THE PERFORMANCE OF LIGHTNING PROTECTION SYSTEM ON 275 KV TRANSMISSION LINES SIGURAGURA-KUALATANJUNG, NORTH SUMATRA, INDONESIA

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Abstract: - The research work has been done to investigate and analyze the lightning protection system on 275 kV Transmission Lines Siguragura to Kualatanjung in North Sumatra, Indonesia. This transmission lines is located near the equator which is known as an area with a high lightning density. Lightning data used in this work derived from National Weather Office shown that the total cloud to ground lightning flashes is very high compare to another area around it. To give good shielding from lightning strikes this transmission lines used three overhead ground wires. The use of 22 pieces of porcelain insulator instead of only 18 pieces with the counterpoises grounding system and the installation of magenetic link to measure the peak current in every tower give the good performance against lightning strikes. But the damages due to lightning strikes were still reported, such as the damages at ground wire and arcing horns.
The work were done by measuring the lightning strikes to the towers, analizing the shielding failure using electrogeometric concept and finite element method. The result shows that the shielding failure flash over rate is zero. The estimation of lightning performance calculated by Whitehead concept give the results of excellent grounding and shielding.
However, by using the lightning data derived from the tropical area, such as the probability of lightning peak current and the field measurement measured by magnetic links shows the different results and it stated as good grounding and shielding performance only.
The transmission liens with three overhead ground wire have given a significant results against lightning strikes compare to the use of only two overhead ground wire in the tropical region.

Key-Words: - lightning ground flashes density, magnetic link, back flashover, shielding failures, lighnting performance.

1 Introduction

The overhead 275 kV transmission lines (T/L) is a super high tension 3 phasa, double circuit T/L with the length of 120 km and use the steel towers. This T/L is connecting hydro power plant switching substations at Siguragura and Tangga to Kuala Tanjung substation to transmit the generated power at Asahan Power Station to the Aluminum Smelter at Kuala Tanjung. This smelting factory requires a very stable supply of electric power due to the smelting process of the Alumunium. An interruption of Power Supply exceeding more than 40 minutes will cause serious damages to the smelting process. In order to minimize power interruption, the T/L was designed and installed to be able to transmit the power even under failure of one circuit. To avoid failure due to lightning strikes to a minimum level three overhead ground wires were installed to get a good shielding angle and to increas the insulation strength 22 pieces of porcelain insulator were installed. The counterpoise grounding system were used to minimized ground voltages. But the damages at ground wire and broken arcing horn along the line due to lightning strikes were still taken palce.

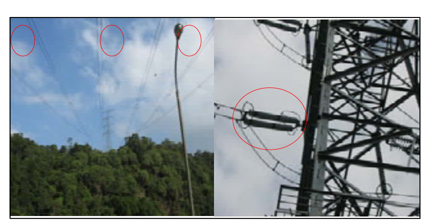


Fig. 1. Three OHGW and 22 pieces porcelain insulator

2 Lightning Data

Cloud to ground srikes of historical lightning data was recorded by lightning detector system belongs to BMG (Meteorological & Geophysical Office). Data contain the information total lightning flash of cloud to ground and intra cloud. Fig. 2 shows lightning flash of cloud to ground for year 2006 until 2007.

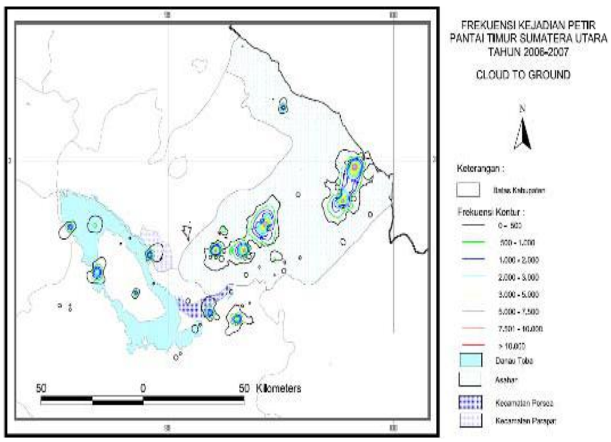


Fig. 2 Cloud to ground lightning flash frequency for year 2006 until 2007.

Probability of lightning peak current derived from research results in central Sumatera on October 2001 until October 2002 by Zoro[1] and data derived from IEEE Standard 1243-1997 [2] were analyzed . Probability of occurrence of a stroke with peak current (I) at ground level (P(I)) followed by the log normal probability density function is given as follows,

$$P(I) = \frac{100}{1+\left(\frac{1}{51.38}\right)^{3.073}} \qquad R^2 = 0.9982 \quad \ldots\ldots (1)$$

$$P(I) = \frac{100}{1+\left(\frac{1}{31}\right)^{2.6}} \quad \ldots\ldots\ldots\ldots (2)$$

3. A Simplified Method

3.1 Back Flashover Rate (BFOR)

In order to estimate line outage due to back flash over, following steps calculation for BFOR [3] were carried out :

a. Critical Current (I_c)

$$I_c = \frac{CFO_{NS} - V_{PF}}{R_e(1-k)} \quad \ldots\ldots\ldots\ldots (3)$$

$$R_e = \frac{R_i Z_g}{Z_g + 2R_i} \quad \ldots\ldots\ldots\ldots (4)$$

Z_g is surge impedance of OHGW in Ohm

$$V_{PF} = K_{PF}.V_{LN} \quad \ldots\ldots (5)$$

For horizontally configured line, K_{PF} = 0.7, For vertically configured line K_{PF} = 0.4, if uncertain, the conservative value of K_{PF} = 0.7 should be used.

b. Critical Flashover Nonstandard (CFO_{NS})

$$CFO_{NS} = \left(0{,}9777 + \frac{2{,}82}{\tau}\right)\left(1 - 0{,}2\frac{V_{PF}}{CFO}\right)CFO \quad \ldots\ldots (6)$$

$$\text{CFO} = \text{n.s}\left(0.4 + \frac{0.71}{\text{t}^{0.75}}\right) \ldots [10^3 \text{ kV}] \quad \ldots\ldots\ldots\ldots (7)$$

$$\text{Time constant : } \tau = \frac{Z_g}{R_i} T_s \quad \ldots\ldots\ldots\ldots (8)$$

T_s is travel time of a span in μs.

c. Impulse of high current footing resistance (R_i)

$$R_i = \frac{R_0}{\sqrt{1 + \frac{I_R}{I_g}}} \quad \ldots\ldots\ldots\ldots (9)$$

$$I_g = \frac{1}{2\pi}\frac{E_o \rho}{R_0^2} \quad \ldots\ldots\ldots\ldots (10)$$

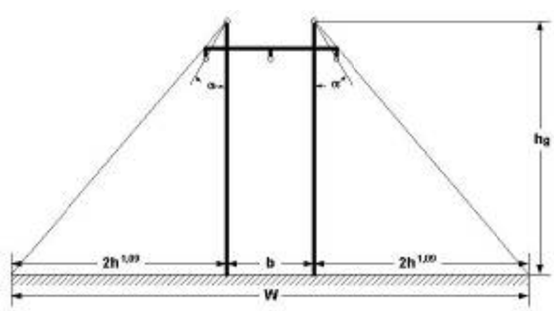
E_0 = 400 kV/m, R_0 is measured or low current footing resistance in Ohm and ρ is soil resistivity in Ohm.m.

d. Number of flashes to line

In oreder to estimate the number flashes to the line, Whitehead estimation can be used. The number of flashes to the line is,

$$N_L = N_g\left(\frac{4.h^{1,09} + d}{10}\right) \quad \ldots\ldots\ldots\ldots (11)$$

N_L = Total flashes exposed of the structure
Ng = Number of Flash to Ground
h = height of structure
d = width of structure = 2b



.Fig 3. Ilustration of tower

Although flashovers can occur at the span between two towers, the flashover to the tower are more significant than the lightning that hit the span, therefore it can be neglected. Strokes within the span can produce voltages at the tower but usually less than those voltages produced by strokes direct to the tower. Only 60% strikes to the tower are considered that can proded BFO at the insulators. Therefore, if only this strikes to be considered, the BFOR will become;

$$BFOR = 0{,}6 N_L P(I > I_C) \quad \text{........ (12)}$$

3.2 Shielding Failure Characteristic

a. Stroke Collection Area for Each I (S_p)

The stroke collection area represents the region where an event with amplitude (I) is attracted to line. The electro geometric (EGM) is applied to calculate the attractive area as shown in fig. 4. The equivalent height of the structure is used in Eriksson expression for attractive radius, instead of the structure height. [4]

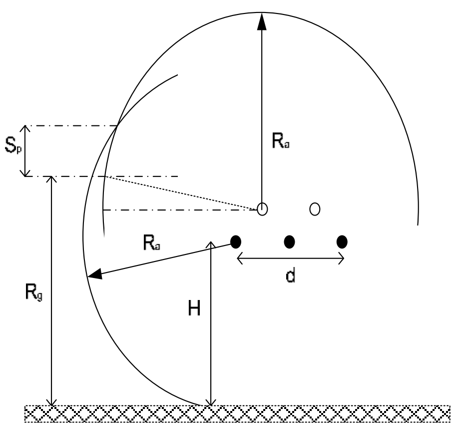


Fig. 4 EMG considering the equivalent height of the structure

$$R_a = H_{eq}^{(0.66 + 2 I x 10^{-4})} x\, I \quad \text{..................... (13)}$$

$$S_p = (2.R_a + d) x\, L \qquad (R_a \le H) \quad \text{........ (14)}$$

$$S_p = \left(\sqrt{R_a^2 - (R_a - H)^2} + \frac{d}{2}\right) x\, L \qquad (R_a > H) \cdots \text{(15)}$$

b. Critical Current (I_c)

The lowest current I_c that is able to cause a line flashover due to shielding failure is calculate for the whole line using expression (15), from the critical flash overvoltage (CFO) and the surge impedance of the line (Z_C). The CFO has a typical value for T/L each nominal voltage. Thus, the value of I_C is the same for all the spans of a given line.

$$I_C = \frac{2CFO}{Z_C} \quad \text{.........................(16)}$$

c. Shielding Failure Flashover Rate (SFFOR)

Once shielding failure area is known for each peak current I, it is possible to find all the peak currents that able to lead shielding failure flashover rate (SFFOR). The expression SFFOR is,[3]

$$SFFOR = 2 N_g L \int_{I_c}^{I_{max}} S_p\, p(i) d(i) \quad \text{........... (17)}$$

d. Shielding Failure Analysis by Finite Element Method (FEM)

Finite Element Method (FEM) PDETool in Matlab 7 [10] can simulate electric field for some *step leader* position arround the T/L tower. Partial differential equation which is used in this method is Poisson equation,

$$-\nabla.(\varepsilon\, \nabla V) = \rho \quad \text{.................................. (18)}$$

ε=εo. εr = dielectric constant.

εo = 8,854 x 10^{-12} F/m, εr = relative constant.

ρ = density charge (C)

In the PDETool Matlab 7, author used *Electrostatics mode*, electric field *E* and scalar potential V is

$$E = -\nabla V \quad \text{.................................. (19)}$$

Dirichlet and Neumann method, each electrostatics potential V and surface charge n.(ε∇V) are considered as a boundary condition.

4. Cases Study

The computation was applied to estimate the lightning performance of two existing lines installation in Siguragura – Kuala Tanjung.

Data shows some characteristics of analyzed T/L 275 kV as follows ;

Tower	:	Cone
Height	:	47.6m and 46m
Average Span	:	400 m
Conductors	:	TACSR 330 mm2
Diameter	:	25.3 mm
Sag	:	12.9 m
Bundled	:	2
Spacing	:	0.4 m
Shield Wires	:	ACSW
Diameter	:	10.55 mm
Sag	:	8.8 m
Insulator	:	Porcelain
Length	:	22 pieces
Nominal Voltage	:	275 kV
T/L Length	:	120 km

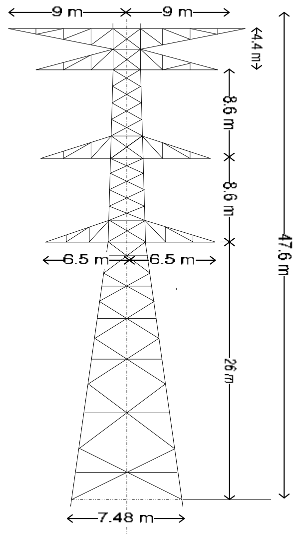


Fig. 5 Characteristic of T/L 275 kV

The study was carried out by using three OHGW and two OHGW. Coupling factor (k) and surge impedance of OHGW (Z_g) for each phase conductor are estimated by influence of mutual surge impedance, self surge impedance and effect of corona.

Table 1. shows the value of coupling factor and surge impedance equivalent of OHGW for three and two ground wires.

Table 1. Value of k and Z_g

	3 OHGW		2 OHGW	
Phase	**Zg (Ohm)**	**k**	**Zg (Ohm)**	**k**
R	235.29	0.49	279.76	0.35
S	235.29	0.32	279.76	0.23
T	235.29	0.19	279.76	0.14

Result of BFOR calculation for three and two OHGW showed in fig.6.

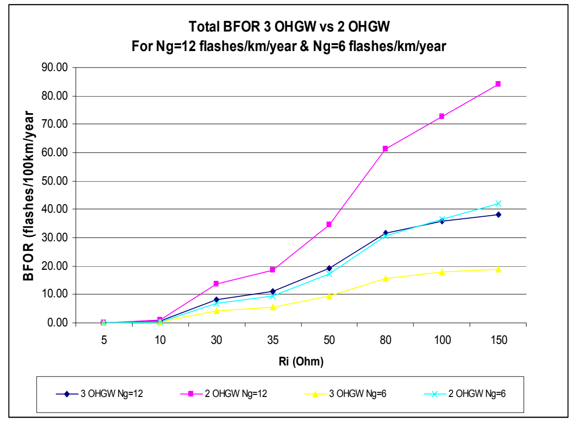


Fig. 6 Total BFOR 3 OHGW and 2 OHGW using Zoro's lightning current probability [1]

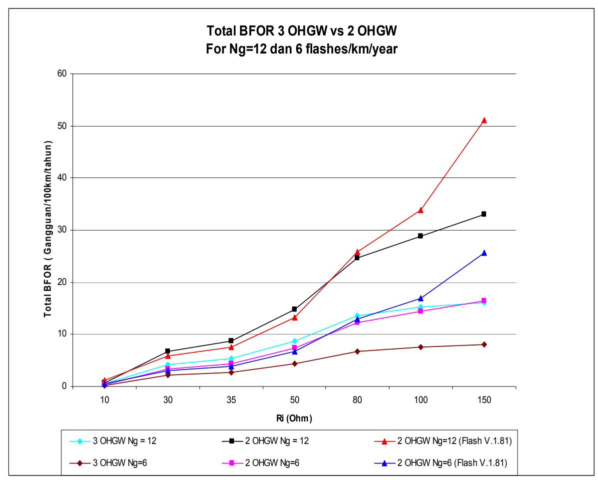
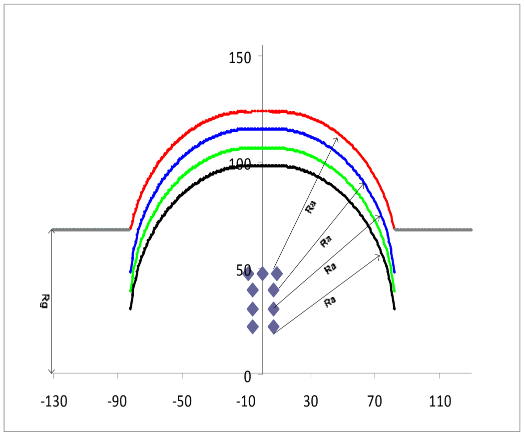


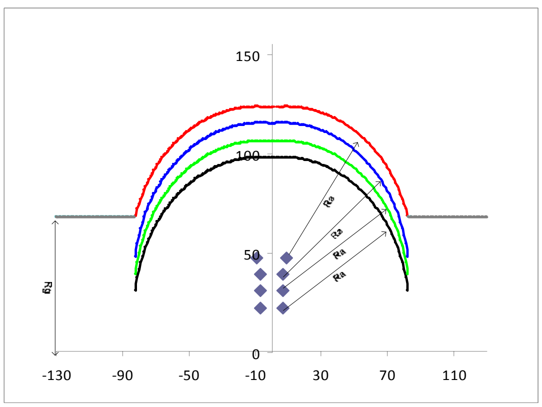
Fig. 7 Total BFOR 3 OHGW and 2 OHGW using IEEE lightning current probability

Figure 6 and 7 shows that three OHGW can reduce BFOR 57% better than two OHGW. For some application, where the cost of three OHGW is not economically and technically justified, or where there is low ground flash density, two OHGW can be used. Two OHGW increase the value of R_e, decreases the coupling factor, k, and will increases BFOR.

For shielding failure flashover rate (SFFOR), critical current (I_c) expression (16) are used to calculate the radius attractive (R_a). To make a model of overhead ground wire and phase lines by FEM-PDETool the Dirichlet condition V=1500MV for cloud, and V=0 for ground wire and ground are chossen. However, Neumann condition assumed for air dielectric there is no surface charge and step leader is assumed to be q=5 C. The phase conductors for Dirichlet condition is V=275 kV.

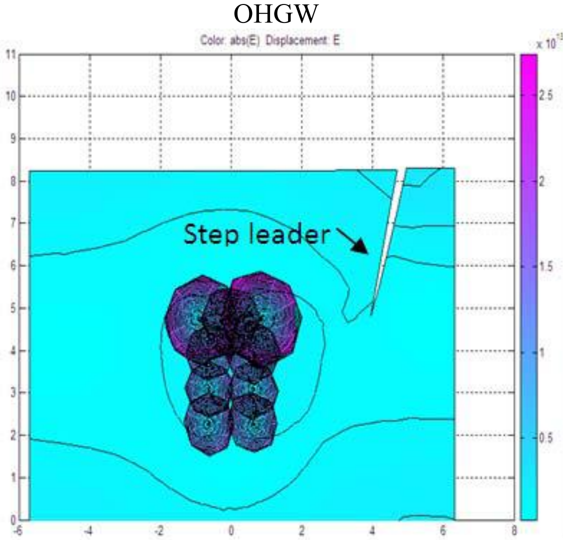


(a)

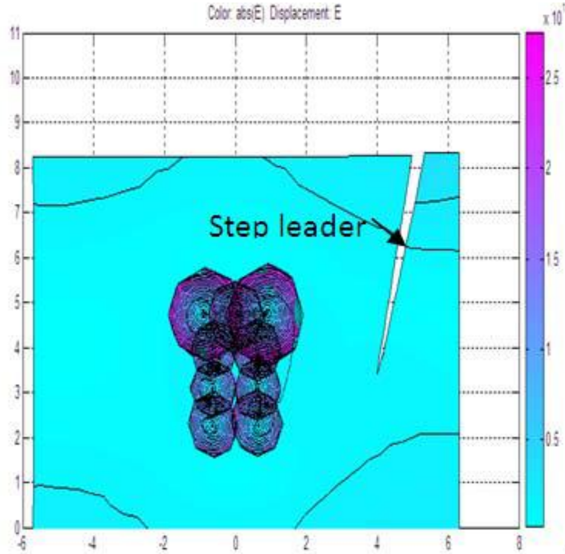


(b)

Fig.8 Radius attractive for (a) 3 OHGW and (b) 2 OHGW



(a)



(b)

Fig.9 Electric field characteristics at the surrounding area of ground wires and phase conductors

5 Analysis

Fig. 8 and 9 show radius attractive for 3 and 2 OHGW and electric field characteristics at the surrounding area of the ground wires and phase conductors.

No stroke collection area (S_p) showed in the model, the value of SFFOR is zero. The result of BFFOR and SFFOR show that T/L 275 kV Siguragura-Kualatanjung have good performance against lightning stroke. With the footing resistance 10 Ohm derived from counterpoises grounding system the total flash over rate is 0.63 flashes/ 100km/year for Ng = 6 flashes/100km/year, this performance is known as -Superior grounding and shielding- [5]. The results of the analyzing the combination of three OHGW and two OHGW is three OHGW should be only used in the area with high lightning flash density.

6 Conclusion

275 kV Transmission lines Siguragura – Kualatanjung has a good performance against lightning strikes. With use of three overhead ground wire and footing resistance of 10 ohm which is derived from the counterpoise grounding system it gave good lightning performance. Calculation by using Whitehead concept the Flash Over Rate is only 0.24 flashes/100km/ year, for Ng = 6 flashes/km/

year and it is recorded as-excellent grounding and shielding- (the IEEE probability of lightning peak current).

However, for the tropical lightning data measured by Zoro [1](dissertation research, 1999), the Flash Over Rate become lower. It is only 0.32 flashes/100km/year, but it is still recorded as -good grounding and shielding-.

It shows that by using the three OHGW the significant results of lightning performance are derived. Back Flash Over rate can be reduced till only 57% compare to two overhead ground wire.

The use of three OHGW in the area with high lightning flash density, such as Indonesia, especially at Sumatra Island region has given the significant improvement of lightning performance of extra high voltage transmission lines in the tropics.

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