

EFFECT OF CONTACT RECOVERY VOLTAGE OF HIGH VOLTAGE POWER BREAKERS WITH DIFFERENT TYPES OF CIRCUIT CHARACTERISTICS

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ABSTRACT

In general we have known the frequent disruption of transmission lines is a natural disturbance, such as lightning disturbance to the transmission network due to transmission network through the air, long, high and spread in various open areas and operate in all kinds of conditions. Among the considerations taken in the transmission line transmission design is the location of the ground wire against the phase wire. Because the ground wire only, so a small percentage on the phase wire. And until now there are no scholars who show the use of lightning for life, have not got a way to prevent or exploit the energy caused by the lightning. Nevertheless, human science continues to thrive with technological advances. With one safety device, an air wire (Overhead Ground Wire) to protect the phase wires from the transmission line.

Keywords: high voltage, transmission, protection, recovery, wave protection.

PENDAHULUAN

At the end of the 19th century the electric power system was grounded. This was understandable because at that time the electric power systems were still small, so when there was an earth wire fault the fault current was still small (± 5 A). In general, if the fault current is 5A or less, the electric arc that occurs at the contacts between the disturbed wire and the earth can still self-extinguish. But the power systems are getting bigger and bigger in both length and power. Thus the currents that arise when the symptoms of "Arching Grounds" occur are increasingly prominent. This phenomenon is very dangerous because it will cause transient overvoltage which can damage the equipment. Therefore, starting from the 20th century, when the power system began to grow, the system was no longer isolated (isolated), which was called the delta system, but the neutral point of the system was grounded through resistance or reactance. Grounding is generally done by connecting the transformer neutral to earth. In general, in Indonesia, using a high voltage transmission network. Indonesia is located on the equator, the amount of thunder is very high. How to get a clear understanding of the calculation of protection in high-voltage transmission networks and how to get the appropriate angle of ground wire protection and safeguards supporting high-voltage transmission networks such as grounding for overpower distribution as a result of a lightning strike hitting the overhead ground wire. also as a protector (Shielding) high voltage transmission network.

The use of the ground wire is intended for protection regarding the phase wire. Here the ground wire functions as a shield, the energy of the lightning strike will flow into the earth through a grounded pole or tower after being captured by the ground

wire. While safety devices such as: Arresters, Fuse Gaps and Rodgaps are limited in their capabilities, so to reduce the effects caused by lightning strikes, an Overhead Ground Wire is used so that isolation coordination will be more economical.

THEORETICAL FRAMEWORK

Grounding Basics

The purpose of grounding is basically: (1) Intended at the neutral point and common earth, intended to reduce the amount of solar overvoltage and control the magnitude of the short circuit current, (2) In a large system that is not grounded, the fault current is relatively large ($> 5 \text{ A}$) so that the electric arc that arises cannot be extinguished by itself, this will cause an "Arching Ground" symptom, in an earthed system the symptom is almost non-existent, (3) To limit the voltages on undisturbed (healthy) phases. In the systems below 115 KV, grounding via the Peterson Coil is widely used. Especially in Europe the grounding with the Peterson Coil has been started since 1990, while in the United States it has only started since the 1930s. In systems with higher voltages (115 KV and above) there is a tendency to ground without impedance (Solid Grounding) or (Effective Grounding). What is meant by Effective Grounding is earthing where the ratio between positive sequence reactance is less than or equal to three, and the ratio of zero sequence resistance and positive sequence reactance is less than or equal to one ($X_0 / X_1 \leq 3; X_1 \leq 1$). (a) 30 KV and 70 KV systems with Peterson Coil, (b). 150 KV system with direct earthing. The 30 KV and 70 KV systems are up to now the largest part of the entire system.

Selection of Earthing System

Selection of earthing system is based on factors are (a) Selectivity and Sensitivity of Ground Fault Relaying, (b) Limitation of ground fault current, (c) Required level of Arrester solar voltage protection, (d) Transient overvoltage limitation.

Unearthed Systems

An unearthed system is a system in which there is no accidental connection between the conductors of the system and the ground. This system has been abandoned by many people because it is not in accordance with the desired conditions.

Ground Fault Relay

Ground fault relay will work well, depending on the amount of fault current to ground. The neutral system is earthed with reactance. In general, the magnitude of the ground fault current is within the limits (25% -100%) of the 3-phase fault current of an earthed system with resistance, the ground fault current is 10% -25% of the 3-phase fault. In general, the success of the ground fault relay is obtained when the ground fault current is greater than 10% of the ground fault current. For systems that are grounded through a large resistance or through the Peterson Coil will have a very small fault current to earth. Especially for the Peterson Coil, it is usually equipped with a device to connect the neutral point directly to earth when a permanent fault occurs, with the aim of increasing the fault current to earth so that a conventional grounding relay can work.

Grounding Method for Dynamic Voltage in Solar Protection Equipment.

According to the American Institute OF Electrical Engineers (AIEE) Committee Report, lightning arresters are divided into two groups, namely "earthed type arresters and grounded type arresters". Earthed type arresters can be used if the

1-phase fault current to earth is not less than 60% of the 3-phase fault current. The above conditions will be met if the system is effectively grounded (Effective Grounding) or $X_0 / X_1 \leq 3$. While the unearthed type arrester is used when the 1-phase fault current is less than 60% of the 3-phase fault current. Lighting arresters are devices that are sensitive to voltage and the connection between the phase wire and earth, so the dynamic voltage on the arrester cannot exceed the rated voltage for all circumstances. system operation. The dynamic voltage of the phase-to-earth wire of a 3-phase system will become unbalanced in a state of ground fault, and the magnitude of this voltage depends on the condition of the system at the time of the fault and the magnitude of the earth impedance.

RESULT AND DISCUSSION

The theory of traveling waves on transmission wires has been developed intensively since 1910, especially in the 1930s. This traveling wave problem is very difficult, so a lot of simplifications have to be made so that it can be used for engineering purposes. At this time traveling waves have been investigated in: (a) Single Wire, (b) Compound Wire, (c) Compound velocity of the traveling wave. The biggest part of something about disturbances in the system is the traveling wave theory, which is about the source of the waves, their characteristics and conditions at the point of transition from transmission.

Sources of Running Waves

Until now the known causes of traveling waves are lightning strikes directly on the phase wire : Indirect lightning strike on the phase wire (Induction) ; Switching Operation ; Disturbances in the system by various faults ; Static state voltage. All these kinds of causes create a charge (heaven) in the phase wire due to a sudden excess energy in the wire. This energy travels down the phase wire, just as we throw a stone into still water in a pond. This propagating energy consists of currents and voltages. The speed of the traveling wave propagates depending on the phase wire constants. In air conduction wire, this propagation speed is approximately $1000 \text{ ft}/\mu \text{ sec}$, so it is the same as the speed of light. On ground wires approx. $500 \text{ ft}/\mu \text{ sec}$. By itself any discontinuity in transmission has no effect on the wave, until the wave reaches it. But when the wave reaches the transition point, a wave change occurs so that there is little difference from the original wave.

Creeping Speed

If an electric energy wave propagates along the phase wire with constants L and C , then the voltage wave with current propagates at the same speed. These two quantities are connected by a proportional factor, namely the phase characteristics.

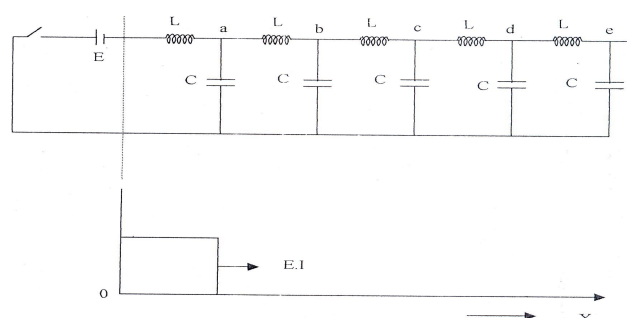


Figure 3.1 Transmission wire with battery

When the voltage wave E reaches point a , the corresponding current from that voltage will charge capacitor C at voltage E . The charge required to increase the voltage one unit length is equal to CE . If the speed of the wave propagation is v cm/second, then the amount of charge needed to fill the wire along v cm every second is equal to $C E v$. This charge is provided by a uniform current flowing in the wire, and to give a charge $C E v$ in one second it takes a current of: $I = C E v$ (3.1)

If the wave propagates as far as x cm, then the electrostatic energy in this section (x cm) is: $W_c = \frac{1}{2} C x E^2$ (3.2)

If L is equal to the inductance of the wire per cm, then at the same time, the electromagnetic energy in the x -long wire: $W_L = \frac{1}{2} L x I^2$ (3.3)

Where :

W_c = Electrostatic energy

W_L = Electromagnetic energy

C = Capacitor

L = Inductance

E = Battery voltage

I = Current that leads to the phase wire

The only source of energy here is the battery. If it takes time t to travel along x cm, $v = x / t$ (3.4)

The energy provided by the battery

$$W_e = E I t ; W_e = W_c + W_L$$

$$\text{So : } E I t = \frac{1}{2} C x E^2 + \frac{1}{2} L x I^2 ; E I = \frac{1}{2} C v E^2 + \frac{1}{2} L v I^2$$

$$v = \frac{E I}{CE/I + LI/E} \dots\dots\dots (3.5)$$

$$\text{From, } I = C E v.$$

$$\frac{E}{I} = \frac{I}{C v}$$

Substitute, we get

$$v = \frac{I}{I/v + L C v}$$

$$v = \frac{I}{L C} \text{ atau}$$

$$v = \pm \frac{\sqrt{1}}{L C} \dots\dots\dots (3.6)$$

Both prices + v and - v apply, i.e.

v positive = forward wave

v negative = backward wave

For an air conductor wire of radius r and height h above the ground, it has the price of inductance and capacity respectively:

$$L = \frac{1}{2} \ln \frac{2h}{r} \cdot 10^{-9} \text{ Henry / cm} \dots\dots\dots (3.7)$$

The $\frac{1}{2}$ factor generated in the inductance of equation (3.7), is caused by the flux inside the wire (Internal Flux), with an even current distribution separation. But in traveling waves, the "Transient Skin Effect" is very large, so the current gathers on the surface of the wire. Thus the internal flux scope is very small and can be neglected, being :

$$L = 2 \ln \frac{2h}{r} \cdot 10^{-9} \text{ Henry / cm} \dots\dots\dots (3.8)$$

$$\text{And the capacity is : } C = \frac{10^{-11}}{18 \ln \frac{2h}{r}} \text{ Farad / cm} \dots\dots\dots (3.9)$$

So by substituting equations (3.8) and (3.9) into equation (3.6), we get the traveling wave speed of :

$$v = 3.10^{10} \text{ cm / second} \dots\dots\dots (3.10)$$

From equation (3.10), it can be seen that the speed of the traveling wave on the air conductor wire is the same as the speed of light in vacuum. As for a solid conductor cable with a radius (r) and insulation wrapping radius (R) and permittivity (ϵ):

$$L = 2 \left(\ln \frac{R}{r} + \frac{1}{2} - \frac{r^2}{3R^2} + \frac{r^4}{12R^4} - \frac{r^6}{60R^6} + \dots \right) 10^{-9}$$

But the inner sphere flux is negligible, since r is much smaller than R hence

factor $\frac{r^2}{3R^2}$ and so on can be ignored, then we will get :

$$L = 2 \cdot 10^{-9} \ln \frac{R}{r} \text{ (Henry/cm)} \dots\dots\dots (3.11)$$

$$C = \frac{\epsilon \cdot 10^{-11}}{R} \text{ (Farad/cm)} \dots\dots\dots (3.12)$$

$$18 \ln \frac{R}{r}$$

So the speed at which the cable propagates is :

$$v = \frac{3.10}{\sqrt{\epsilon}} \text{ cm /second} \dots\dots\dots(3.13)$$

For available cables it is generally $\epsilon - 2.5 - 4$ so the speed of propagation in the cable is approximately $\frac{1}{2}$ to $\frac{2}{3}$ the speed of light.

Shape and Specifications of Waves

The general shape of a traveling wave is as follows:

Wave specifications : Specifications of traveling waves ; Wavefront and tail Specifications of a traveling wave: (a) Crest voltage of the wave, E (KV), i.e. the maximum amplitude of the wave, (b) Wavefront (Front), t1 (microseconds), i.e. the time from the beginning to the peak. In this practice, it is taken from 10% E to 90%E, see Figure 3.2b. (c) Tail of the wave (Tail) is the part behind the peak. Wavelength (Lengght) t2 (microseconds) is the time from the beginning to the point 50% E on the tail. (d.) Polarity is the polarity of a positive or negative wave. A traveling wave (surge) is expressed as follows: E, t1 x t2

So a wave with positive polarity, crest = 1000 KV, front 3 microseconds, and length 21 microseconds is expressed as: + 1000, 3 x 21.

Mathematical Expression of a Traveling Wave

The basic expression of a traveling wave is mathematically expressed by the equation below: $e(t) = E(e^{-at} - e^{-bt})$; E, a and b are constants.

From the variation of a and b, various waveforms can be formed that can be used as an approximation of a traveling wave, for example:

a. Very long square wave :

$$\begin{aligned} a &= 0 \\ b &= \infty \\ e &= E \end{aligned}$$

b Exponential Wave

$$\begin{aligned} a &= \infty \\ e &= E e^{-at} \end{aligned}$$

c. Wave with linear face

$$\begin{aligned} a &= 0 \\ b &\rightarrow 0 \\ E &\rightarrow \infty \end{aligned} \left. \vphantom{\begin{aligned} b &\rightarrow 0 \\ E &\rightarrow \infty \end{aligned}} \right\} bE \text{ limited (Finite)}$$

$$\begin{aligned} e &= E (1 - e^{-bt}) / b = E (bt - b^2 t^2 / 2 + \dots\dots) \\ &= (bE)t \end{aligned}$$

d. Damped Sine Wave

$$\begin{aligned} a. &= \alpha - j\omega \\ b. &= \alpha + j\omega \\ E &= E_0 / 2j \\ e &= E / 2j e^{-\alpha t} (e^{j\omega t} - e^{-j\omega t}) \\ &= E e^{-\alpha t} \sin \omega t \end{aligned}$$

e Typical lightning wave

$$\left. \begin{array}{l} a \\ b \\ c \end{array} \right\} \text{ Limited and real}$$

Very long square waves are often used in calculating running waves for system safety, as they are the most dangerous to equipment. The steepness of the wave will cause maximum gradient while the long tail causes maximum oscillation in the coil windings.

Typical lightning disturbance is the most similar to the lighting surge waveform seen on an oscilloscope. This waveform depends on a and b, otherwise when the wave specifications are given a, b, and E can be found. When E, a, b, are known, the crest, face, and length of the wave can be determined.

Crest and Tail

Crest occurs when $t = t_1$, that is the time reach peak of volatge

d e t

$$\frac{d}{dt} E (-a e^{-at} - b e^{-bt}) = 0$$

$$a e^{-at_1} = b e^{-bt_1}$$

So :

$$t_1 = \frac{\ln b / a}{b - a} = \frac{1/a \ln b / a}{b / a - 1} = B / a \dots \dots \dots (3.14)$$

and

$$E_{\text{peak}} = E (e^{-B} - e^{-Bb/a}) \dots \dots \dots (3.15)$$

3.3.2 Panjang Gelombang

Time to $\frac{1}{2}$ peak = t_2

$$\begin{aligned} E_{\text{peak}} / 2 &= E (e^{-Bt_2/t_1} - e^{-bt_2}) \\ &= E (e^{-Bt_2/t_1} - e^{(b/a)Bt_2/t_1}) \\ \frac{1}{2} E (e^{-B} - e^{-Bb/a}) &= E (e^{-Bt_2/t_1} - e^{-(b/a)Bt_2/t_1}) \end{aligned}$$

This equation expresses the relationship between t_2/t_1 for a certain range of b/a . But because this equation is transcendental, it is possible to find t_2/t_1 by filling in certain prices (making a graph) or by approximation. at1 as b/a from equation (3.11) E crest / E as b/a from equation (3.15) t_2/t_1 as a function of b/a from equation (3.16). An example of using a graph to determine the constants a, b, and E, for waves + 1000, 3 x 21: $t_2/t_1 = 7$. From the curve of t_2/t_1 we get $b/a = 28.5$, then from this b/a we get $at_1 = 0.122/3 = 0.28$.

$$\begin{aligned} \text{So } a &= 0,122/t_1 = 0,122/3 = 0,041 \\ b &= 28,5 a = 28,5 \times 0,041 = 1,15 \\ E &= E_1/0,825 = 1000/0,825 = 1175 \end{aligned}$$

The wave is :

$$E = 1175 (e^{-0,041} - e^{-1,151})$$

Transmission Line Protector

As we know that lightning is a dangerous aspect of interference with transmission lines that can thwart the reliability and security of the power system and cannot be avoided, while safety devices such as arresters, fusegaps and rodgaps have limited capabilities, so to reduce the consequences they use wires. so the coordination of isolation will be economical. The use of ground wire is intended to protect transmission lines against lightning strikes. Especially a direct strike on the phase wire. Here the ground wire serves as a shield. Lightning strike energy will flow into the ground through towers or poles that are grounded by the ground. Among the considerations taken in designing the distribution of transmission lines is the location of the ground wire to the phase wire. Because the ground wire must be laid in such a way, the lightning strikes are concentrated on the ground wire only so that only a small percentage is on the phase wire.

Overhead Ground Wire

The aerial ground wire is the conducting wire, st or AsCR placed over the phase wires. Initially this wire was intended as protection against induced stroke (induction caused by a lightning strike around the transmission wire, so the strike is not direct). However, later it turned out that from practice and theory, the main cause of interference was direct strokes.

Induced Stroke

When an electric current through a cloud falls to the earth, the electric current is induced on the ground towards the opposite pole to that of the cloud (Fig. 4.1). The shape of the cloud area spreads and covers part of the ground surface, the covered ground surface is larger than the cloud surface itself. The base of the bottom of the cloud is usually negative, so the induction of electric currents in the earth is usually positive. If the transmission wire is a dividing line between the cloud surface and the ground, an electric current will appear on the surface of the conductor line and the ground wire.

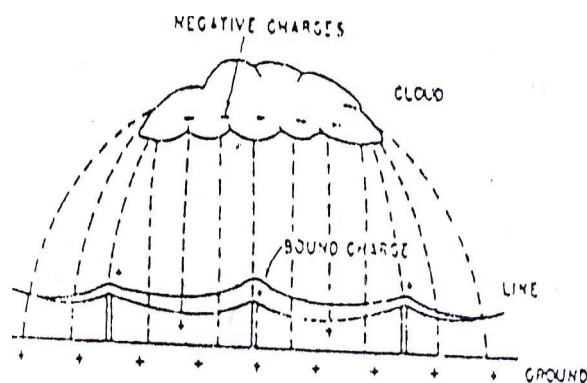


Figure 4.1. Cloud area and boundaries of the ground and transmission network

The collection of electric current in the conductor line is caused by leakage around the insulator and rotation of the conductor outside the influence of clouds. Electric current more easily collects above the ground wire with displacement perpendicular to the arrangement of the ground. If a strike originating from a cloud hits the ground near the dividing line, the cloud area will collapse at a certain time and the electric current jumps on the conductor line and is free to move in the opposite direction, forming a round wave that may end up forming a current flow plain (Fig.4.2).

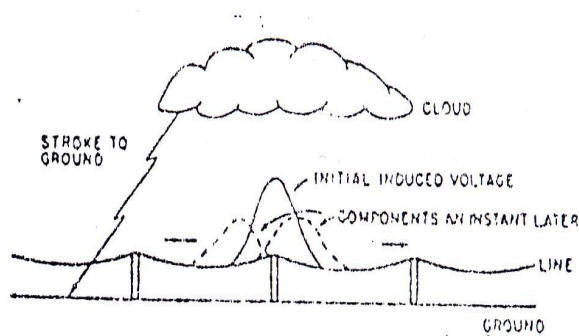


Image. 4.2. Voltage induction in the transmission network with cloud collapse region.

The electric current under the ground wire adjacent to the towers and on the conductor line moves very quickly and dissipates gradually in the corona and loses charge. The voltage appearing in the conductor line depends on the ratio (size) of the collapse of the cloud area and the capacity of the space between the network and the ground, if the circuit is without aerial ground wires, and if there is a collapse of the cloud area at zero time, the voltage in the conductor will be proportional to the increase in the potential gradient from the procurement of the cloud height enlargement of the aerial ground wire above the ground surface increases the conductor's resistance to the ground, and with the increase in clouds that bring many halos, the capacity further increases because the effective diameter of the ground increases with the halo.

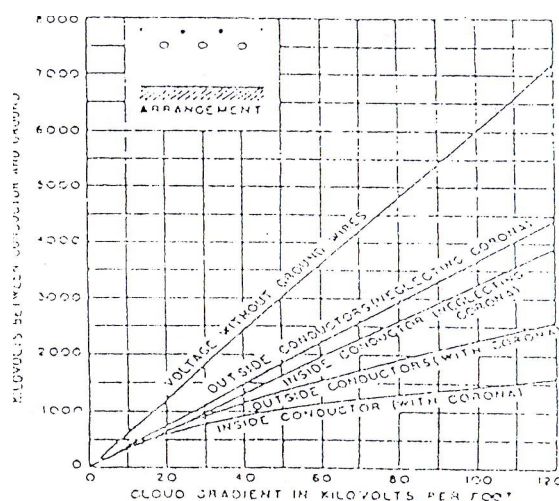


Fig.4.3. Induced potential between conductor and ground near the stroke from cloud to ground. In the open diagram depicted conductor network, and the black circle air ground wire.

Figure 4.3. shows the induced voltage between conductor and ground for different gradients of cloud and without ground wire, for networks above ground level and distance between conductors than the average high voltage network. Comparison of the voltage calculations of the conductor with ground wire protection with the comparison of the voltage on the conductor without ground wire protection. Figure 4.3. Shows the safety ratio of approximately 0.25 for the inside of the conductor, when in comparison to the halo calculation.

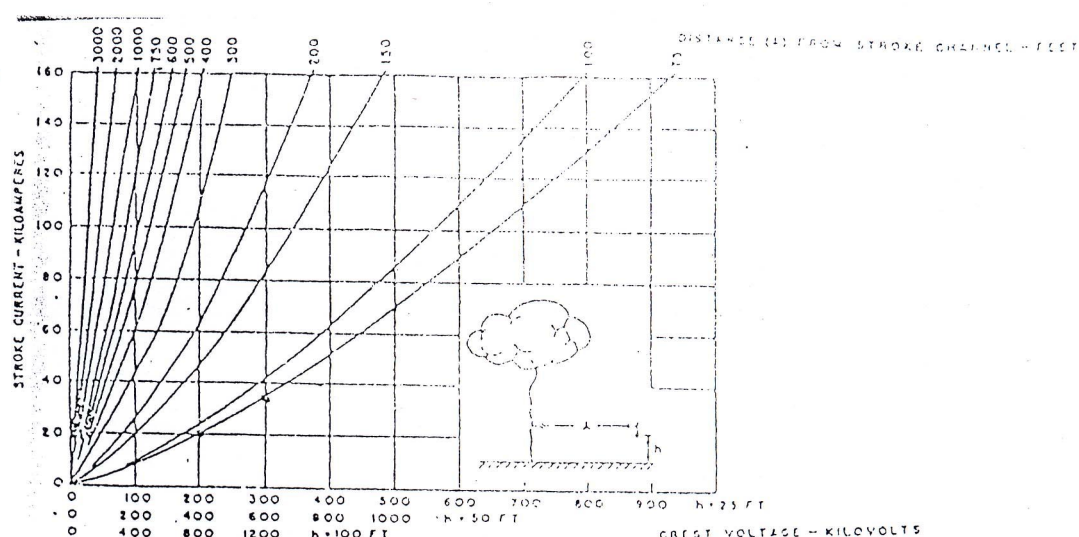


Figure 4.4. Calculating the price of the peak induced voltage on the transmission network near the stroke, describing the stroke current, the line distance from the stroke current, the line distance from the conductor height.

The voltage produces a balance of the height of the peak transmission network conductor of the electric current to the ground stroke and the distance of the stroke line. Figure 4.4. gives the highest calculation of the induced surging electric current in a conductor that is not protected by an aerial ground wire and serves as the current stroke, the distance of the current stroke and the height of the conductor. Calculation on the curve as shown in Figure 4.4. can be known alternating electric current velocity for the difference in electric current at a place as follows: 0-50,000 amperes 120 feet per us; 50,000-10,000 amperes, 400 feet per us. Figure 4.4. shows a less favorable situation than the picture of high currents, high transmission lines and ground strikes near transmission lines, the first voltage peak at 1000 KV may be induced under the conductor. A reduction in content can be seen if the airborne ground wires can be reduced.

Direct Hit On Tower

For direct splice, the ground wire protects (shields) the phase wire, and to obtain good protection the position of the ground wire must meet several important requirements.

1. The ground wire must be high enough above the phase wires and arranged so as to prevent strike on the phase wires.

2. At the center of the gate the ground wire shall have sufficient clearance above the phase wire to prevent a partial jump in the time required for the negative reflected wave from the tower to return to the center of the gate and this will reduce the voltage at the center of the gate.
3. Tower leg resistance must be low enough to limit the voltage on the insulator so that no spark occurs in the insulator.
4. When used for protection against substations, the ground wire must be long enough so that incoming surges can be reduced to a non-hazardous value when they reach the substation.

Direct strike is the main cause of disturbance caused by lightning. When a strike hits a transmission tower, an enormous current flows to the ground and a pair of traveling waves propagate the ground wire. For ease of calculation, for the moment the tower surge impedance can be neglected and it is assumed that the tower is earthed through a constant resistance R .

Figure 4.5. shows a lightning strike with a surge impedance z to the tower, under ideal conditions.

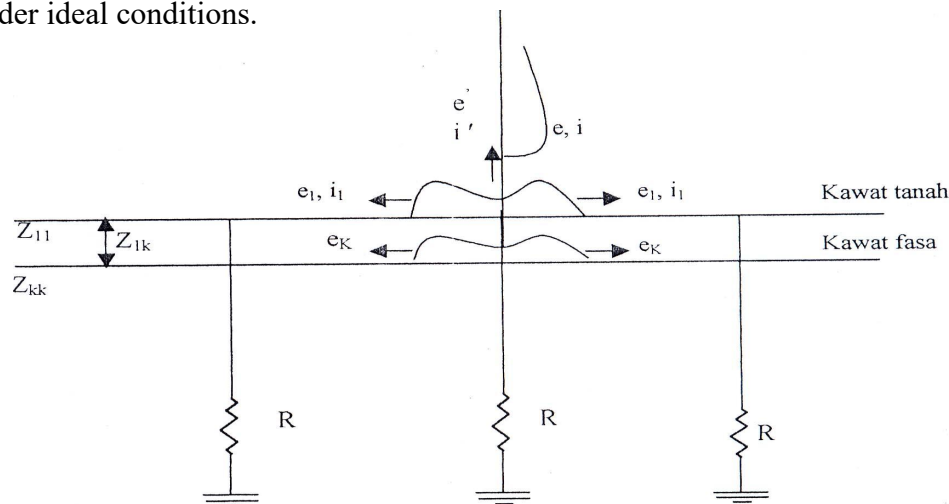


Figure 4.5. Waves traveling on a ground wire caused by lightning

Wave e_1 propagates on the ground wire, and induced wave e_k propagates on the phase wire. Suppose:

Z = surge impedance of lightning (ohms)

Z_{11} = own surge impedance of the equivalent wire

Z_{kk} = own surge impedance

Z_{1k} = common surge impedance between the equivalent ground wire and phase k wire

e = lightning strike reflected wave (volts)

e' = reflected wave in the lightning strike channel

e_1 = incident wave on the ground wire

e_k = incident wave on phase k wire

R = tower leg resistance (Ohm)

I = tower current (A)

Since no current flows from the tower to the phase wire,

$$\text{Then : } e + e' R l + e_1 \dots \dots \dots (4.1)$$

$$i + i' = 2 i_1 + 1 \dots \dots \dots (4.2)$$

where, $I = e/Z$; $i' = -e/Z$; $i_1 = e_1/Z_{11}$

substitute these prices in (4.2)

$$e/Z - e'/Z = 2 e_1/Z_{11} + e_1/R \dots \dots \dots (4.3)$$

or

$$\frac{e + e - e_1}{Z} = \frac{2e_1}{Z_{11}} + \frac{e_1}{R}$$

$$e_1 (1/R + Z/Z_{11} + 1/Z) = 2e/Z$$

So,

$$e_1 = \frac{2R Z_{11}}{2ZR + Z_{11}(R + Z)} e \dots \dots \dots (4.4)$$

The initial wave on the k phase wire is :

$$e_k = Z_{lk} i_1 = \frac{Z_{lk}}{Z_{11}} e_1 \dots \dots \dots (4.5)$$

When waves e_1 and e_k reach the next tower, they are reflected and reacted. Now consider a system of n conductors with m ground wires on a tower grounded through resistance R .

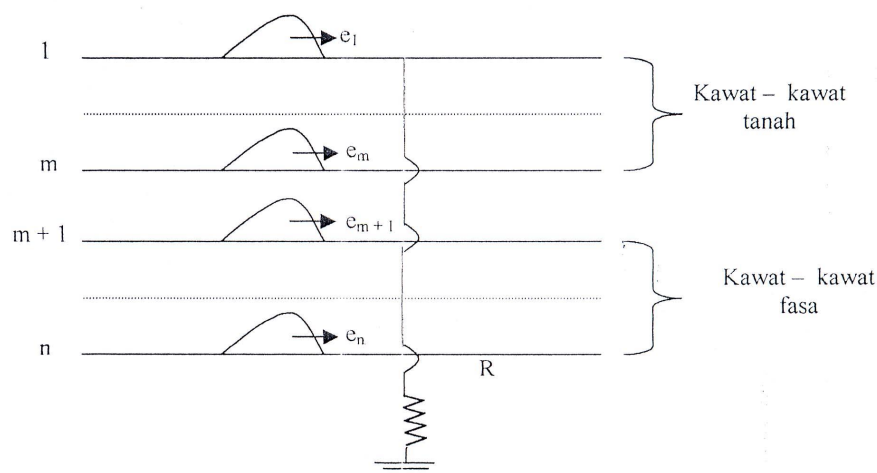


Figure. 4.6. Multiple wire system

For conductor line applies

$$e_k + e_k' = e_k'' \quad k = 1, 2, \dots, n \dots \dots \dots (4.6)$$

Since the ground wires are tied to the tower, then

$$e_1' = e_2' = \dots = e_m' = R l \dots \dots \dots (4.7)$$

So,

$$e_k - e_k' - e_k = e_k - e_k' - (e_k + e_k') = -2 e_k' \dots \dots \dots (4.8)$$

and

$$e_k' = e_k'' - e_k = e_k'' - e_k + (e_1 + e_1') - e_k \text{ untuk } k \leq m \dots \dots \dots (4.9)$$

on the phase wire applies,

$$i_k + i_k' - i_k'' = 0 \quad \text{for } k > m \dots \dots \dots (4.10)$$

but,

$$\begin{aligned} i_k &= Y_{1k} e_1 + \dots \dots \dots + Y_{nk} e_n \\ &= \sum_{r=1}^n Y_{rk} e_r \quad \text{for } K > m \end{aligned}$$

Analog

$$\begin{aligned} i_k'' &= \sum_{r=1}^n Y_{rk} r''_r \quad \text{for } k > m \dots \dots \dots (4.11) \\ I_k'' &= \sum_{r=1}^n Y_{rk} r''_r \quad \text{for } k > m \end{aligned}$$

Substituted *4,11) in (4.10), become :

$$\sum_{r=1}^n Y_{kr} (e_r - r'_r) = 0 \quad \text{for } k > m \dots \dots \dots (4.12)$$

By separating the above and entering (4.8), we get :

$$\sum_{r=1}^n Y_{kr} e'_r + \sum_{m+1}^n k r e'_r = 0 \quad \text{untuk } k > m \dots \dots \dots (4.13)$$

With (4.9) equation (4.13) become :

$$\sum_{r=1}^m Y_{kr} [(e_1 + e'_1) - e_r] - \sum_{m+1}^n Y_{kr} e'_r = 0 \quad \dots \dots \dots (4.14)$$

or,

$$\begin{aligned} \sum_{m+1}^n Y_{kr} e'_r &= - \sum_{r=1}^m Y_{kr} [(e_1 + e'_1) - e_r] \\ &= - \sum_{r=1}^m Y_{kr} (e_1 - e_r) - \sum_{r=1}^m Y_{kr} e'_r \end{aligned}$$

If $r = 1$, so $Y_{k1} (e_1 - e_1) = 0$, become :

$$- \sum_{r=2}^n Y_{kr} (e_1 - e_r) = \sum_{r=1}^m Y_{kr} e'_r + \sum_{m+1}^n Y_{kr} e'_r \quad \text{for } k > m \dots \dots \dots (4.15)$$

From law of kirchoff (in ground wire) dan (4.7)

$$(i_1 + i_1' + i_1'') + \dots \dots + (i_m + i_m' + i_m'') = I = e''/R \dots \dots \dots (4.16)$$

Because

$$i_k + i_k' - i_k'' = \sum_{r=1}^n Y_{kr} (e_r - e'_r - r''_r) \quad \text{for } k \leq m \dots \dots \dots (4.17)$$

So (4.16), become :

$$\sum_{k=1}^m \sum_{r=1}^n Y_{kr} (e_r - e'_r - e''_r)$$

$$\begin{aligned}
 &= \sum_{k=l}^m \left\{ \sum_{r=l}^m Y_{kr} (e_r - e'_r - e''_r) + \sum_{m+l}^n Y_{kr} (e_r - e'_r - e''_r) \right\} \\
 &= \sum_{k=l}^m \left\{ \sum_{r=l}^m Y_{kr} (-2e'_r) + \sum_{m+l}^n Y_{kr} (-2e''_r) \right\} \\
 &= 1 = \frac{e''_r}{R} = \frac{e_1 + e'_1}{R} \dots\dots\dots(4.18)
 \end{aligned}$$

Equations (4.15), (4.18) complete the (n - m + 1) simultaneous equations for (e''₁, e''_{m+1}....., e''_n) on the ground wire and are independent of the incident wave, (e₁,.....e_m) on the ground wire and independent of the incident wave on the phase wire. Since e''₁ has been obtained the reflected and incident waves can be found from

$$\begin{aligned}
 &e''_1 = e''_2 = e''_m = e_1 + e'_1 \\
 \text{So} & \\
 &\left. \begin{aligned} e'_2 &= e''_2 - e_2 = (e_1 + e'_1) - e_2 \\ \dots\dots\dots \\ e'_m &= e''_m - e_m = (e_1 + e'_1) \end{aligned} \right\} \dots\dots\dots(4.19)
 \end{aligned}$$

If there is only one ground wire, or m ground wires are replaced with one equivalent ground wire, then (4.18) and (4.13) taking m = 1 can be simplified

$$\begin{aligned}
 &Y_{11} e'_1 + \dots + Y_{1n} e'_n = -\frac{e_1 + e'_1}{2R} \\
 &Y_{21} e'_1 + \dots + Y_{2n} e'_n = 0.. \\
 &\dots\dots\dots \\
 &Y_{n1} e'_1 + \dots + Y_{nn} e'_n = 0
 \end{aligned} \dots\dots\dots(4.20)$$

So,

$$e'_k = \frac{-M_{lk}}{\begin{vmatrix} Y_{ll} & \dots & Y_{ln} \\ \dots & \dots & \dots \\ Y_{nl} & \dots & Y_{nn} \end{vmatrix}} \cdot \frac{e_1 + e'_1}{2R} \dots\dots\dots(4.21)$$

But

$$\frac{-M_{lk}}{\begin{vmatrix} Y_{ll} & \dots & Y_{ln} \\ \dots & \dots & \dots \\ Y_{nl} & \dots & Y_{nn} \end{vmatrix}} = Z_{kl} \dots\dots\dots(4.22)$$

So (4.21), become,

$$e'_k = -\frac{Z_{kl}}{2R} (e_k - e'_1) \dots\dots\dots(4.22)$$

For k = 1,

$$e'_1 2R = -Z_{11} (e_1 + e'_1)$$

$$e'_1 (2R - Z_{11}) = -Z_{11} (e_1 + e'_1)$$

$$e'_1 = -\frac{Z_{11}}{2R + Z_{11}} e_1 = a e_1 \dots\dots\dots (4.23)$$

$$e'_l = e + e'_l = \frac{2R}{2R + Z_{11}} e_l = b e_1 \dots\dots\dots (4.24)$$

For phase wire

$$e'_1 = -\frac{Z_{kl}}{2R + Z_{11}} e_1 = c e_1 \dots\dots\dots (4.25)$$

$$e''_k = e_k + e'_k = e_k + c e_1 \dots\dots\dots (4.26)$$

So all reflected and forward waves depend only on e_1 . When the initial waves reach the other tower, they are reflected and transmitted according to equations (4.23) – (4.26). The reflected wave that reaches the first tower from the reflection point is reflected back. And this process will occur repeatedly as illustrated in Figure 4.7

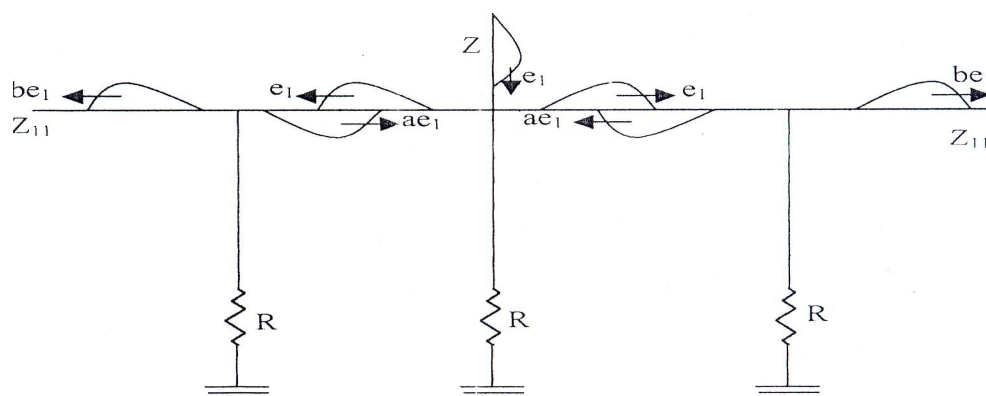
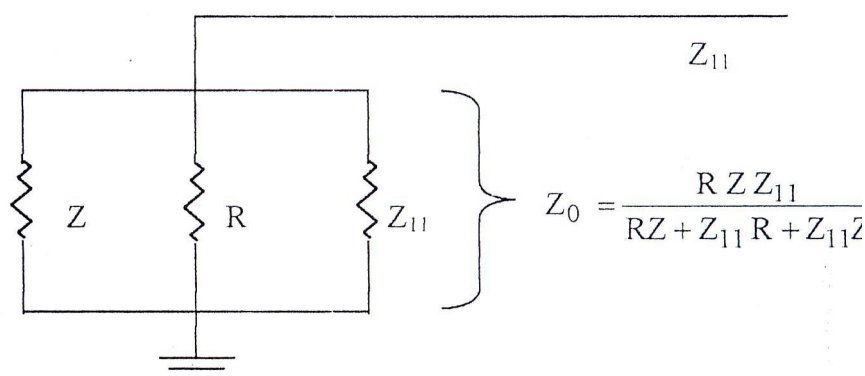


Figure 4.7. Reflection and refraction waves on the ground wire

The reflected wave coming from the right to tower 1 is a e_1 , and is reflected on the tower. The reflection coefficient can be obtained by parallelizing Z , R , and Z_{11} See Figure 4.7



Picture. 4.8. R-equivalent circuit for the reflected wave from the right

The reflection coefficient is::

$$\begin{aligned} \frac{Z_0 - Z_{11}}{Z_0 + Z_{11}} &= \frac{\frac{RZ Z_{11}}{RZ + Z_{11}(R + Z)} - Z_{11}}{\frac{RZ Z_{11}}{RZ + Z_{11}(R + Z)} + Z_{11}} \\ &= \frac{-Z_{11}(R + Z)}{2RZ + Z_{11}(R + Z)} \dots\dots\dots(4.27) \end{aligned}$$

The coefficient of pass on tower 1 is::

$$1 - \frac{-Z_{11}(R + Z)}{2RZ + Z_{11}(R + Z)} = \frac{2RZ}{2RZ + Z_{11}(R + Z)} \dots\dots\dots(4.28)$$

So the wave that propagates to the right or left of tower 1 is the position of the reflection wave and refraction wave on tower 1,

$$\frac{2RZ - Z_{11}(R + Z)}{2RZ + Z_{11}(R + Z)} a e_1 = \alpha e_1 \dots\dots\dots(4.29)$$

For waves on the phase wire

$$e_k = \frac{-2Z_{1k}(R + Z)}{2RZ + Z(R + Z)} a e_1 = e_k + \beta e_1 \dots\dots\dots(4.30)$$

If we pay attention to the equations above, it can be seen that the same results will be obtained if the lightning has a Z surge, the first tower is earthed through resistance R, and the phase wire and ground wire only go in one direction from tower 1 (Figure 4.9).

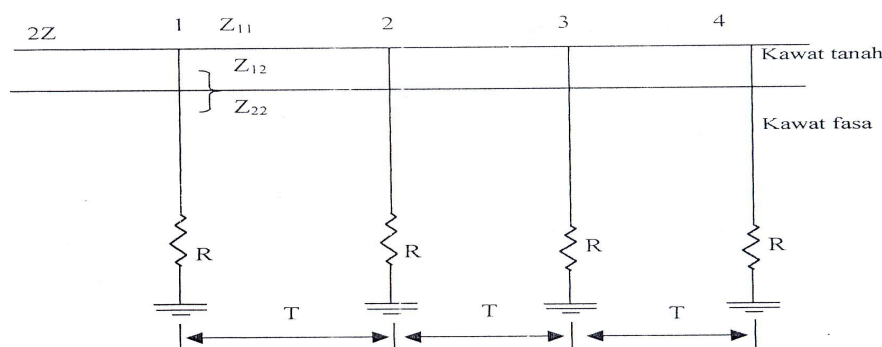


Figure. 4.9. Equivalent circuit of Figure 4.5

Tower Leg Resistance Effect

Low tower leg resistance has five benefits: 1.Reduces ground wire voltage, 2.Reduces phase wire voltage, 3.Reduces what voltage the insulator, 4.Limits interference to a small distance, 5.Shortens the length of time that dangerous voltages occur

Disturbances that cause direct strikes affecting the wire are not simple waves propagated along the transmission, but waves generated by repeated reflections, and these must be limited to a short distance and must be quickly limited.

Waveform Effect

The longer the wave front and the lower the voltage, the more reflected waves that arise and have begun to minimize the incident wave.

Strikes at Midspan

If lightning strikes the ground wire at the midspan where $R = 0$ and flash-over does not occur, then from (4.4) and (4.5),

$$e_1 = \frac{2Z_{11}e}{Z_{11} + 2Z} \quad \text{for ground wire.....(4.31)}$$

$$e_k = \frac{Z_{lk}}{Z_{11}} e_1 \quad \text{for phase wire.....(4.32)}$$

$$e_1 - e_k = \frac{Z_{11} - Z_{lk}}{Z_{11}} e_1 \quad \text{for isolator.....(4.33)}$$

These voltages remain until they are reduced by the reflected waves from the towers. If the span length in micro seconds is T , then that time must be exceeded before reduction occurs. During that time, the flashover between the ground wire and the phase wire must be far enough away so that the sparkover voltage is not reached before the reflection wave arrives that will reduce the midspan voltage.

Representative Voltage for Strikes on Towers Expressed in Current I, and Flash Current I0/2

In the shaoe of tower I

$$V_g = V_{\text{menara}} = RI \quad (g = \text{ground wire})..... (4.34)$$

$$V_p = RI = \frac{Z_{lr}}{Z_{ll}} \quad (p = \text{phase wire}).....(4.35)$$

$$\begin{aligned} V_{\text{isolator}} &= V_g - V_p \\ &= RI \left(\frac{Z_{11} - Z_{lr}}{Z_{11}} \right) \quad \text{.....(4.36)} \end{aligned}$$

Usually, $\frac{Z_{lr}}{Z_{11}} = 0,2 \text{ to } 0,3$

$$\text{From, } V_{\text{isolator}} = (0,7 - 0,8) RI \quad \text{.....(4.37)}$$

In the form of I0/2 lightning current

Lightning current $I0/2$ is the current that occurs when lightning strikes at a point with zero ground resistance. The current conducted depends on the impedance connected to the surge impedance of the lightning itself. For example, if the lightning surge impedance Z ($= 400 \text{ ohms}$) where the current wave $= I0/2$, will flow $I0$ at a point with zero ground resistance.

But if this lightning current $I0/2$ hits the tower of its solar impedance - $Z11$ and its foot resistance R , then the voltage at the strike is :

$$e = I_0/2 \cdot Z \dots\dots\dots (4.38)$$

then from the above equation, the voltage on the tower is :

$$e_1 = \frac{2RZ_{11}}{2RZ + Z_{11}(R + Z)} ZI_0 / 2$$

$$e_1 = \frac{I_0}{1/Z + 1/R + 2/Z_{11}}$$

$$= R' I_0 \dots\dots\dots (4.39)$$

Where

$$R' = \frac{I}{1/Z + 1/R + 2/Z_{11}}$$

$$= \text{equivalent resistance at the point of strike}$$

The current at the foot of the tower (before the arrival of the reflected wave from the other tower is :

$$I = \frac{R'}{R} I_0 \dots\dots\dots (4.40)$$

Protection of Substations

The protection of the substation is divided into 2 parts: a. Protection against direct strike, b. Protection against waves coming from the transmission wire. Protection against direct lightning is by means of a ground wire. If this protection is perfect, what needs to be considered is the waves coming from the transmission wire. If the phase wires are sufficiently protected from direct strikes, then the source of the traveling wave is usually a spark jump from the insulator, generally this voltage is higher than the basic isolation level (ITD) of the substation equipment, this overvoltage must be carried out to ask by the arrester or tools other protection. To calculate the impulse voltage at the substation, it is defined in two ways:

- a. Danger area or vulnerable zone, is the distance outside the wire where a surge wave can arise and endanger the substation.
- b. The station refraction index is a measure of the change in crests and wavefronts it experiences when it enters the substation.

The length of the hazard is a function of: a. Attenuation and wave distortion on the channel, b. Index canal from substation. While the canal index itself depends on: a. The shape of the incoming wave, b. Transition characteristics of substation equipment and protective devices.

Along the propagation of the transmission wire, the waves experience attenuation and distortion caused by the corona, skin effects, soil resistivity, and churn. In addition, its shape can also change due to reflection when it reaches the substation.

Effect of Ground Wire Protection

As a result of the flow of lightning energy into the ground, the overvoltage that arises in the line insulator can be limited, thereby limiting the penetration of the insulator. To obtain unique results, the placement of the ground wire must meet the following requirements:

1. The ground wire must be sufficiently high above the phase wires and arranged so as to prevent direct striking of the phase wires.

2. In the middle of the gate, the ground wire must have a phase wire to prevent partial jumps
3. Tower leg resistance must be low enough.

Failure Shield

Starting in the 1920s, many theories, experiments and experiences were put forward by investigators regarding the function of the ground wire to protect the phase wire on transmission lines. In 1960 Provoost put forward an excellent resume on the role of the ground wire. Based on that theory Provoost draws the conclusion that:

1. For angle protection < 180 transmission wire shielding is good
2. For a protective angle of $180 < < 300$ is not good
3. For corner protector 300 ugly

Then Konstenko, Poloroy and Rosenfeld in 1961 put forward even more danceable compositions. They showed that the amount of lightning disturbance due to shield failure is a function of shielding angle and tower height ht as seen from the empirical relation of equation (4.41).

$$\log \varphi = \frac{\theta \sqrt{h_1}}{90} - 4 \dots\dots\dots (4.42)$$

Where :

φ = The quotient of the number of lightning hitting the phase wire and the number of lightning hitting the transmission line.

θ = Shaft angle on tower, degrees

ht = height of the ground wire on the tower, meters

So the number of faults due to shielding failure,

$$N_{SF} = \varphi N_L \eta \dots\dots\dots (4.43)$$

At that time equation (4.42) was considered by most transmission line engineers to be superior to the other methods.

Example of Calculation of Determining the Angle of Protection in a High Voltage Transmission Network

The magnitude of the protection angle has a relationship with the height of the tower, where the higher the transmission tower the higher the possibility of protection failure. In order to protect (reduce) this protection failure, a small protection angle must be chosen. The formula that can be used to calculate the angle of protection is as follows:

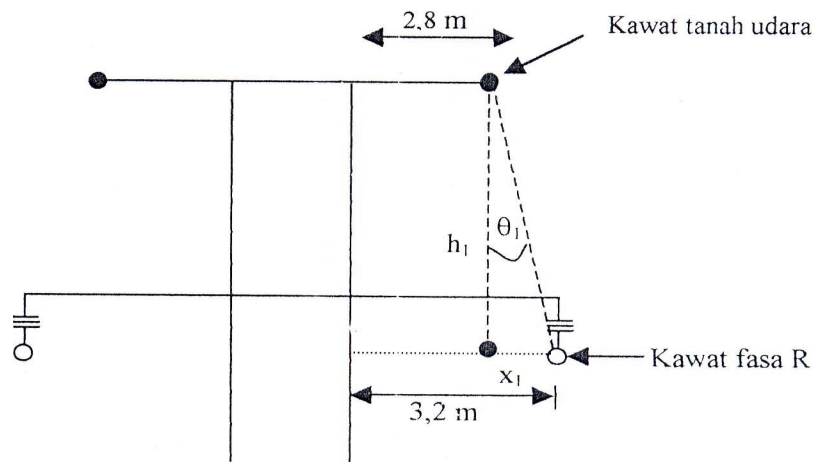
$$\theta = \arctan \frac{x}{h} \dots\dots\dots (4.43)$$

Where : h = the distance between the ground wire and the horizontal line connecting the phase wires.

x = gap between the length of the cross arm of the ground wire and the phase wire

θ = protection of angle

- a. Calculation of shielding angle between ground wire and phase wire R



$$x_1 = 3,2 - 2,8 = 0,4 \text{ m}$$

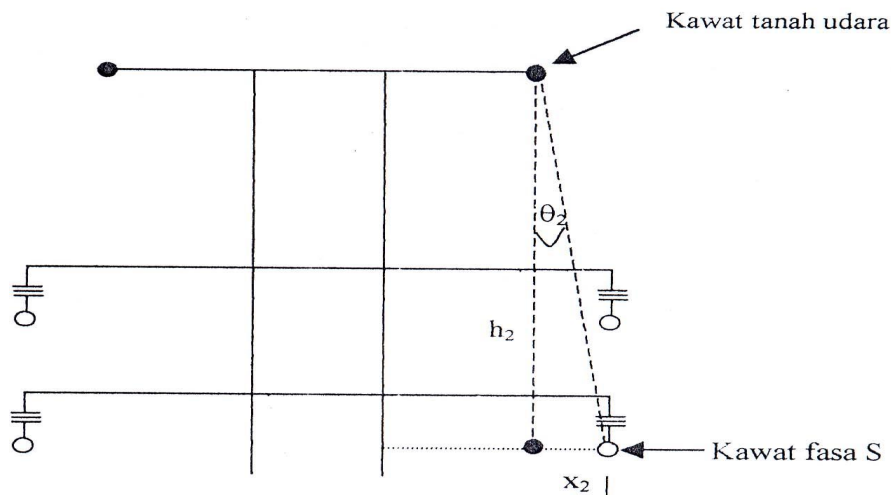
$$h_1 = 5,22 \text{ m}$$

$$\theta_1 = \arctan \frac{x}{h}$$

$$\theta_1 = \arctan \frac{0,4}{5,22}$$

$$\theta_1 = 4,38^\circ$$

- b. Calculation of shielding angle between ground wire and phase wire S



$$x_1 = x_2 = 0,4 \text{ m}$$

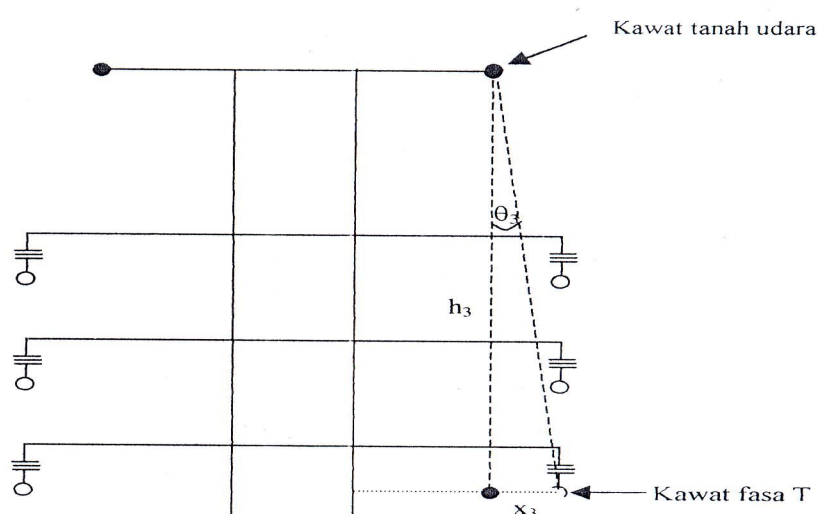
$$h_2 = 5,22 + 4,38 = 9,6 \text{ m}$$

$$\theta_2 = \arctan \frac{x_2}{h_2}$$

$$\theta_2 = \arctan \frac{0,4}{9,6}$$

$$\theta_2 = 2,39^\circ$$

c. Calculation of shielding angle between ground wire and phase wire T



$$x_1 = x_2 = x_3 = 0,4 \text{ m}$$

$$h_3 = 5,22 + 4,38 = 13,98 \text{ m}$$

$$\theta_3 = \arctan \frac{x_3}{h_3}$$

$$\theta_3 = \arctan \frac{0,4}{13,98}$$

$$\theta_3 = 1,63^\circ$$

CONCLUSION

From the discussion in the previous chapters, the authors draw several conclusions, among others: (1) The frequent interference to the transmission network is natural disturbances, such as frequent lightning disturbances to the transmission network caused by long and largest transmission network buildings in various regions and in all kinds of air conditions, (2) In the construction of a transmission network that really needs to be considered is the design of transmission line protection for the location of the phase wire.(3)This transmission wire configuration should receive greater and serious attention.(4).The protective angle of the ground wire according to the calculation example is obtained for :

- The value of the protective angle between the ground wire and the phase wire R is 1 = 4.380
- The value of the protective angle between the ground wire and the S phase wire is 2 = 2.390
- The value of the protective angle between the ground wire and the T phase wire is 3 = 1.630

So for a shielding angle < 180 the transmission wire shielding is good, Air ground wire serves as a safety to reduce the consequences of indirect lightning strikes.The transmission network tower can be earthed by passing the overcurrent on the ground wire through the transmission tower.

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