

PAPER • OPEN ACCESS

The Effect of Grounding Resistance About Back Flashover on 150 KV Transmission Network in Main Station of Sungguminasa - Tallasa (Makassar)

To cite this article: Naomi Lembang *et al* 2018 *J. Phys.: Conf. Ser.* **1090** 012077

View the [article online](#) for updates and enhancements.

You may also like

- [Electrical breakdown of soil under nonlinear pulsed current spreading](#)
L M Vasilyak, V Ya Pecherkin, S P Vetchinin *et al.*
- [Research on the Method to Measuring Tower Grounding Resistance by Distributing Multi Electrodes around Local Area](#)
Honghe Huang, Pinggang Ding, Guohua Liu *et al.*
- [The use of physically activated and soil composed bentonite as environment friendly for grounding resistance](#)
Y Martin, D Permata, D Despa *et al.*



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

The Effect of Grounding Resistance About Back Flashover on 150 KV Transmission Network in Main Station of Sungguminasa - Tallasa (Makassar)

Naomi Lembang¹, SalamaManjang², IkhlasKitta²

Electrical Engineering Department¹, Post Graduate Program Of Hasanuddin University², Jl. Perintis Kemerdekaan KM. 10 Makassar, Sulawesi Selatan, 90245, Indonesia

E-mail: naomi_lembang@ymail.com¹, salamamanjang@gmail.com², ikhlaskitta@gmail.com²

Abstract. Lightningsurge on transmission network is a natural problem that affecting electricity voltage. This impact on the occurrence of equipment damages as result of *back flashover*. *Back flashover* causes an impulse wave due to the increase of voltage on the transmission and has a large grounding resistance value. There has been a disturbance in the transmission system SULSELBAR causing black out on Tuesday, January 19th, 2016 at 14:13 pm. The disturbance occurred along with the rain and strong winds accompanied by lightning which caused the load loss of 746 MW. The research was conducted to determine the occurrence of direct lightning strikes on each tower, the effect of grounding resistance to *back flashover* on 150 kV transmission network in main station of Sungguminasa - Tallasa, using modeling simulation of peak menara transmission network 150 kV in main station of Sungguminasa - Tallasa with software ATPDraw (Alternative Transient Program). The simulation results depicting one of the phase wire reach the peak current of 359.89 MA. In this condition occurs disruption that causing the impulse voltage and back flashover with disturbance current 22.65 kA. The large of grounding resistance has an average voltage exceeding the capacity limit from 1001.54 kV to 1042.31 kV. Based on the calculation, the impulse voltage obtained is 5.271 MV close to simulation result of ATPDraw(Alternative Transient Program) by 4.530 MV. The calculation of the current wave when there is lightning disturbance in the transmission line with a peak current of 60 kA and the wave front time of 1 μ s, obtained the highest value that is on the tower 39 the grounding value of 5.4 Ω , the grounding value obtained reflection coefficient of -0.937 and insulator voltage at 957.036 kV, the results of this research held the measurement of tower 39 using *Megger Det4tr* and obtained the grounding value on the tower feet of 12.22 and 9.97 ohm. What makes this case interesting is that the installation is located in a wet-sand soil type, undertaken decrease grounding value of 39 of parallelization methods by adding 2 copper rods (*arde*) 5/8 inch diameter in 4 meters long and the addition of mixture of carbon and NaCl, the result of was able to reduce the magnitude of grounding resistance is 0.78 ohm, close to the calculation results of parallelization method is 0.0864 ohm. This method is more accurate because the disturbance of back flashover can be avoided by lowering the high grounding value due to lightning strikes and protecting other equipment, can be used in long-term, inexpensive and simple, very suitable applied of wet soil

1. Introduction

Lightning strike is a very serious threat in electrical systems where its network is widespread [1], disturbance for transmission that causing major loss for electricity service providers. On transmission network 150 kV, main station of Indonesia have problems with equipment damage caused by lightning strikes that immediately strike the ground wire and tower. At voltage exceeds or equal to critical limit voltage of isolator back flashover so that occurs *Back Flash Over* (BFO) and causing the form of impulse wave due to increase voltage of transmission network to the end of network of main station that can damages isolation. Therefore, that needs to be done is a study about the performance of transmission network 150 kV as result of lightning strikes using ATPDraw(Alternative Transient Program), The ATP(Alternative Transient Program) has been used to study the lightning performance of transmission lines [2]. to get the profile of voltage as it exceed or equal to critical limit of isolator back flashover or current result by using ATPDraw(Alternative Transient Program) tools. The result of point conditions BFO occurring in a transmission tower 150 kV Sungguminasa-Tallasa and using the theory of running wave to calculate lightning disturbances of tower that is BFO back flashover, due to reflection of a travelling waves formed by the lightning strike, where the reflections from the tower base will arrive much sooner at the tower topthen reflections from adjacent towers [3].



In order to reduce the likelihood of blackouts and the damage of transmission device as result of BFO (Back Flashover), then it conducted by lowering the grounding value with long-term durability. It conducted at point of BFO occurrence on the transmission tower of Sungguminasa-Tallasa.

To lowering the grounding value, then use grounding copper rods (*arde*) by grounded under the soil surface as deep as 4.20 meters in parallel close to the tower pole and the addition of NaCl + C (salt + charcoal) by measuring the grounding using parallelization method. Conductor connector of grounding system from electrical channel to salt can reduce grounding impedance simultaneously. The increase of voltage exceed the safe limit can be developed a continuous counter connected to the salt water can stabilize the potential profile [4].

Comparison of the addition of salt and bentonite to the grounding value by using rod type to lowering grounding value [5]. So that the effect of grounding quantity is expected in the future to be considered to reduce the damage of transmission line equipment on main station 150 kV as result of the lightning surge.

2. Methods

The method of analysis in this study used 4 (four) problem-solving techniques with mathematical equations that will be simulated on ATPDraw (Alternative Transient Program), as well as mathematical equations to calculates the magnitude of grounding resistance to the voltage generated lightning disturbance on the isolator, and to calculate the grounding rod on tower feet, as follows:

2.1. Impulse Voltage

It is defined as a double exponential waveform which can be expressed by the equation:

$$(t) = Voe - at - e - bt \quad (1)$$

On the other hand, within some 30 m of the tower base (i.e. concentrated tower grounding system), the tower grounding impedance exhibits only current dependence, which can be modelled in accordance with guidelines provided in [6] and implemented in (Electromagnetic Transient Program) EMTP-ATP (Alternative Transient Program) software package by means of the MODELS language [7].

An analysis model of transmission line lightning strain 150 kV is simulated by using ATPDraw (Alternative Transient Program) software. The modelling of transmission line used in this simulation is using the historical data of lightning strike disturbance that happened at 150 kV transmission line especially in GI (Gardu Induk) Sungguminasa and GI (Gardu Induk) Tallasa on 19 January 2016.

Transmission line of the electrical system, especially in Tragi Bulukumba under interconnected GI Sungguminasa, GI Takalar, GI Jeneponto and GI Bulukumba were located on the line between the sea and the mountain that has many cumulonimbus clouds that produce lightning [8].

Voltage source is modelled by ATP (Alternative Transient Program) model (Alternating Current) AC3ph (3-phase source). Voltage source AC (Alternating Current) in ATPDraw (Alternative Transient Program) software is used peak amplitude of voltage system. The modelling of voltage source AC (Alternating Current) can be done by converting a voltage system of 150 kV_{L-L(RMS)} to $V_{\text{peak}} = \sqrt{2} / \sqrt{3} \times V_{\text{L-L(RMS)}}$.

The transformer is modelled by a transformer component 3-phase ideal with a primary and secondary voltage ratio of 150 kV/20 kV = 7.5. As installed on field, the transformer group Yy load 20 kV connected to each transformer is modelled in ATPDraw (Alternative Transient Program) software using RLcY3 component. The following is the average of load percentage of each transformer installed and can be seen in Table 1.

Table 1. Capacity and transformer load installed on transmission line of Tragi Bulukumba

No.	Substation	Installed Capacity (MVA)	Load (%)
1	Sungguminasa	60	46
2	Tallasa	20	12
3	Tallasa	30	16
4	Jeneponto	20	8
5	Jeneponto	30	12
6	Bulukumba	20	17
7	Bulukumba	30	26

*Data source = PT PLN Persero. AP2B Sulselrabar

The load on this simulation is modelled by using RLcY3 component and the equations :

$$R = \sqrt{3} V^2 / P \quad (2)$$

$$L = \sqrt{3} V^2 / (2\pi f Q) \quad (3)$$

2.2. Voltage on Disturbance (BFO)

Strike on the ground wire or tower causing the increase of voltage that can cause BFO (Back Flashover) on the tower isolator, with the equation:

$$V_L = i \times R\varepsilon + L \frac{di}{dt} + V_M \quad (4)$$

2.3. Lightning Disturbance on the Tower

To calculate the lightning disturbance on the tower, i.e disturbance due to the back flashover, we use the theory of running wave, with equation [9]:

- a. Calculates the possibility of the number of fire jumps

$$V_{50\%} 2 \mu\text{det} = \left(K_1 + \frac{K_2}{t^{0.75}} \right) \times 10^3 \text{ kV} \quad (5)$$

1. Calculating ground wire surge impedance and coupling factor of ground wire corona radius :

$$R \ln \left(\frac{2h}{R} \right) = \frac{V}{E_o} \quad (6)$$

2. Surge impedance of a single ground wire :

$$Z_{11} = Z_{22} = 60 \sqrt{\ln \frac{2h}{r} \ln \frac{2h}{R}} \quad (7)$$

- b. Reflection coefficient on the base of the tower for R

$$d = \frac{R - Z_t}{R + Z_t} \quad (8)$$

Table 2. One data Tower and grounding resistance at Tragi Bulukumba GI Sugguminasa - GI Tallasa

No	Tower	Grounding(Ohm) = R ε
1	T. 39	5.4
2	T. 40	5.3
3	T. 46	4.6
4	T. 112	0.8
5	T. 114	0.6
6	T. 113	0.4

- c. Voltage on isolator

This calculation is done for all the flash currents of 60 kA and the front of light wave that given 1 μ .

$$V_i = e_o \left\{ (1 - K)T + d \left[\left\{ T - 2 \left(\frac{h_t}{c} - \frac{x_1}{c} \right) \right\} + (b - Ka) \left(T - \frac{2h_t}{c} \right) \right] + d^2 b \left[\left\{ T - 2 \left(\frac{2h_t}{c} - \frac{x_1}{c} \right) \right\} + (b - Ka) \left(T - \frac{4h_t}{c} \right) \right] + d^3 b \left[\left\{ T - 2 \left(\frac{3h_t}{c} - \frac{x_1}{c} \right) \right\} + (b - Ka) \left(T - \frac{6h_t}{c} \right) \right] \right\} \quad (9)$$

2.4. Grounding on Two Copper Rods on Tower in Transmission 150 kV GI Sungguminasa - GI Tallasa at Tower 39

Implementation of this grounding system is done on the tower SUTT 150 kV between Sungguminasa station and Tallasa main station at tower 39 located on Pallangga subdistrict which was held on 4 May 2017. In the implementation of parallelization system of this grounding installed 2 copper rods at a distance of 2 meters from each foot tower A and C with the addition of charcoal and salt. The giving of charcoal and salt is reduced gradually as shown in figure 7 in the parallelization measurement.

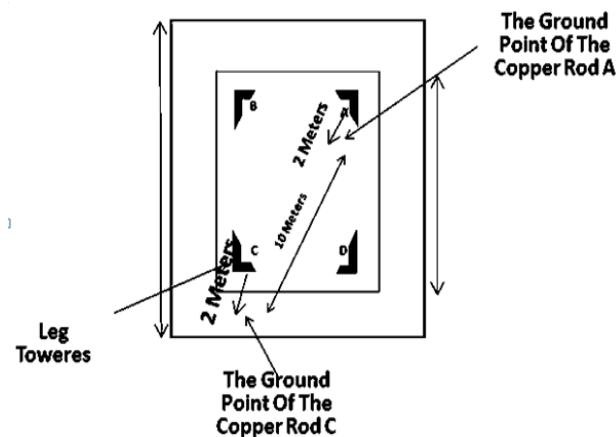


Figure 1.Grounding construction of tower transmission 150 kV (top view).

The resistance of tower foot 10 Ohm can be obtained by using one or more ground rods and/or counterpoise systems. **addition of a counterpoise combined with the effect of the sea water can help to reduce the voltage rise and then the grounding resistance at each tower [10].** The selection of a ground rod and/or a counterpoise system depends on the type of ground type resistance in which the transmission tower is located. Using a single ground rod, tower foot resistance is calculated using the following equation [11]:

$$R = (\rho / 2\pi L) \ln (2L / d) - 1 \quad (10)$$

Measuring 2 copper conductor rods with a parallelization model price A is a multiple of ground rods, two rods is placed everywhere, given salt, the three given [11].

$$A = \sqrt{ar} \quad (11)$$

Types of soil.

Table 3.Resistance of soil type

NO	Types of Soil	The kind Resistance (ohm.m)
1	Marshland	10 up to 40
2	Clay and Fields	20 up to 100
3	Wet Sand	50 up to 200
4	Wet Gravel	200 up to 3000
5	Sand and gravel dry	<10.000
6	Rocky Ground	2000 up to 3000
7	Sea water and fresh water	10 up to 100

*Source: PUIL 2000

3. Result and Discussion

In the analysis of the Back Flashover (BFO), special attention is given to the influences emanating from the insulator strings flashover characteristic and lightning statistics. The model could be applied to the transmission line as a whole or some of its portions, e.g. first several towers emanating from the substation or several towers crossing a mountain ridge [12]. Model analysis of transmission line 150 kV especially along the transmission line there are 81 towers located 26.43 km in GI Sungguminasa and GI Tallasa. The modelling of single diagram Tragi Bulukumba on Alternative Transient Program (ATPDraw). Table 4 is the calculation result of transformer capacity on the transmission line Sungguminasa –Tallasa.

Table 4.Transformer capacity installed on main station

No	S (MVA)	P (MW)	Q (MVAR)	R (Ohm)	L (mH)
1	46	37	27,72	18,745	79,597
2	12	10	7,44	69,841	296,564
3	16	13	9,54	54,467	231,282
4	8	7	5,04	103,098	437,785
5	12	9	7,02	74,019	314,307
6	17	14	10,44	49,772	211,344
7	26	20	15,3	33,962	144,211

*Data source = PT PLN Persero. AP2B Sulselrabar

3.1. The modelling of single diagram Tragi Bulukumba connecting GI Sungguminasa - GI Tallasa.

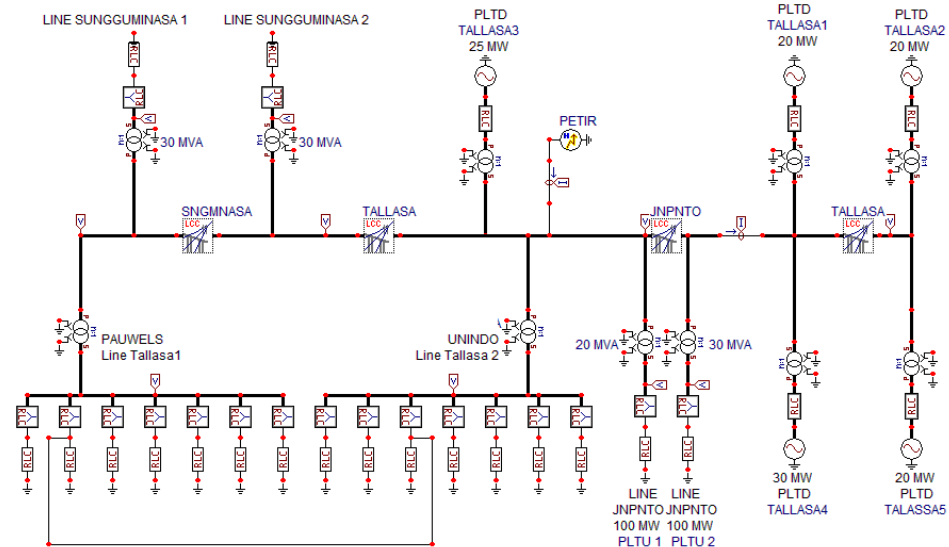


Figure 2.Simulation model of single diagram of Tragi Bulukumba connecting GI Sungguminasa - GI Tallasa after lightning strikes.

The shape of simulation result of front and end time wave of lightning is 0.15 s or 1/50 μ s, the value of lightning peak current reaches 359.89 MA, resulting in a disruption to the electrical system and causes the occurrence of impulse voltage on Busbar and back flash over (BFO), The back flashover performance is estimated by means of several flashover models. They perform differently depending on the lightning waveform and investigated tower [13].

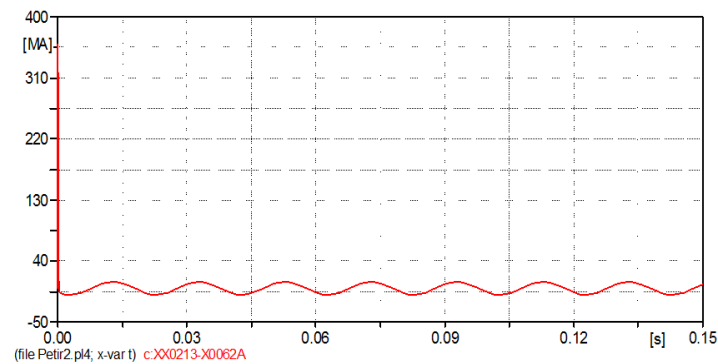


Figure 3.Model of lightning current type Heidler

3.2. Impact analysis the occurrence of back flashover (BFO) that affecting transmission line 150 kV GI Sungguminasa - GI Tallasa due to lightning strikes.

The simulation results for the current on transmission line 150 kV GI Sungguminasa - GI Tallasa is 22.65 kA and waveform in period $T = 50 \mu s$.

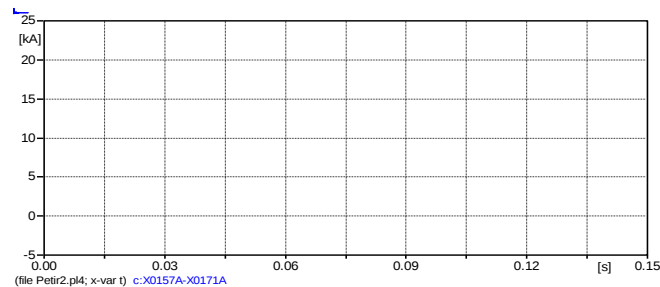


Figure 4.Current on electrical system of Tragi Bulukumba

Table 5 is a data tower and grounding resistance of Tragi Bulukumba under interconnected GI Sungguminasa, GI Takalar, GI Jenepono and GI Bulukumba, there are several towers that have a large earth resistance value so that it can affect the occurrence of back flashover (BFO). Impact analysis of the occurrence of BFO (back flashover) is obtained the highest result of 1042.31 kV is in tower 39.

Table 5. Data tower and the magnitude of grounding resistance that causes back flashover (BFO).

No.	Tower	Ground (Ohm) = R_g	Measurement results (kV)	No.	Tower	Ground (Ohm) = R_g	Measurement results (kV)
1	T.38	5.2	1037.78	21	T.65	3.8	1006.07
2	T.39	5.4	1042.31	22	T.66	3.6	1001.54
3	T.40	5.3	1040.05	23	T.68	3.6	1001.54
4	T.41	5	1033.25	24	T.69	4.6	1024.19
5	T.42	5	1033.25	25	T.70	4.6	1024.19
6	T.43	5.2	1037.78	26	T.72	4	1010.60
7	T.44	4.2	1015.13	27	T.73	3.8	1006.07
8	T.45	4.4	1019.66	28	T.74	3.8	1006.07
9	T.46	4.6	1024.19	29	T.75	3.8	1006.07
10	T.47	4.6	1024.19	30	T.76	4	1010.60
11	T.48	4.4	1019.66	31	T.77	4.2	1015.13
12	T.49	4.4	1019.66	32	T.78	3.8	1006.07
13	T.50	3.6	1001.54	33	T.79	4.8	1028.72
14	T.51	3.6	1001.54	34	T.80	4.6	1024.19
15	T.52	3.8	1006.07	35	T.81	4.2	1015.13
16	T.53	3.6	1001.54	36	T.82	4	1010.60
17	T.60	3.6	1001.54	37	T.90	3.6	1001.54
18	T.61	3.6	1001.54	38	T.93	3.6	1001.54
19	T.62	3.8	1006.07	39	T.94	3.6	1001.54
20	T.64	3.8	1006.07	40	T.96	3.6	1001.54

3.3. The Analysis of Impulse Voltage Magnitude on Transmission Line 150 kV due to Back Flashover (BFO).

Simulation results of Figure 5 shows the impulse voltage values due to lightning strikes in GI Sungguminasa - GI Tallasa.

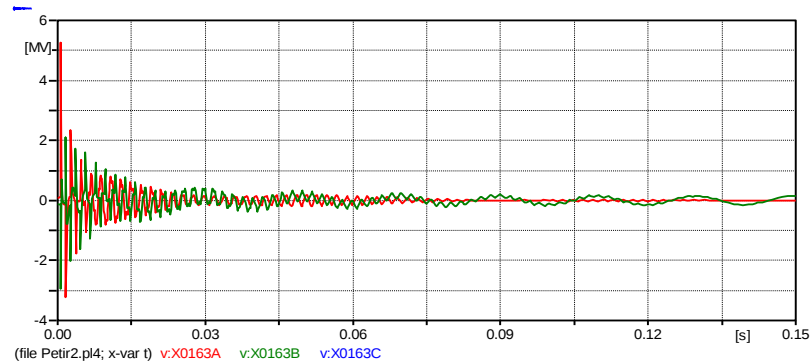


Figure 5. Impulse voltage due to lightning strikes on transmission line GI Sungguminasa - GI Tallasa.

The simulation result on Tragi Bukulumba, the lightning current that is too high greatly affects the voltage on the electrical system. So the important role to resolve the lightning strikes is the grounding resistance of each tower, on average there is a large grounding resistance in some towers along GI Sungguminasa - GI Tallasa so that the voltage of back flash flashover (BFO) is strongly affects the disturbance of the electrical system. Hence, the conclusion that the very high lightning current in the electrical system of GI Sungguminasa - GI Tallasa makes R-phase becomes unstable which is increased by 5.271 MV and then the transition period decrease to 190.59 kV and at the end period is decrease drastically to 3595 V. Lightning peak currents used is a simulation current of 22.65 kA and grounding 0.3 ohms so that the voltage in the phase wire is:

$$V = \frac{Z \cdot I}{2} = \frac{0,4 \, \Omega \cdot 22,65 \, \text{kA}}{2} = 4,530 \, \text{MV}$$

The impulse voltage obtained from the calculation of 5.271 MV approximate the simulation result of Alternative Transient Program (ATPDraw) is 4.530 MV. If seen from the calculation of the impulse voltage then it has exceeded BIL isolator is 750 kV. This indicates that it will cause a flashover, thus propagating in both opposite directions on the line toward the GI to both sides of transmission line. So that the relay will work read interruptions and tripped PMT/CB (Circuit Breaker) on both sides of the main station.

3.4. Impact Analysis of the Occurrence of Lightning Disturbance of Tower that Causing Back Flashover (BFO) with the Theory of Running Wave affecting transmission line 150 kV GI Sungguminasa - GI Tallasa due to a lightning strike.

In this method assumed that the lowest phase will experience the earliest fire jumps due to lightning strikes on the tower. In this calculation is done up to 1 μ det because at that time a negative reflection wave from adjacent tower (average gate length 300 meters) has reached the tower struck by lightning and this wave will reduce the voltage on the tower. Several models have been proposed for representing towers [14], [15], [16]. The simplest one is based on a single conductor distributed parameter line. Tower surge impedance values range from 100 to 300 ohms [17],

The line to be calculated is a line owned by PLN, i.e. Sungguminasa-Tallasa channel. This line is a dual air transmission line 150 kV with a configuration of wire and tower as shown in Figure 6. The data of wire and isolator are:

Radius of ground wire:	0.45 cm
Radius sub-conductors of phase wire:	1.45 cm
Total sub-conductors:	2
Distance between sub-conductors:	45.7 cm
High ground wire on the tower:	37.7 m
High phase wire C or A on the tower:	25.5 m
Large ground wire and phase wire:	7 cm
Distance length of isolator:	6.43 m

This calculation will see the effect of the magnitude of the grounding resistance to the voltage generated by the lightning disturbance of isolator. Therefore, we will use some grounding values obtained from the data of the State Electricity Enterprise, i.e. on voltage 5,4 Ω , 5,3 Ω , 4,6 Ω , 0,8 Ω , 0,6 Ω , and 0,4 Ω . This calculation gradually and its stage is indicated by number given on the front.

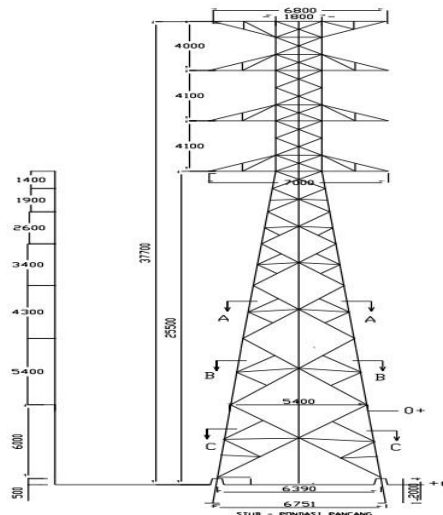


Figure 6.A configuration of wire and tower.

Table 6. The calculation result of lightning disturbance on the tower (calculation for C and A phases).

T (μdet)	I_o (kA)	R (Ω)	d	V_i (kV)
1	60	5,4	-0,937	957,036
		5,3	-0,938	954,967
		4,6	-0,946	937,819
		0,8	-0,99	842,694
		0,6	-0,993	838,454
		0,4	-0,995	834,238

The calculation result of highest voltage values on tower 39. The reflection coefficient is -0.937 and the voltage on the isolator is 957.036 kV, the greater of grounding value on the tower, it will increase the reflection coefficient value which means the possibility to occur back flashover will also be greater. This will cause the voltage value of isolator will also be greater. So, efforts made in the form of correcting the value of grounding resistance of foot tower by make parallelization modeling of ground rods with the addition of charcoal and salt. This is intended to reduce the grounding value of tower foot as well as to add lightning discharge point. The addition of ground point has a very maximum impact.

3.5. Grounding of Tower Feet and grounding Analysis of Two Copper Rods on the Tower Transmission 150 kV GI Sungguminasa - GI Tallasa on Tower 39.

Protection of transmission line against lightning disturbance using ground wire at tower foot to reduce tower foot resistance, to obtain tower foot resistance is less than 5 ohm. Then, conduct the grounding application of 2 copper rods by parallelization method with the addition of charcoal and salt, with a distance of grounding two meters from the tower feet A and C as shown 1. The installation of copper is done in square tower on the side 10 m. Two copper rods are installed 420 cm in deep from the tower foot A and C connected using BC (Bare Core) wire 50 mm in coupling at the tower foot, ground type of tower 39 is wet sand soil. Field corrosion test results in Poland show evidence of better corrosion protection by copper coated steel earth electrodes compared with zinc coatings made using different technologies [18].

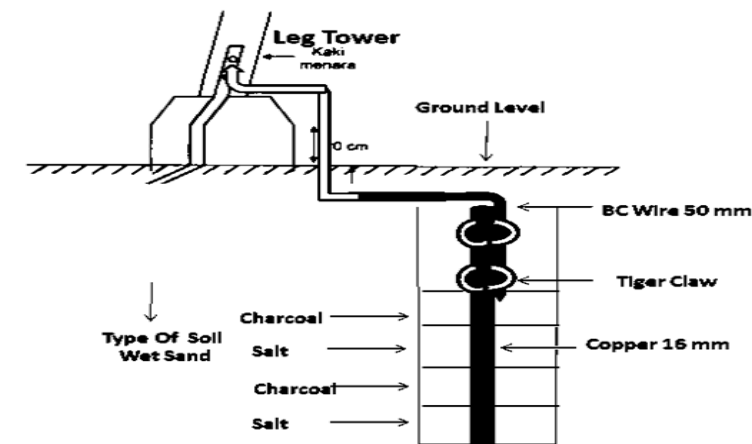


Figure 7. Ground rods of grounding from side.

Table 7. Measurement results of grounding on transmission Tower 39.

PLN Data	Leg of Tower (without Copper Charcoal and Salt)		Grounding of 1 Copper (Clasped Legs of Towers)		Parallelization Of Legs Coupled Tower OF Charcoal and Salt Addition
	Leg of Tower A	Leg of Tower B	Leg of Tower A	Leg of Tower B	Leg Of Tower A and B
5 ohm	12,22 ohm	9,97 ohm	1,24 ohm	1,74 ohm	0.78 ohm

Table 8. Calculation result of ground rods

1 Copper Rod	2 Copper Road
2,6071 Ω	0,0864 Ω

The calculation result of two copper rods with parallelization model installed perpendicular to the ground is 0.0864 Ohm. So the calculation has met the applicable requirements under 5 Ohm. This results showed that the configuration of rod electrode grounding with the addition of charcoal and salt is 0.78 can reduce the magnitude of grounding resistance. It means the more electrode is installed in the ground the smaller of value of grounding resistance, the longer of grounding copper to the ground touch the water the better the decrease of grounding value, and the addition of charcoal and salt affecting the decline in the grounding value because charcoal and salt contain chemicals in the soil particularly a number of soluble organic or inorganic substances need to be considered. To achieve an effective decrease in grounding resistance by grounded the copper deeper until it reaches where the salt and charcoal solutions are exposed to water or wet conditions. The objective of minimizing the grounding value of tower foot and increasing the point of lightning discharge, so that continuity of electricity service does not occur blackout during the rainy season due to lightning strike and can protect the transmission equipment 150 kV GI Sungguminasa - GI Tallasa.

4. Conclusion

The results of this research can be concluded as follows; the simulation results of lightning strike one of the phase wires on transmission line GI Sungguminasa - GI Tallasa so that occurs a disturbance to the electrical system resulting in the impulse voltage on the busbar and back flashover (BFO). The calculation of 81 towers due to the magnitude of the grounding resistance on transmission line 150 kV GI Sungguminasa - GI Tallasa the average of voltage exceeds the predetermined capacity limit of the occurrence of back flashover (BFO) in isolator.

The calculation of running wave of reflection coefficient and the highest voltage is on tower 39 which means the possibility to occur back flashover will be greater already exceeds the limits of (Basic Impulse Level) BIL isolator 750 kV. There are several tower conditions that must be minimized the value of grounding, one of which is in tower 39.

This research is presented for a reduction of new grounding using copper or rod with a mixture of charcoal and salt. This method is more accurate because the disturbance of back flashover can be avoided by lowering the high grounding value due to lightning strikes and protecting other equipment, can be used in long-term, inexpensive and simple, very suitable applied of wet soil. For the content of charcoal need further research on the effect of each soil types. This method can last long, make the application will be more effective and efficient.

References

- [1] Z. Reynaldo, P. Y. Eko, 10 October 2008, *Lightning Performance of Extra High Voltage 500 Kv Lines at East Java – Indonesia*, IPTEK, *The Journal for Technology and Science*, Vol. 19, No. 4, November 2008, 100.
- [2] J.A Martinez, Member, IEE, and F Castro-Aranda, 2003, *Lightning Performance Analysis of Transmission Lines Using the EMTP*, Barcelona, Spain, IEEE, 300.
- [3] P. Sarajcev, J. Vasilj, D. Jakus, 2015, *Method for estimating backflashover rates on HV transmissions lines based on EMTP-ATP and curve of limiting parameters*, University of Split, FESB, Department of Power Engineering, R. Boskovic 32, HR-21000 Split, Croatia, Elsevier, *Electrical Power and Energy systems* 78 (2016) 127-137, 129.
- [4] S. W. Georges, Member, IEEE, F. H. Slaoui, P. J. Lagace, Member, IEEE, X. D. Do, Senior Member, IEEE and J. Forth, Member, IEEE, 2003, *Evaluation of Grounding System Impedance of a Near Sea Water HV Electric Power Installation*, 1591.
- [5] I. Janardana. *Perbedaan Penambahan Garam Dengan Penambahan Bentonit Terhadap nilai Tahanan Pentanahan Pada Sistem Pentanahan*, VOL, 4 No. 1 Januari – Juni 2005, 24.
- [6] IEEE WG, 1996, *Modeling guidelines for fast front transients*. IEEE Trans. PowerDeliv. 11 (1) (1996) 493-506.
- [7] L. Prikler, H.K. Hoidalen, 2009, *ATPDRW version 5.6 for Windows9x/NT/2000/XP/Vista: User's Manual*, Norwegian University of Technology, Trondheim, Norway.
- [8] H.W. Dommel, 1986, *Electromagnetic Transients Program*, Portland, Reference Manual, Bonneville Power Administration.
- [9] T.S. Hutauruk, 1991, *Gelombang Berjalan Dan Proteksi Surja*, Jakarta, Erlangga, 132.
- [10] S. Georges, F. Slaoui, P. J. Lagac, X.D. Do, Senior Member IEEE, J. Fortin, Member IEEE, 1999 IEEE, *Evaluation Of The Effect Of Salt Water And A Counterpoise On The Voltage Profile Of A HV Power Transmissions Line Grounding System In A Two Layer With High Resistivity Soil*, Montreal, Canada, , 1020.
- [11] T.S. Hutauruk, 1991, *Pengetanahan Netral Sistem Tenaga Dan Pengetanahan Peralatan*. Jakarta, Erlangga, 141.
- [12] Sarajcev Petar, 12 May 2014, *Monte Carlo method for estimating backflashover rates on high voltage transmission lines*. University of Split, FESB, Department of Power Engineering, R. Boskovic 32, HR-21000 Split, Croatia, Elsevier, *Electric Power Systems Research* 119 (2015) 247-257.
- [13] Mackow, A., Kizilcay, M, *Mitigation methods to improve the lightning performance of hybrid transmission line*. Sigen, Germany, The work was supported by German TSO, Amprion.
- [14] W.A. Chisholm and Y.L. Chow, September 1983, *Lightning surge response of transmission towers*, i *IEEE Trans, on Power Apparatus and Systems*, vol. 102, no. 9, pp. 3232-3242.
- [15] M. Ishii et al, July 1991, *Multi-story transmission tower model for lightning surge analysis*, i *IEEE Trans, on Power Delivery*, vol. 6, no. 3, pp. 1327-1335.
- [16] A.R. Hileman, 1999, *Insulation Coordination for Power Systems*, Marcel Dekker.
- [16] M. Robert, L. Marek, N. Radoslaw, 2010, *Influence of Climatic Conditions in China on Reliability of Power Earthing System*, IEEE, 1546.
- [17] A. Imece, Chairman, January 1996, *Modeling guidelines for fast transients*, IEEE Trans, on Power Delivery, vol. 11, no. 1.
- [18] M. Robert, L. Marek, N. Radoslaw, 2010, *Influence of Climatic Conditions in China on Reliability of Power Earthing System*, IEEE, 1546.