover for the IEC waveform is faster than for the CIGRE waveform.

Table 2 Minimum surge current that causes back flashover for lightning striking to the ground wire

Footing grounding	Current Standard	Surge current (kA)*)	Critical voltage (kV)	Time to flashover (μs)
Horizontal	IEC	47.4	3360	2.89
	CIGRE	47.5	3320	2.97
Vertical	IEC	49.0	3373	2.87
	CIGRE	48.0	3338	2.99
Grid	IEC	48.5	3395	2.96
	CIGRE	48.0	3308	2.88

*) the minimum surge current that causes the insulators back flashover

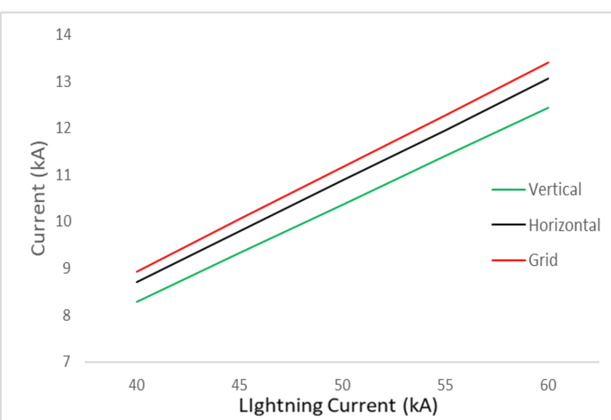
The simulation was carried out for the lightning current, starting from a magnitude of 40 kA to 60 kA and increasing by 5 kA. The simulation result is shown in Table 3. Form this table, the magnitudes of insulator terminal voltage and current flow in the footing tower in distinct grounding systems and lightning current impulses. From Table 3, the insulator terminal voltage and currents in the footing tower increase due to the lightning current. Vertical grounding systems result in the insulator voltage being highest, followed by horizontal and grid grounding for both waveforms, but the lowest current flow in footing grounding is vertical grounding.

Table 3 Terminal crest voltages of the string insulator and the currents flow in tower footing when the lightning strike to the ground wire

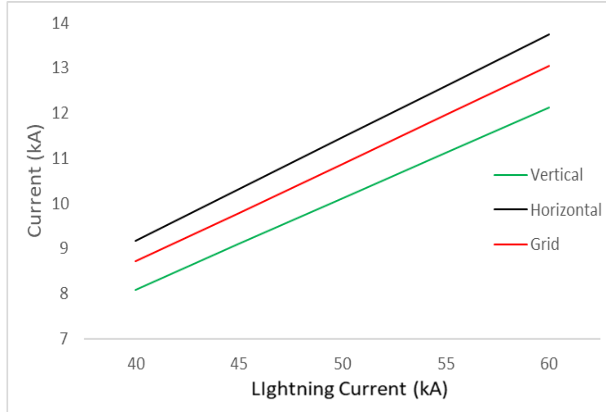
Groundin system	Lightning current (kA)	The IEC Std		The CIGRE Std	
		Voltage kV1)	Current kA2)	Voltage kV1)	Current kA2)
Vertical	40	2491	8.29	2473	8.08
	45	2786	9.33	2764	9.10
	50	3080	10.36	3045	10.11
	55	3375	11.40	3346	11.11
	60	3669	12.43	3638	12.12
Horizontal	40	2434	8.94	2426	8.71
	45	2722	10.05	2711	9.79
	50	3009	11.17	2998	10.88
	55	3290	12.28	3284	11.96
	60	3584	13.40	3571	13.05
Grid	40	2407	9.33	2395	9.17
	45	2691	10.49	2676	10.31
	50	2975	11.66	2959	11.46
	55	3258	12.82	3241	12.60
	60	3542	13.99	3523	13.75

1) The crest over voltage on the string insulator terminal
2) The current flows through in the footing grounding

Comparison of the currents in different grounding system and waveform are shown in Fig. 10 (a) and Fig. 10 (b). Grounding systems result in different significantly of the currents flow in the footing grounding, if the lightning current is the CIGRE waveform comparable the IEC waveform. Therefore, can be said that wave front Tf and wave tail Tt influence on the footing current. This is corresponding to simulation result studied was published [4, 14].



(a) The IEC surge current strike to the ground wire

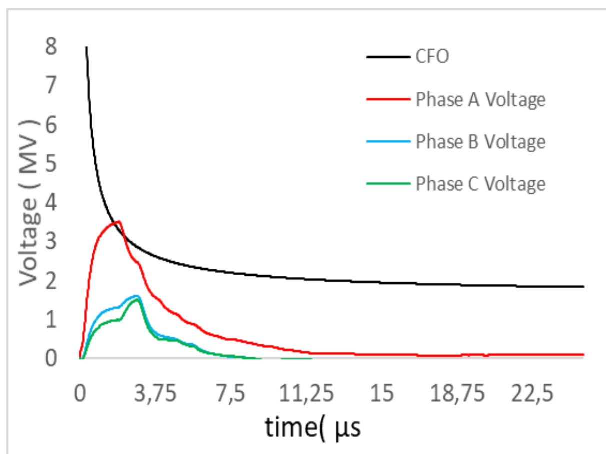


(b) The CIGRE surge current strike to the ground wire

Fig.10 Current flows in footing grounding when the surge current strike to the ground wire.

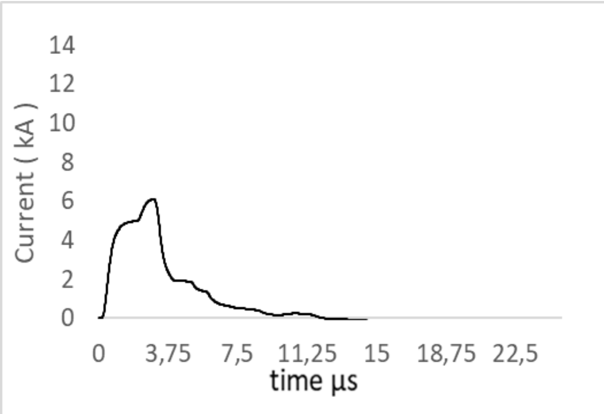
3.2 Lightning striking to phase line

Three-phase transmission line composed of phase A, phase B, and phase C. Phase A is the highest at the above of the ground surface, therefore phase A gets direct striking lightning. Lightning impulse characteristics of the IEC and the CIGRE were simulated, and the voltage waveform and the current flow in footing tower are presented in Figs. 11 and 12 (horizontal grounding presented only).



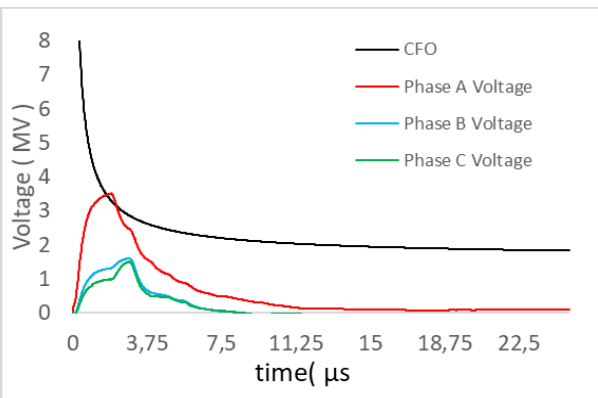
(a) Back flashover voltage

Fig. 12 show the insulator experienced BFO on phase-A only because phase-A gets a direct lightning stroke, whereas two phases, viz., phase-B and phase-C do not experience BFO. These conditions result in the voltage in phase-A being much higher than in phases B, and phase-C. Nevertheless, phase-B and phase-C voltage increase as a result of the inducing effect. When BFO occurs, the lightning current has flowed to the ground through the footing-tower; only horizontal grounding is presented in this paper.

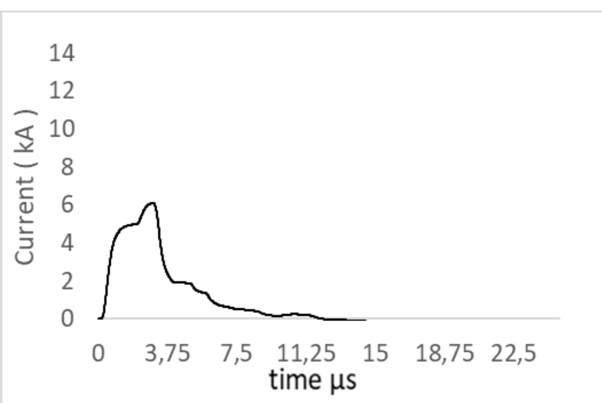


(b) Current waveform

Fig.11 Back flashover voltages and currents flow in Horizontal grounding waveform caused by the lightning strike of the IEC current waveform to phase line.



(a) Back flashover voltage



(b) Current waveform

Fig. 12. Back flashover voltages and currents flow in Horizontal footing grounding waveform caused by the lightning strike of the CIGRE current waveform to phase line.

The waveforms of the BFO voltage and the current exhibit same trend in different grounding systems and different waveforms, actually, the current magnitude resulted. The minimum lightning currents that can cause BFO the insulator is shown in Table 4. This table is explaining results of the effect of the lightning current waveform striking the phase line in two standards, i.e., IEC and CIGRE and different footing groundings. The insulator critical voltage on grid grounding has the highest reach of 3395 kV when CIGRE waveform standard striking phase line otherwise, it is the lowest for IEC waveform standard, which its magnitude of 3308 kV. The time to flashover is longest on vertical grounding with CIGRE lightning current, and the fastest is the grid footing with CIGRE also.

Table 4 Minimum surge current that causes back flashover for lightning strike to the phase line

Footing grounding	Current Std.	Surge current (kA)*)	Critical voltage (kV)	Time to flashover (μs)
Horizontal	IEC	26.4	2860	1.97
	CIGRE	26.5	2797	2.06
Vertical	IEC	26.7	3021	1.95
	CIGRE	26.5	2938	2.02
Grid	IEC	26.4	2889	1.96
	CIGRE	26.5	2846	1.98

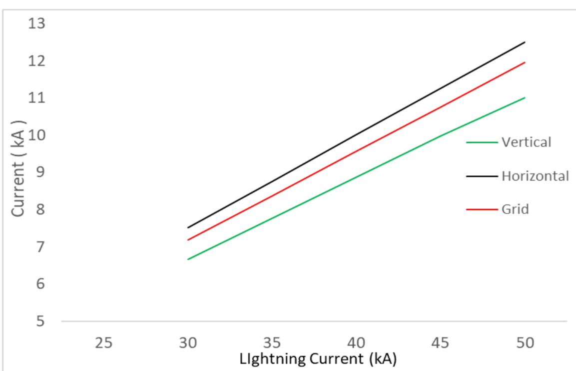
Effect of the lightning current comprehensively was presented in Table 5. The table shows the lightning current effect striking on phase-A line. The currents vary from 25 kA to 50 kA by increasing 5 kA. There are no current flows to ground when the lightning current strikes of 25 kA to phase line for all grounding types because the BFO insulator has not occurred. From this table, the currents flow to the ground when the lightning current of 30 kA strike the phase line. The insulator terminal voltages for IEC waveform are 3809 kV, 3796 kV, 3794 kV in the vertical, the horizontal and the grid, respectively. For same current when lightning surge of the CIGRE waveform, the voltages are lower (2759 kV, 3739 kV, and 3725 kV).

Fig. 13 shows the currents flow in in the footing tower when the phase line A subjected to lightning strike. The currents in vertical grounding are higher than in another. This is indicating that the current characteristics. It means that the current magnitude was influenced by footing tower grounding, however, this difference is not significant.

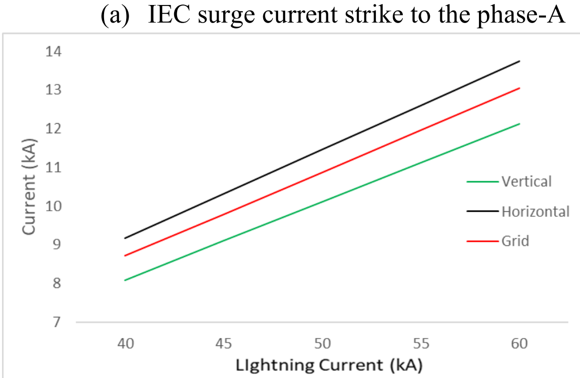
Table 5 Terminal crest voltages of the string insulator and the currents flow in tower footing when the lightning striking to phase line

Grounding system	Lightning current (kA)	IEC Std		CIGRE Std	
		Voltage kV[1)]	Current kA[2)]	Voltage kV[1)]	Current kA[2)]
Vertical	25	3204	0	3157	0
	30	3809	6.68	3759	6.55
	35	4415	7.78	4361	7.63
	40	5021	8.88	4962	8.71
Horizontal	50	6236	11.01	6165	10.87
	25	3192	0	3140	0
	30	3796	7.19	3739	7.05
	35	4399	8.38	4337	8.21
	40	5002	9.57	4340	9.38
Grid	25	1502	0	3129	0
	30	3794	7.53	3725	7.42
	35	4398	8.77	4321	8.64
	40	5010	9,12	4332	9.58

1) The crest over voltage on the string insulator terminal
2) The current flows through in the footing grounding.



(a) IEC surge current strike to the phase-A



(b) CIGRE surge current strike to the phase-A

Fig. 13. Back flashover voltages and currents flow in Horizontal footing grounding waveform caused by the lightning strike of the CIGRE current waveform to phase line

4 Conclusions

The simulation has been carried out to investigate the effect of lightning surge strikes on the ground wire and the phase-line of a 275 kV tower. Differences in lightning current waveforms (IEC and CIGRE) and footing-tower grounding (horizontal, vertical, and grid) provide the different results. The results exhibit that critical voltage of the insulators when the lightning strikes to ground wire are larger than the lightning current strikes at phase line and the critical voltages for grounding types are not significant different, but grid grounding are highest.

The magnitude of current surge that can cause BFO insulators from (47.4 to 49.0) kA, and time to flashover from (2.87 to 2.99) µs. For lightning direct stroke on the phase line, the critical voltage on vertical grounding is highest on (2839 to 3021) kV. Critical back flashover voltage of the insulator is lower caused by the CIGRE than the IEC. The voltage is lowest when the tower is grounded by the horizontal, then by the grid and the vertical for lightning strokes on the wire grounding, but the footing current, the magnitude, and time to flashover are almost similar. The lowest voltage that caused the BFO insulator is 2797 kV, 26.5 kA surge current and a flashover time of 2.06 µs.

Acknowledgement

The authors gratefully acknowledge the financial support of the Universitas Sumatera Utara 2020 Talent, titled "Determination of Critical Voltage of Back Flashover on Extra High Voltage Transmission Line by Simulation.

References

[1] R. Bhattarai, R. Rashedin, S. Venkatesan, A. Haddad, H. Griffiths, N. Harid,"Ligthning performance of 275 kV transmission line". 2008. 43rd International Universities Power engineering Conference. https://doi.org/10.1109/UPEC.2008.4651622

[2] R. Zoro, "Tropical Lightning Current Parameter and Protection of Transmission Line", International Journal on Electrical engineering and Informatics, 2019, vol. 11, no. 3, pp.506-514. https://doi.org/10.15676/ijeei.2019.11.3.4

[3] D. Filipovic-Greic, B. Filipovic-Greic and Ivo Uglesic,"Lightning critical flashover of high voltage insulators Laboratory measurement and calculations". International Review of electrical engineering (IREE), March-April 2012,vol.7, no.2, pp.4321-4328.

[4] Silveira, F. H., and Visacro, S. "Lightning Performance of Transmission Lines: Impact of Current Waveform and Front-Time on Backflashover Occurrence". IEEE Transactions on

Power Delivery, 2019, 34(6), 2145–2151. https://doi.org/10.1109/TPWRD.2019.2897892,
[5] S. Hardi, F. Mirza, F.R.A. Bukit, Rohana."Influence of Ligthning Characteristics on Back Flashover in Extra High Voltage Line: A Case study". Journal Physic Conference Journal of Physics: 2021. Conference Series, Volume 1811.https://doi.org/10.1088/1742-6596/1811/1/012048
[6] J. A. M. Velasco J. C. Araujo and S. Bedoui," Lightning performance analysis of transmission lines using the Monte Carlo method and parallel computing".Revista chilena de ingeniera, 2018, vol. 26, no. 3, pp. 398-408. https://doi.org/10.4067/S0718333052018000300398
[7] Mobarakei, S. T., Sami, T., & Porkar, B. Back Flashover phenomenon analysis in power transmission substation for insulation coordination. 2012 11th International Conference on Environment and Electrical Engineering, EEEIC 2012 - Conference Proceedings, (2012). 170–174. https://doi.org/10.1109/EEEIC.2012.6221567
[8] M. Liu, Z. Li, R Jin Z. Zeu, C. song and R. Wang,".Research on influences of lightning current amplitude and wave-head time to overhead line lightning over voltage" International conference on advance in material, machinery and electrical engineering. (AMMEE), 2017,pp.305- 310. https://doi.org/10.2991/ammee-17.2017.59.
[9] S. Hardi, Hariadi, A. Fitriyani, Rohana, D. Nataliana" Transient characteristic of transmission line and tower footing grounding due to lightning strike"2023. https://doi.org/10.1063/12.0014826
[10] M. A. Abd-Allah, T. Elyan and E. Belal, "Back flashover analysis for Egyptian 500 kV and 220 kV transmission tower". International Journal of Scientific Research Publication. April 2016. Vol. 6, pp. 289-297.
[11] O. S. Gouda, A. Z. El Dein and G. M.Amer." Parameters affecting the back flashover terminal the overhead transmission line insulator caused by lightning". Proceeding of the 14thInternational Middle East Power System Conference, Cairo, 2010. pp.44-49.
[12] Silveira, F. H., and Visacro, S." Lightning Performance of Transmission Lines: Methodology to Design Grounding Electrodes to Ensure an Expected Outage Rate. *IEEE Trans. Power Del.*, Feb. 2015**,** vol. 30, no. 1, pp. 237-245**.** https://doi.org/10.1109/TPWRD.2014.2332457.
[13] Christodoulou, .A., Ekonomou, L., Papanikolaou, N., et al.: Effect of the grounding resistance to the behavior of high-voltage transmission lines surge arresters. *IET Sci. Meas. Technol.* (2014), **8**(6), 470–478. https://doi.org/10.1049/iet-smt.2014.0017
[14] W. Anekthanasuwan, P. Jumrain, T. Jumpradit and Nit Petcharaks, " Analysis back flashover terminal insulator string on a 115 kV transmission tower by PSCAD". KKU Journal Engineering, July - September 2015, 42 (3), pp. 226-234. https://doi.org/10.14456/kkuenj.2015.24.
[15] A. Arismunadar, "High Voltage Engineering" 8thed, Pradya Paramita, Indonesia, 2001, pp. 28-45.
[16] Guide for Safety in AC Substation Grounding Based on Institute of Electrical and Electronic Engineers (IEEE std 80:2000). In IEEE Standards Association, (2013), 80-2013.
[17] R. Verma and Mukhedkar D," Fundamental consideration and impulse impedance of grounding grids'. IEEE Transactions on Power Apparatus and System, 1981, vol. 100, no.3, pp1023-1030.

Biographies

Surya Hardi received the Bachelor degree from Universitas Sumatera Utara (USU-Medan-Indonesia), Master degree from Institute of Bandung Technology (ITB-Indonesia) and Ph.D degree from Universiti Malaysia Perlis (UniMAP-Malaysia). He is a Professor at Department of Electrical Engineering, USU, Indonesia. His research interest includes: power quality, protection system and power system grounding, and high voltage engineering.
Corresponding author: surya.hardi@usu.ac.id

Ferry Rahmat Astianta Bukit was born September 17, 1989, in Medan, North Sumatera Utara, Indonesia. He did his undergraduate work at Universitas Sumatera Utara in Medan, North Sumatera, Indonesia. He received a Bachelor of Electrical Engineering in 2011. After a while, he worked for a private company. He continued taking a master's program in Electrical Engineering at Institut Teknologi Bandung, Bandung, West Java, Indonesia, from 2013-2015. Until now, he is lecturer at Universitas Sumatera Utara. He can be contacted at email: ferrybukit@usu.ac.id.

Riza R. Wirasari received the Bachelor's degree from Universitas Pembangunan Panca Budi Medan (Medan-Indonesia). Master degree from Universitas Muhammadiyah Medan (UMSU-Indonesia). She is a Lecturer of Electrical Engineering Department, Universitas Alwasliyah, Medan, Indonesia. Her research interest includes: Protection systems and power system grounding. email: riza.wirasari14@gmail.com

Irfan Nofri received his Bachelor's degree from Universitas Muhammadiyah Sumatera Utara in 2020 and his Master's degree from Universitas Muhammadiyah Sumatera Utara in 2023. He is a Lecturer and Laboratory Assistant in Electrical Engineering Study Program Universitas Muhammadiyah Sumatera Utara-Indonesia. His research interests include: power quality, renewable energy and system control. Department of Electrical Engineering, email: irfannofri@gmail.com

Muhd Hafizi Idris Bachelor of Electrical, Electronic and System Engineering, Universiti Kebangsaan Malaysia (UKM), 2002-2006 he Works as Protection Engineer, Transmission Division, Tenaga Nasional Berhad (TNB), 2006-2009. Master of Electrical Power Engineering, Universiti Teknologi Malaysia (UTM), 2009-2011. Lecturer, School of Electrical System Engineering, Universiti Malaysia Perlis (UniMAP), PHD in Electrical System Engineering at School of Electrical System Engineering, Universiti Malaysia Perlis (UniMAP), Perlis-Malaysia, email: hafiziidris@unimap.edu.my

Muzamir Isa received D.Sc (Tech.) (High Voltage Eng.) (Aalto University, Finland) M.Eng. (Elect. Eng) (KUiTTHO & FH Koln, Germany, B.Eng. (Hons.) (Electrical -Power) (UTM). He is a Profesor at School of Electrical Engineering, UniMAP, Perlis-Malaysia email: muzamirisa@unimap.edu.my