Optimization of Grounding Resistance to Minimize Transient Currents at 150 kV Sulselrabar System

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Abstract*—Interference on transmission system line Sungguminasa – Tallasa led to black out (widespread outages) SULSELRABAR on Tuesday, January 19, 2016 at 14.13. The disorder occurs along with rain and high winds accompanied thunderstorms that so hard third loss burden of 746 MW. This research aims to optimize the value of grounding resistance in the event of lightning strikes and analyze the loss due to the loss of the load. The method used is to use the ATPDraw simulation and case study in areas that have experienced disruption lightning strikes in particular line Sungguminasa – Tallasa by using the paralelisasi method of copper rod. The results of this research show that the magnitude of the grounding resistance have an average voltage exceeds the limits of the capacity of the start 1001.54 kV 1042.31 kV up to, so that the occurrence of voltage impulse flashover and back with the current disruption reaches 22.65 kA. Calculation of wave running in the wake of the failure of transmission line grounding values obtained 5.4 Ω, of the value of the reflection coefficient obtained the grounding of 0.937, and voltage-on insulator worth 957,0 .36. For the measurement of tower 39 use Megger Det4tcr retrieved value grounding at the foot of the tower and 12.22 9.97 Ω, the results of this research are able to attenuate the magnitude of resistance grounding in custody i.e. of 0.78 Ω and approaching the calculation methods paralelisasi i.e. 0.0864 Ω. 746 MW of load loss of the start 14.13 hours – 22.00: due to black out the interference cause any harm because 37/5000 National Electricticy Company of Indonesia Rp. 8.355.200.000,-

Keywords: ATPDraw; Back Flashover; Wave Run; Grounding Resistance; Surja Lightning

I. Introduction

Transmission line plays an important role in the process of channeling power from power plants, hence reliable power transmission system is required with adequate level of security. One of the causes of damage to the main equipment and other equipment, such as the substations, is the lightning strike both directly and indirectly on the equipment in the transmission and the equipment at the substation [1].

Lightning is a very serious threat in the power system, which results in heavy losses to electricity service providers. In the 150 kV transmission line network, there is a problem of equipment damage caused by lightning strikes that immediately grabbed the ground wire and tower. When the voltage exceeds or equal to the crystal boundary voltage of the fire jump on the insulator, will cause the phenomenon of BFO (Back Flashover). The disturbance occurred along with the rain and strong winds, accompanied by a violent lightning, which caused the burden of 746 MW. In order to reduce the possibility of blackouts and damage to transmission equipment due to BFO, it is done by lowering the value of grounding resistance. Performed at the point of occurrence of BFO on Sungguminasa-Tallasa transmission tower.

Sulselrabar system is a complex system, because it operates at a voltage of 150 kV. In the operation many dynamics that occur, and not infrequently disrupt the performance of the system. Therefore, some studies are needed to support the performance of the system, one of which is proposed in this study. In addition, several studies of this system have also been performed such as stability [2-5] and load forecasting [6-8]. Several related studies have been conducted and show satisfactory results, including [9, 10], whereas the focus of the researcher here is the application of related methods to the Sulselrabar system. This paper proposes a method of lowering the earth's value by using a ground-cut copper (ground) copper 420 cm deep, with a parallelization method on the tower pole. The grounding measurement method uses the parallelization method.

II. Grounding

The grounding function of the substation is to limit the voltage that exists between the apparatus with the equipment, the equipment with the ground and the leveling of the gradient of voltage occurring on the ground surface due to the fault currents flowing in the ground. To determine the planning of a substation grounding system must be considered several factors, among others:

1. The amount of fault current that may occur.
2. Land area that can be used for grounding.
3. Type resistance around the substation.
4. The shape, size and type of conductor used as earth electrode

When using a grounding rod, tower foot resistance is calculated using the following equation:

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

Where :

R = Tower foot resistance, Ohm.
ρ = Earth type resistance, Ohm-m.
L = The length of the grounding rod, meter.
d = Diameter earthing rod, meter.

According to the above equation, tower foot resistance will decrease by increasing the length of the grounding rod. However, this relationship is not direct, and this will reach a point where the addition of the grounding rod will only reduce the tower resistance slightly. In this case a parallel grounding rod is used, the above formula can still be used to calculate tower foot resistance, if the variable "d" is changed to "A" and the earthstation radius equals Eq. 2. A is a multiple of the grounding rod that depends on the placement of each earth stem as follows:

2 The rods are placed anywhere. $A = \sqrt{ar}$ (2)

3 The rods are placed in triangular $A = \sqrt[3]{a^2}\, r$ (3)

4 The rods are placed in a rectangle $A = \sqrt[4]{2\frac{1}{2a^2}}\, r$ (4)

Where :

r = the radius of each rod (must be the same)
a = the distance between the grounding stem.

For areas with hard and rocky soil layers or areas of high soil type resistance, a grounding stem is not practicable. When a counterpoise system is used, the tower foot resistance can theoretically be calculated using the following equation:

$$R = \sqrt{r\rho}\ .\ \mathrm{Coth}\left(L\sqrt{\frac{r}{\rho}}\right) \text{ ohm} \quad (5)$$

Where :

L = Length of wire, meter
ρ = Earth type resistance, ohm-meter
r = Wire resistance, Ohm / meter

When the lightning surge reaches the counterpoise, the effective resistance of the counterpoise is high, (about 15 ohm). This initial resistance is the surge impedance of the counterpoise. As the surge propagates along the wire, its resistance decreases to a fixed value given by the above formula. The purpose of the counterpoise design is to achieve a fixed resistance from the counterpoise before the voltage at the top of the tower reaches the flashover of the insulator. The minimum counterpoise length can be calculated using the formula:

$$L = \sqrt{\frac{\rho}{r}}\ \mathrm{Coth}^{-1}\left[R / \sqrt{r\rho}\right] \quad (6)$$

When counterpoise is too long, two or more wires may be used in counterpoise, until a desired 10 Ohm resistance is obtained [11].

III. Research Methods

This research is done with qualitative and quantitative effort. Qualitatively by lowering the grounding resistance for a long period of time [12]. Quantitatively by reducing the grounding resistance at the foot of the tower by using copper stem planting with a depth of 4 meters from the ground surface. Type This research is descriptive research that aims to know the state of the system at the time of lightning strikes on the transmission line 150 kV sulselrabar using ATPDraw software.

The method of analysis in this research is the mathematical equation, the equation of calculating the magnitude of earth resistance to the voltage generated by the lightning disturbance in the isolator, and calculation using the grounding stem on the tower feet, as follows:

1. Impulse Voltage

The impulse voltage is defined as a double exponential waveform which can be expressed by the equation:

$$(t) = Vo\ e - at - e - bt \quad (7)$$

The transmission line modeling used in this simulation is using historical data of lightning strike disturbance that has occurred in 150 kV transmission line specially in substation Sungguminasa and substation Tallasa transmission line on January 19, 2016. The load on this simulation is modeled by using RLcY3 component by using equation:

$$R = \sqrt{3}\ {V^2}/{P} \quad (8)$$

$$L = \sqrt{3}\ {V^2}/{(2\pi f Q)} \quad (9)$$

2. Voltage on disturbance (BFO)

Splashes on the ground or tower lead to an increase in voltage, which can cause BFO (Back Flashover) on the tower isolator, with the equation:

$$V_L = i \times Re + L\frac{di}{dt} + V_M \quad (10)$$

3. Lightning disturbance in tower

To calculate the flash interruption of the tower, which is a disturbance due to back flashing (Back Flashover), the wave theory is used, with the equation:

a. Calculate possibility of flashover

$$V_{50\%}\ 2\ \mu\mathrm{det} = \left(K_1 + \frac{K_2}{t^{0,75}}\right) \times 10^3\ kV \quad (11)$$

b. Calculating Wire Surge Impedance and Radius Factor of ground wire corona.

$$R \ln\left(\frac{2h}{R}\right) = \frac{V}{E_0} \quad (12)$$

c. Wire impedance ground:

$$Z_{11} = Z_{22} = 60\sqrt{\ln\frac{2h}{r}\ln\frac{2h}{R}} \quad (13)$$

$$Z_g = \frac{Z_{11} + Z_{12}}{2} \quad (14)$$

The trailing factor between the ground wire and the bottom phase wire:

$$K_C = \frac{Z_{21} + Z_{22}}{Z_{22} + Z_{12}} \quad (15)$$

The impedance of the surge between the phase wire and the ground wire and the impedance of the surge between the two ground wires is:

$$Z_{e1} = 60 \ln(b_{e1}/a_{e2}) \quad (16)$$

d. Impedance surge tower type A.

$$Z_t = 30 \ln\left[\frac{2(h^2+r^2)}{r^2}\right] \quad (17)$$

e. Coefficient of a and reflection b:

$$a = \frac{2 \times Z_g}{Z_g+2Z_t} \quad (18)$$

f. Tower peak voltage:

$$e = \frac{Z_g Z_t}{Z_g+2Z_t} I_t \quad (19)$$

$$e = e_0 t \quad (20)$$

g. The reflection coefficient at the base of the tower for R

$$d = \frac{R-Z_t}{R+Z_t} \quad (21)$$

TABLE I TOWER DATA AND RESISTANCE GROUND ON SUBSTATION BULUKUMBA

No	Tower	Grounding (Ohm) = Rɛ
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

h. Voltage on isolator.

This calculation is performed for a 60 kA lightning current.

$$V_i = e_o\left\{(1-K)T + d\left[\left\{T-2\left(\frac{h_t}{c}-\frac{X_i}{c}\right)\right\} + (b-Ka)\left(T-\frac{2h_t}{c}\right)\right] + d^2 b\left[\left\{T-2\left(\frac{2h_t}{c}-\frac{X_i}{c}\right)\right\} + (b-Ka)\left(T-\frac{4h_t}{c}\right)\right] + d^3 b\left[\left\{T-2\left(\frac{3h_t}{c}-\frac{X_i}{c}\right)\right\} + (b-Ka)\left(T-\frac{6h_t}{c}\right)\right]\right\} \quad (22)$$

Ground of two copper rods in 150 kV transmission tower substation Sungguhminasa - substation Tallasa on tower 39

Implementation of the grounding system is carried out on the 150 kV SUTT tower between Sungguminasa substation with the Tallasa substation, precisely at tower 39, located in Pallangga sub-district, held on May 4, 2017. In implementing this earthing parallelization system is planted 2 copper rods at a distance of 2 meters from each foot tower B and C.

TABLE II MEASUREMENT OF GROUNDING TOWER 39

Measurement of grounding from transmission line Panakukang on Tower 39	Measurement of grounding tower 39.	
	Foot Tower B	Foot Tower C
5 ohm	12,22 ohm	9,97 ohm

IV. RESULTS AND DISCUSSION

The analysis model used is the transmission line on substation Bulukumba, the transmission line modeling used ATPDraw program, which uses the historical data of lightning strike disorder that happened on January 19, 2016, especially along the 150 kV transmission line which is 26.43 km, in substation Sungguminasa and substation Tallasa. The transformer modeling is modeled using a 3 phase ideal transformer component with a primary and secondary voltage ratio of 150 kV / 20 kV = 7.5.

The following is a single line diagram of transmission line Bulukumba that connects substation Sungguminasa - substation Tallasa before a lightning strike.

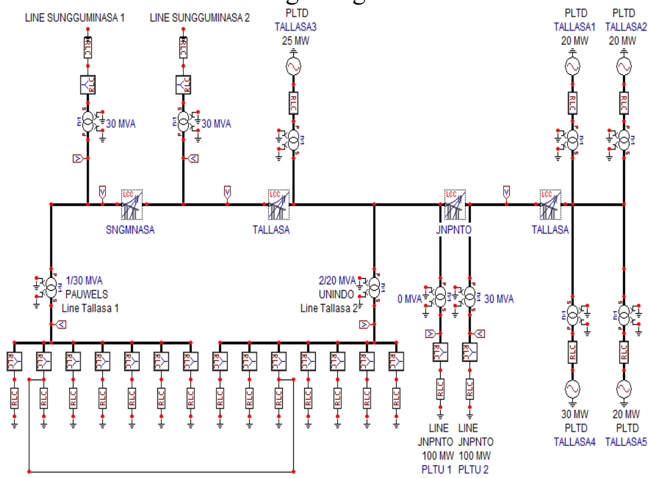

Fig 1. Substation Bulukumba modeling, connecting substation Sungguminasa - substation Tallasa before a lightning strike

The following is the simulation results shown in Figure 2.

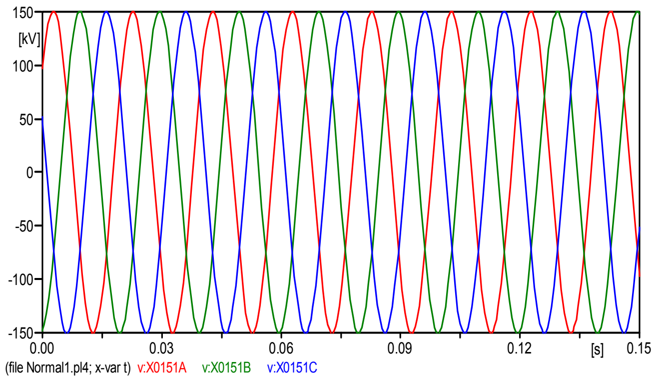

Fig 2. Simulation result of voltage in normal condition

Here is a single model diagram of transmission line Bulukumba that connects substation Sungguminasa - substation Tallasa after a lightning strike.

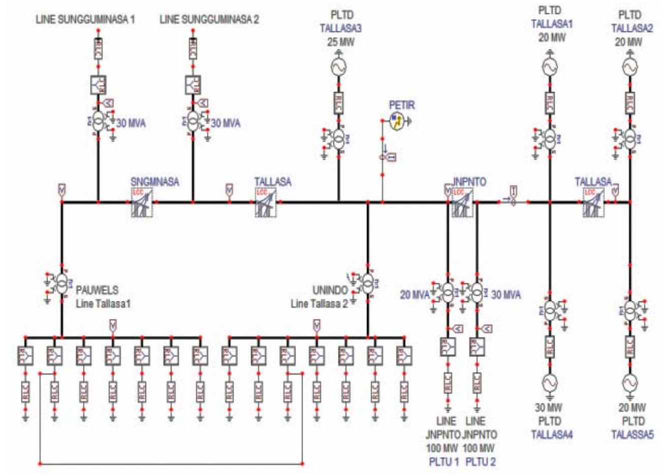

Fig 3. Single Simulation Model Diagram transmission line Bulukumba Linking substation Sungguminasa - substation Tallasa After a Lightning Strikes

From the simulation result of figure 4, lightning disturbance grabbed one of the phase wire on substation Sungguminasa transmission line - substation Tallasa. The peak lightning current value reaches 359.89 MA. As a result, there is a disruption in the electrical system resulting in the impulse voltage on the busbar and back flash over (BFO).

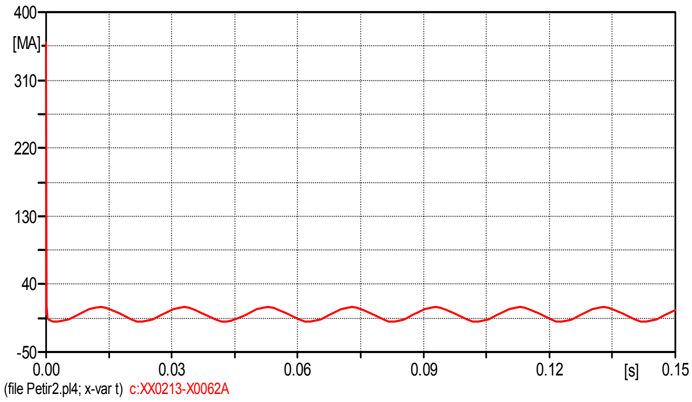

Fig 4. Lightning current model type Heidler

From the simulation results for the current on Transmission Line 150 kV substation Sungguminasa - substation Tallasa is equal to 22.65 kA and waveform in time T = 50 μs,

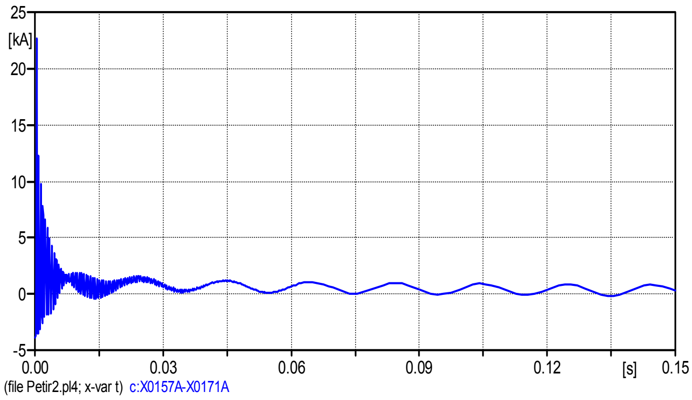

Fig 5. Current on Line substation Bulukumba

Table 3 is an analysis of tower data and grounding resistance in Bulukumba substation, including substation Sungguminasa, substation Takalar, substation Jeneponto and substation Bulukumba. There are several towers that have a large earth resistance value, so that it can affect the occurrence (BFO).

TABEL.III DATA TOWER AND LARGE GROUNDING RESISTANCE RESULTING IN OCCURRENCE (BFO).

No.	Tower	Grounding Resistance Rε (Ohm)	Analysis of back flash over calculation (BFO)
1	T.38	5.2	1037,78 kV
2	T.39	5.4	1042,31 kV
3	T.40	5.3	1040,05 kV
4	T.41	5	1033,25 kV
5	T.42	5	1033,25 kV
6	T.43	5.2	1037,78 kV
7	T.44	4.2	1015,13 kV
8	T.45	4.4	992,48 kV
9	T.46	4.6	1024,19 kV
10	T.47	4.6	1024,19 kV
11	T.48	4.4	1019,66 kV
12	T.49	4.4	1019,66 kV
13	T.50	3.6	1001,54 kV
14	T.51	3.6	1001,54 kV
15	T.52	3.8	1006,07 kV
16	T.53	3.6	1001,54 kV
17	T.60	3.6	1001,54 kV
18	T.61	3.6	1001,54 kV
19	T.62	3.8	1006,07 kV
20	T.64	3.8	1006,07 kV
21	T.65	3.8	1006,07 kV
22	T.66	3.6	1001,54 kV
23	T.68	3.6	1001,54 kV
24	T.69	4.6	1024,19 kV
25	T.70	4.6	1024,19 kV
26	T.71	4.2	1015,13 kV
27	T.72	4	1010,60 kV
28	T.73	3.8	1006,07 kV
29	T.74	3.8	1006,07 kV
30	T.75	3.8	1006,07 kV
31	T.76	4	1010,60 kV
32	T.77	4.2	1015,13 kV
33	T.78	3.8	1006,07 kV
34	T.79	4.8	1028,72 kV
35	T.80	4.6	1024,19 kV
36	T.81	4.2	1015,13 kV
37	T.82	4	1010,60 kV
38	T.90	3.6	1001,54 kV
39	T.93	3.6	1001,54 kV
40	T.94	3.6	1001,54 kV
41	T.96	3.6	1006,07 kV
42	T.97	3.6	1001,54 kV
43	T.99	3.8	1037,78 kV
44	T.104	3.6	1042,31 kV

Large Impulse Voltage Analysis In 150 kV Transmission Channels Due to Back Flash Over (BFO)

Figure 6 shows the impulse voltage value due to a lightning strike on substation Sungguminasa - substation Tallasa.

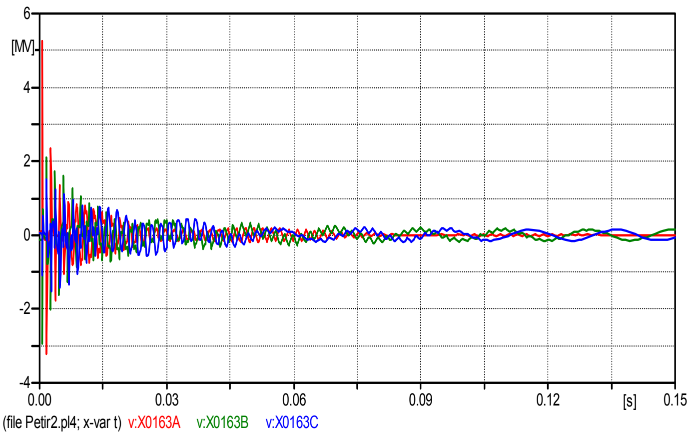

Fig 6. Impulse Voltage due to lightning strike on substation Sungguminasa Transmission Line - substation Tallasa

Where on the phase wave R shows the value of impulse voltage at the time of 5.271 MV. S phase wave shows the impulse voltage value at face time of 2.093 MV. The phase wave T shows the impulse voltage value at the time of 1.5103 MV.

Simulation results Figure 6 shows the impulse voltage values due to lightning strikes in substation Tallasa - substation Jeneponto. Fugure 7 shows the phase wave R shows the impulse voltage value of 3.70 MV. S phase wave shows an impulse voltage value of 1.153 MV. The phase wave T shows an impulse voltage value of 749 kV.

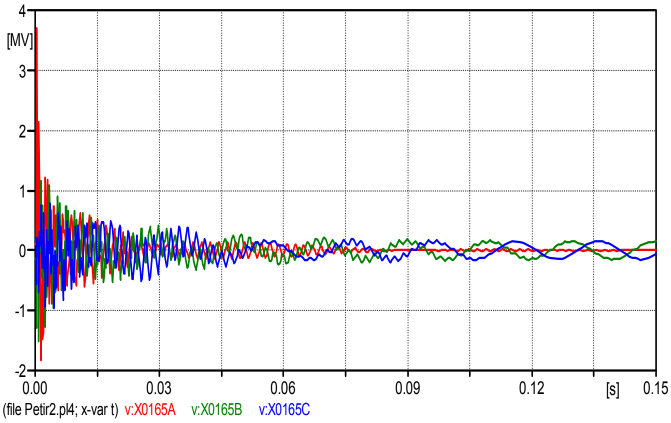

Fig 7. Impulse Voltage due to lightning strike on substation Tallasa Transmission Line - substation Jeneponto

Analysis of the impact of the occurrence of lightning disturbances on towers that resulted in BFO interference with the wave theory that affected the 150 kV transmission line substation Sungguhminasa - substation Tallasa due to lightning strikes.

In this method it is assumed that, the lower phase is experiencing flashover due to lightning strikes on the tower. In the calculation is only done until 1 µdet, because at that time the negative reflection wave from adjacent tower (average length taken 300 meters) has reached the tower struck by lightning and this wave minimizes the voltage on the tower.

The channel to be counted is the Sungguminasa-Tallasa line, which is a 150 kV dual air transmission line with wire and tower configurations. The wire and isolator data are as follows:

- Radius of ground wire : 0,45 cm
- Radius sub-conductors of phase wire : 1,45 cm
- Number of subconductors : 2
- The distance between subconductors : 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 swing ground wire and phase wire : 7 cm
- Length of isolator : 6,43 m

This calculation looks at the effect of the magnitude of the earthing resistance to the voltage generated by the lightning disturbance of the insulator. Therefore, some earth values obtained from National Electricity Company of Indonesia data are 5.4 Ω, 5,3 Ω, 4,6 Ω, 0,8 Ω, 0,6 Ω, and 0,4 Ω.

TABLE IV LIGHTNING DISTURBANCE COUNT RESULTS ON TOWER (CALCULATION FOR PHASE C OR A)

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

From the calculation, when there is lightning disturbance in the transmission line with a peak flow current of 60 kA and a wavefront time of 1 µs, the value of the voltage on the isolator varies depending on the grounding value held by the tower. When the grounding value is 5.4 Ω, the reflection coefficient is -0.937 and the voltage at the isolator is 957,036 kV. When the grounding value is 5.3 Ω, the reflection coefficient is -0.938 and the voltage on the insulator is 954.967 kV. When the grounding value is 4.6 Ω, the reflection coefficient is -0.946 and the voltage on the insulator is 937,819 kV. When the grounding value is 0.8 Ω, the reflection coefficient is -0.99 and the voltage at the isolator is 842.694 kV. When the grounding value is 0.6 Ω, the reflection coefficient is -0.993 and the voltage on the insulator is 838.454 kV. When the grounding value is 0.4 Ω, the reflection coefficient is -0.995 and the voltage on the insulator is 834.238 kV.

The design estimates and calculation of the value of resistance are as follows:

Electrode length (L) = 4 meter

Planting Distance (Hb) = 10 meter

Electrode diameter (D) = $\frac{5}{8}$ inch = 1,588 cm

Electrode radius (r) = 1,588/2 = 0,794 cm

Soil resistivity (ϱ) = 50 Ohm-meter for wet sand

$$R_{d1} = \frac{\varrho}{2\pi L}\left[\ln\left(\frac{2L}{a}\right) - 1\right] \quad (23)$$

$$= \frac{50}{2.3{,}14.4}\left[\ln\left(\frac{2.4}{0{,}794}\right) - 1\right]$$

$$= 1{,}990\,[\ln 10{,}075 - 1]$$

$$= 2{,}6071\ \Omega$$

The calculated value of grounding resistance for a single copper rod planted perpendicular to the ground is 2.6071 Ohm. So the calculation of single-rod copper grounding resistance values meets the applicable requirements, under 5 Ohm. The results showed that, the configuration of the planting of rod electrodes capable of reducing the amount of grounding resistance.

Analysis with two copper rods by parallelization method. The parallel grounding rod used above can still be used to calculate tower foot resistance when the variable "d" is changed to "A" and the radius of the grounding rod is the same. Price A is a multiple of grounding rods, two rods placed anywhere.

$$A = \sqrt{ar} \quad (24)$$

r = the radius of each rod (must be the same)

a = the distance between the grounding rods.

Electrode length (L) = 4 meter
Planting Distance (Hb) = 10 meter
Electrode diameter (D) = 5/8 inch = 1,588 cm
Electrode radius (r) = 1,588/2 = 0,794 cm
Soil resistivity (ϱ) = 50 Ohm-meter for wet sand

$$A = \sqrt{ar} = \sqrt{10 \times 0{,}794} = \sqrt{7{,}94} = 2{,}817$$

$$R_{d2} = \frac{\varrho}{2\pi L}\left[\ln\left(\frac{2L}{A}\right) - 1\right]$$

$$= \frac{50}{2.3{,}14.4}\left[\ln\left(\frac{2.4}{2{,}817}\right) - 1\right]$$

$$= 1{,}990\,[\ln 2{,}839 - 1]$$

$$= 0{,}086\ \ 4\ \Omega$$

The calculation value of grounding resistance for two copper rods with parallelization model planted perpendicular to the ground is 0.0864 Ω. So the calculation of the value of earthing resistance of copper rod by parallelization method has met the applicable requirements under 5 Ohm. The results showed that the configuration of the planting of rod electrodes capable of reducing the amount of grounding resistance, meaning that more elekroda planted in the soil, the smaller the value of resistance.

Effect of change of grounding resistance in tower 39 to back flashover voltage value.

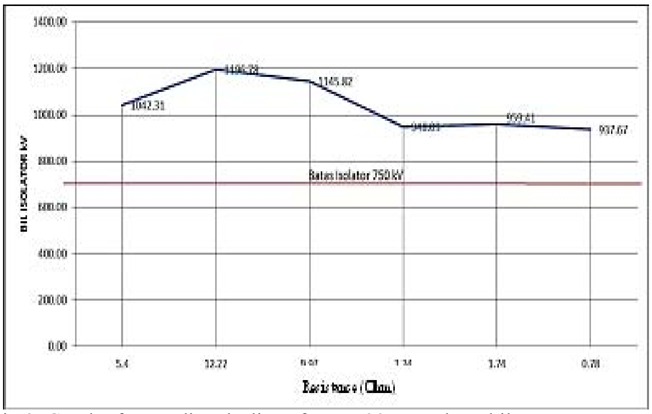

Fig 8. Graph of grounding decline of tower 39 on Isolator bil

V. Conclusion

From the tower 39, there is a change in the grounding resistance that occurs every additional copper rod, before the addition of the copper rod the rated BFO voltage is 1042.31 kV with 5.4 ohm grounding resistance. From the measurement results in the foot A is 1196,78 kV with a resistance value of 12.22 ohm and foot C is 1145.82 kV with a resistance value of 9.97 ohms. From these results, it looks beyond the BIL isolator, which resulted in the back flashover. After the variation of copper rods, the resistance value is decreased. With 1 copper rod on leg A obtained voltage equal to 948,09 kV with value of resistance 1,24 ohm, on foot C obtained 959,41 kV with value of 1.74 ohm resitansi. With 2 copper parallelization method obtained 937,67 kV with resistance value 0,78 ohm obtained decrease of earth resistance and decrease of BFO voltage approaching BIL isolator that is 750 kV, it is seen to avoid back flaschover.

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