Lightning Outage System using Two-Point Method

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***Abstract* - The main role of an electric power system is to provide and distribute electrical energy reliably and continously to its electrical loads. Nowadays, power plants are interconnected. This interconnection provides a backup system, that is, if there are disruptions in a power plant or transmission lines, the electric power supply can still be maintained. Lightning outage in transmission lines is a disturbance caused by lightning strikes at phase conductors of a 500 kV Extra High Voltage (EHV) Transmission Lines. Since the continuity of electricity supply is important, an application software that able to examine the reliability level of distribution lines- which its results can be later compared with the real disturbances- is needed. The two-point method is one of the methods that can be used in the optimazation process of lightning outage calculations. Research results show that the R-Phase is the most sensitive one toward lightning strikes due to its position at the uppermost of the tower of EHV lines, with the number of strikes of 0.34/23,093km/year.**

Keywords - Lighting outage, two-point method, phase.

I. INTRODUCTION

The demand of electrical energy in Indonesia is increasing, along with the increasing population and economic growth. To be highly-realiable, the electrical power system should be supported by a reliable protection system whichprotect the system safely and efficiently. Nowadays, power plants are interconnected. This interconnection provides a backup system, that is, if there are disruptions in a power plant or transmission lines, the electric power supply can still be maintained.

Although the system has been well planned, in fact there have been total blackouts which occurred in several cities or countries.For instance, in Indonesia on April 13, 1997; in New Zealand on February 28, 1998; and in London on August 23, 2003. The incident in 1997 reoccured in Indonesia on August 18, 2005 which there was a total blackout for 3 hours in most of the island of Java, resulting in 42 trips of Electric Railway (KRL) in JABOTABEK canceled, 15 flights at Soekarno-Hatta delayed and a lot of traffic jams [1].

The main role of an electric power system is to provide and distribute electrical energy reliably and continously to its electrical loads. In general, the reliability of a power system can be defined as the ability of a system to provide a sufficient power supply with satisfactory quality. The reliability of an electric power systemis determined by adequacy assessment and security assessment.It means that the reliability of electric power system is determined by the system ability to supply enough electrical energy to customers,that fulfill certain requirements, satisfactorilyas well as its ability to keep functioning under un-anticipated disturbances, such as short circuit or loss of system elements[1];[3];[4].

One of the drawbacks of the electric power system in Indonesia is the existence of voltage instability and overloads which in turn affect other systems. Therefore, we need a software that can predict the lightning outage due to lightning strikes on 500 kV EHV transmission lines (SUTET).

II. LIGHTNING OUTAGE

Lightning outage is a disturbance caused by lightning strikes on transmission lines, either directly or indirectly (induction strikes), which cause disruption tothe continuity of electrical power distribution from the corresponding transmission line.

On the transmission line, lightning is an unplanned disruption of electrical power distribution. The unit of the disturbance or so-called the number of lightning outagesis expressed in unit of outage/100 km / year

Types of Lightning Outages
Outages caused by lightning strikes are divided into two groups [5,6]:

a. Outage due to direct strikes, which consists of:
   - Lightning outage on the ground wire
   - Lightning outage on the phase conductor
b. Outage due to indirect lightning (induction strikes).

On the extra high voltage transmission line, outages due to indirect lightning (induction strikes) can be ignored since its probability is very small. For calculation purposes, disturbances due to lightning on the ground wire can be further classified into three types, depending on the place where the lightning struck, i.e.:

a. Lightning disturbances on the transmission tower, which is a disturbance caused by lightning strikes on ground wire close enough to the tower
b. Lightning disturbance on the quarter distance of the tower
c. Lightning disturbance on the mid-rangedistance of the tower

III. TWO-POINT METHOD

If there are lightning strikes on a transmission tower, then there will be overvoltages propagating along the tower. Due to weak insulation of the insulator, sparks to the phase conductors occur, resulting in short circuit to the ground. This disturbance is called *backflashover*.

If the lightning does not hit ground wires or transmission tower but directly hit phase conductors, there will be a very high overvoltage on the striking point which propagate along the the phase conductor and reach the insulator. If the insulator cannot withstand the resulting overvoltage, sparks occur, causing a short circuit to the ground.

3.1. Iso-keraunic Level (IKL)

Isokeraunic Level (IKL) describes theaverage number of thunderstorm per year in an area. The value of IKL determines the number of lightning strikes to the ground and transmission lines.

IKL data of Indonesia can be obtained from the Indonesian Agency for Meteorology and Geophysics.

3.2. Lightning Strikes to the Ground

The number of lightning strikes to the ground in an area is proportional to the corresponding area's IKL, which can be expressed as

$$N = 0{,}12 \cdot IKL \qquad (1)$$

where :

N = number of lightning strikes to the groundper km^2/year

IKL = number of thunderstorm per year

3.3. Lightning Strikes to the Transmission Lines

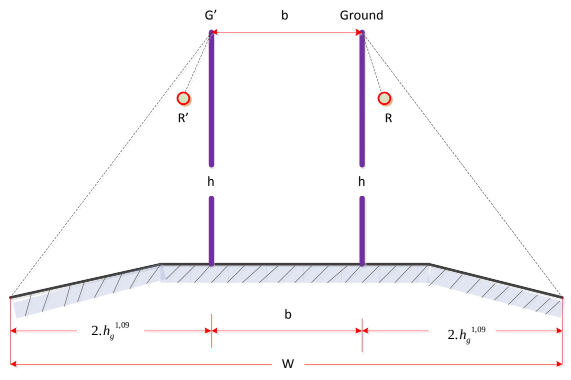

Figure 1. *Width of electric shadow Source [4]*

The transmission line can form electric shadows on the ground below it. Lightning usually head to the ground within the shadow the transmission line instead. Contrary, lightnings outside the shadow area do not hit the transmission line. Figure 1 shows the shadow width of a transmission line using 2-wire ground approach.

The average height of wires in Figure1is :

$$H = Y - \frac{2}{3} \cdot \text{Average Sag} \qquad (2)$$

where :

H = average height of conductors above ground (m)

Y = conductor height above ground (m)

The width of electric shadow proposed by *whitehead* is as follows :

$$W = b + 4.\ h_g^{1{,}09} \qquad (3)$$

where :

W = width of electric shadow(m)

b = distance between ground wires(m)

h_g = average height of ground wires (m)

Then, the shadow area of a 100 km transmission line can be expressed as:

$$A = 100 \cdot (b + 4.\ h_g^{1{,}09}) \cdot 10^{-3}\ km \qquad (4)$$

Or

$$A = 0{,}1 \cdot (b + 4 \cdot hg\ 1{,}09)\ km^2\ /100\ km\ \text{line's length.} \qquad (5)$$

Using equantions 1 and 5, the number of strikes to the transmission line can be calculated as :

$$N_L = 0{,}012 \cdot IKL. (b + 4.\ h_g^{1{,}09}) \qquad (6)$$

where :

N_L = number of strikes to the transmission line per 100 km per year

IKL = number of thunder storm per year

h_g = average height of ground wires (m)

b = distance between ground wires (m)

3.4. Lightning Strikes to the Ground Wires and Tower

The above equation indicates the number of lightning strikes to all parts of transmission lines, including to the tower and phase conductors, either at the quarter or half distance from the tower.

As discussed in the previous sections, 60% of the total strikes hit the tower while the rest is negligible. This is because the transmission tower is higher than the ground wire in the mid-distance between the towers. Hence, the transmission towers attract lightnings stronger. The number of lightning strikes to the tower can be calculated as follows:

$$N_T = 0{,}6\ (N_L - Ns) \qquad (7)$$

where:

N_T = number of strikes to the tower per 100 km per year

N_L = number of strikes to the transmission line per 100 km per year

N_S = number of outagedue to protection failure per 100 km per year

3.5. Probability of Lightning Current

A lightning usually consists of several strikes. Approximately 55% of lightnings consist of more than one strike, with the average is three.

Based on the research results of R. Anderson, the probability of lightning current peak valueis obtained using:

$$P = \frac{1}{1+\left(\frac{I}{31}\right)^{2,6}} \qquad (8)$$

where :

P = Probability of Lightning Current

I = Lightning Current (kA).

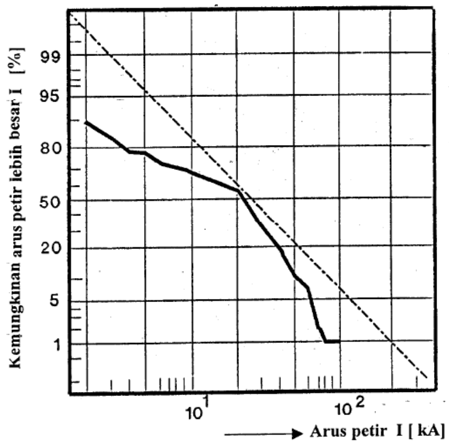

Figure 2. Accumulative probability of lightning current

3.6. Converting The Radius of Bundled Conductor into Those of Single Equivalent Conductor

Extra high voltage transmission line usesbundled conductors. To simplify calculations, those bundled conductors are reduced to a single equivalent conductor using the equation:

$$R_{ek} = \sqrt[N]{r_{11} \cdot r_{12} \cdot r_{13} \ldots\ldots r_{1n}} \qquad (9)$$

where :

R_{ek} = radius of the single equivalent conductor (m)

R_{11} = radius of sub-conductor 1 (m)

R_{1n} = distance between sub-conductor 1 to sub-conduktor n (m)

N = number of conductors

3.7. The Effective Radius of Ground Wire and Phase Conductor

If there are high voltages on the ground wire and the phase conductor, then the effect of the arising corona should be taken into account. The diameter of the corona sheath of the ground wire can be more than one meter and will affect the induced voltage in the phase conductor. The radius of the corona sheath of a single conductor can be calculated using the following equation:

$$R \ln \frac{2.h}{R} = \frac{V}{Eo} \qquad (10)$$

where :

R = radius of corona sheath

h = average height of conductors above ground (m)

V = voltage across the conductors (kV)

Eo = gradient threshold of corona where its sheath cannot re-emerge (kV/m)

The effective radius of a bundled conductor, by taking into account the corona, is:

$$Rc = R + R_{ek} \qquad (11)$$

where :

Rc = radius of the bundled conductor corona sheath (m)

R = radius of the corona sheath (m)

R_{ek} = radius of the single equivalent conductor (m)

3.8. Calculation of Surge Impedance

The self surge impedance of a single conductor, by taking account corona, is:

$$Z_{nn} = 60\sqrt{\ln\frac{2.h}{R_{ek}}\ \ln\frac{2.h}{R_c}} \qquad (12)$$

where :

Z_{nn} = self surge impedance of the single conductor n (ohm)

H = average height of conductors above ground (m)

R_{ek} = radius of single conductor (m)

R_c = radius of the corona sheath of the bundled conductor (m)

Mutual surge impedance of two ground wires is:

$$Z_{12} = 60 . \ln\left(\frac{b_{12}}{a_{12}}\right) \qquad (13)$$

where :

Z_{12} = mutual surge impedance of ground wire 1 and ground wire 2 (ohm)

b_{12} = distance from ground wire 1 to ground wire 2 (m)

a_{12} = distance between ground wire 1 and ground wire 2 (m)

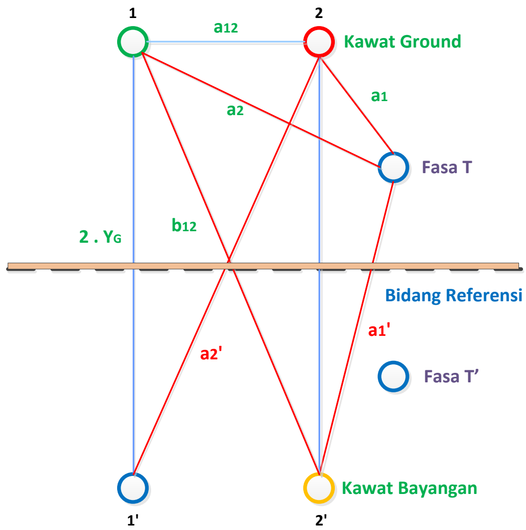

Figure 3. Cross section of a transmission line

Figure 3. depicts the cross section of a transmission line, along with its wires and shadows.

On the other hand, the equivalent surge impedance of two non-identical ground wires can be expressed as:

$$Zs = \frac{Z_{11} + Z_{22} + Z_{12}}{4} \quad (14)$$

where :
Zs = equivalent surge impedance of two ground wires (ohm)
Z_{11} = self surge impedance of ground wire 1 (ohm)
Z_{12} = mutual surge impedance of ground wire 1 and 2 (ohm)
Z_{22} = self surge impedance of ground wire 2 (ohm)

To calculate the surge impedance of a tower, a model approach from Sargent and Darveniza with adjustments according to the tower's shape, is used.
Taking into account the shape of the tower, the tower surge impedance is calculated using the following equation:

$$Z_T = 30 \ln\left(\frac{2\,(h^2 + r^2)}{r^2}\right) \quad (15)$$

where
Z_T = tower surge impedance (ohm)
h = tower height(ohm)
r = tower base radius (m)

3.9 *Determining the Coupling Factor of A Phase Conductor*

Lightning strike currents flowing in the ground wire will induce voltages, called the coupling voltages, to each phase conductor. The ratio of theinduced voltage of each phase to the tower peak-voltage is called the coupling factor. The coupling factor between the ground wire and the phase conductor can be calculated using two ground wires approach, as follows: [4]

$$K_n = \frac{Z_{n1} + Z_{n2}}{Z_{11} + Z_{12}} \quad (16)$$

where :
K_n = coupling factor
Z_{n1} = mutual surge impedance of phase-n conductor and ground wire 1 (ohm)
Z_{n2} = mutual surge impedance of phase-n conductor and ground wire 2 (ohm)
Z_{11} = self surge impedance of ground wire 1 (ohm)
Z_{12} = mutual surge impedance of ground wire 1 and 2 (ohm)

3.10. Lightning Propagation Time on the Tower

The lightning propagation time on a tower includes two propagations, i.e.the lightning propagation time from the top to the base of the tower; and the propagation time from the top to the arm of the tower.
The lightning propagation time from the top to the base of the tower follows the equation:

$$\tau_T = \left(\frac{h}{300}\right) \mu s \quad (17)$$

where :
τ_T = lightning propagation time from the top to the base of the tower (μs)
h = tower height (m)

The lightning propagation time from the top to the arm of the tower follows the equation:

$$\tau_{pn} = \frac{Yn}{300} \cdot 0{,}85 \quad (18)$$

where :
τ_{pn} = lightning propagation time from the top to the nth arm (μs)
Yn = height of the nth arm (m)

The lightning propagation time to the nearest tower is :

$$\tau_s = \frac{\text{Average of span distance}}{300\,x\,0{,}9} \quad (19)$$

where :
τ_s = lightning propagation time to the nearest tower (μs)

3.11. Reaction of The Transmission Tower To Lightning Strikes

To get the induced voltage of a phase conductor, the voltage at the top of the tower should be calculated first. After each surge voltage of insulators have been calculated, these voltages will be used for futher calculation.

The discussion in this section use a simplified method based on the following conditions :

a. Among many strikes contained in a lightning, only one is used in the calculation. It is assumed that the the strike waveform reaches the peak value at2 μs
b. Calculations are only carried out at two time points, i.e. at t = 2 μs and t = 6 μs .
   Sparks occured at time greater 6 μs (t > 6 μs) is considered rare because of the volt-time curvature on this area is flat.

3.12. Calculation of Voltages at The Top of The Tower

If at t_0 = 2 μs there is no reflection of lightning current wave from a nearby transmission tower, then the voltage at the top of the tower that is struck by lightning is as follows:

$$(V_T)_2 = \left[Z_I - \frac{Z\omega}{1-\omega}\left(1 - \frac{\tau_T}{1-\omega}\right)\right].I \quad (20)$$

where :
$(V_T)_2$ = voltage at the top of the tower at t = 2 μs (kV)
Z_T = intrinsic impedance (ohm)
$Z\omega$ = tower wave impedance (ohm)
ψ = damping ratio
τ_T = lightning propagation time from the top to the base of the tower (μs)
I = lightning current of 1 pu (1kA)

Intrinsic impedance is a parallel combination of the tower surge impedance $Z_T$and the ground wire's surge impedance Zs/2, i.e. :

$$Z_I = \frac{Z_S . Z_T}{Z_S + 2.Z_T} \quad (21)$$

where :

Z_I = intrinsic impedance (ohm)
Zs = equivalent surge impedance of two ground wires (ohm)
Z_T = tower surge impedance (ohm)

The wave impedance of the tower is calculated using the following equation:

$$Z_{\omega} = \left[\frac{Z_S{}^2.Z_T}{(Z_S+2.Z_T)}\right].\left(\frac{Z_T-R}{Z_T+R}\right) \quad (22)$$

dimana :
Z_{ω} = tower wave impedance (ohm)
Z_T = tower surge impedance (ohm)
R = average tower foot resistance (ohm)

Damping factor is obtained from:

$$\psi = \left(\frac{2.Z_T-Z_S}{2.Z_T+Z_S}\right).\left(\frac{Z_T-R}{Z_T+R}\right) \quad (23)$$

where :
ψ = damping factor
Z_T = tower surge impedance (ohm)
Zs = equivalent surge impedance of two ground wires (ohm)
R = average tower foot resistance (ohm)

If there are reflections of the current wave fromanearby tower, then there are reflected voltages at the top of the tower at 2 μs which can be expressed as

$$(V'_T)_2 = \frac{-4.K_S.(V_T)_2{}^2}{Z_S}.\left[\frac{1-2.(V_T)_2{}^2}{Z_g}\right].(1-\tau_S) \quad (24)$$

where :
$(V'_T)_2$ = reflected voltage from the nearest tower at 2 μs (kV)
$(V_T)_2$ = tower peak voltage at 2 μs (kV)
K_s = goal damping factor (0.85)
τ_s = lightning propagation time to the nearest tower (μs)
Z_g = surge impedance of the ground wire (ohm)

3.13 Calculation of Tower Arm Voltage

To obtain arm voltage, the voltage of the transmission tower, i.e. the voltage of the tower foot resistances, should be calculated first. The refraction factor is obtained by:

$$\alpha_R = \frac{2.R}{Z_T+R} \quad (25)$$

where :
α_R = refraction factor of the tower foot resistances.
Z_T = tower surge impedance (ohm)
R = average tower foot resistance (ohm)

IV. RESEACRH METHODS

The purpose of developing this lightning outage software is to facilitate the detection of the electrical power distribution continuity.The reliability of the transmission line depends on the means of distribution and equipment used. The means of distribution is arranged based on the time needed to revive the power supply after aninteruption due to lightning strikes.

The data used in this research is based on the data of 500 kV EHV lines in Gresik – West Surabaya area, which includes :

1. The average sag of phase conductors and ground wires.
2. The average tower resistance
3. The length of hanging insulators
4. Diameter kawat fasa dan tanah
5. The diameter of phase conductors and ground wires.
6. The length of the lines

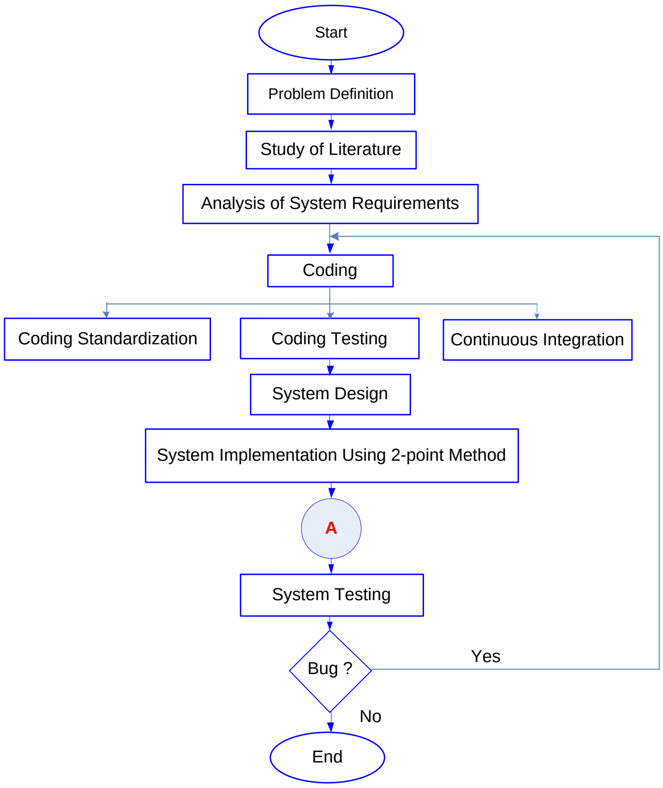

Figure 4. General Research Flowchart

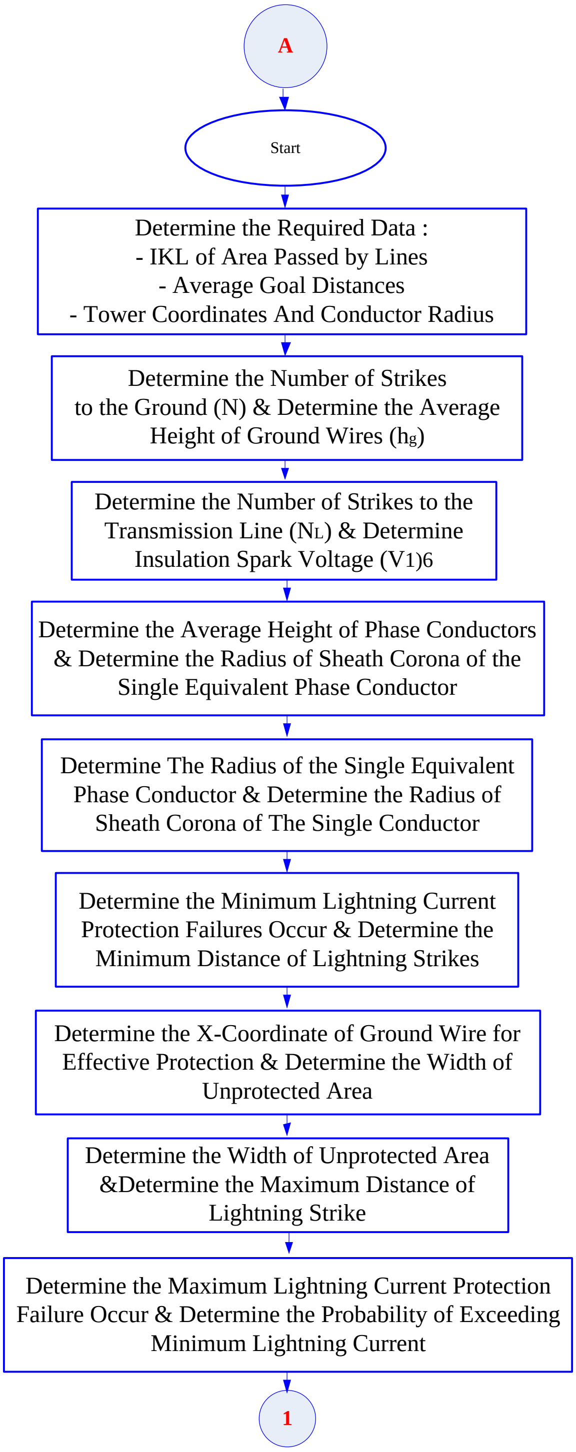

Figure 5. Flowchart of Two-Point Method

The data of nature required is the number of thunderstorm per year (IKL) for area under the 500 kV EVH Transmission Lines of Gresik – West Surabaya. The transmission data is based on those of steel tower of AA type with dual configuration (i.e. with parallel phase arrangement). The ground wire, which protects phase conductors from lightning strikes, uses galvanized steels with diameters of 16 mm^2 and 12,6 mm^2 while the average sag is 10.10964 meters.

Type of insulator used in the EHV lines is made of ceramic. The number and type of disc insulators in one string is determined by the level of insulation required and the level of local pollution in the corresponding area. The conductor used on the 500 kV line of Gresik - West Surabaya is theAluminum Conductor Steel Reinforced (ACSR) with the average sag of each tower is 11.97046 meters.

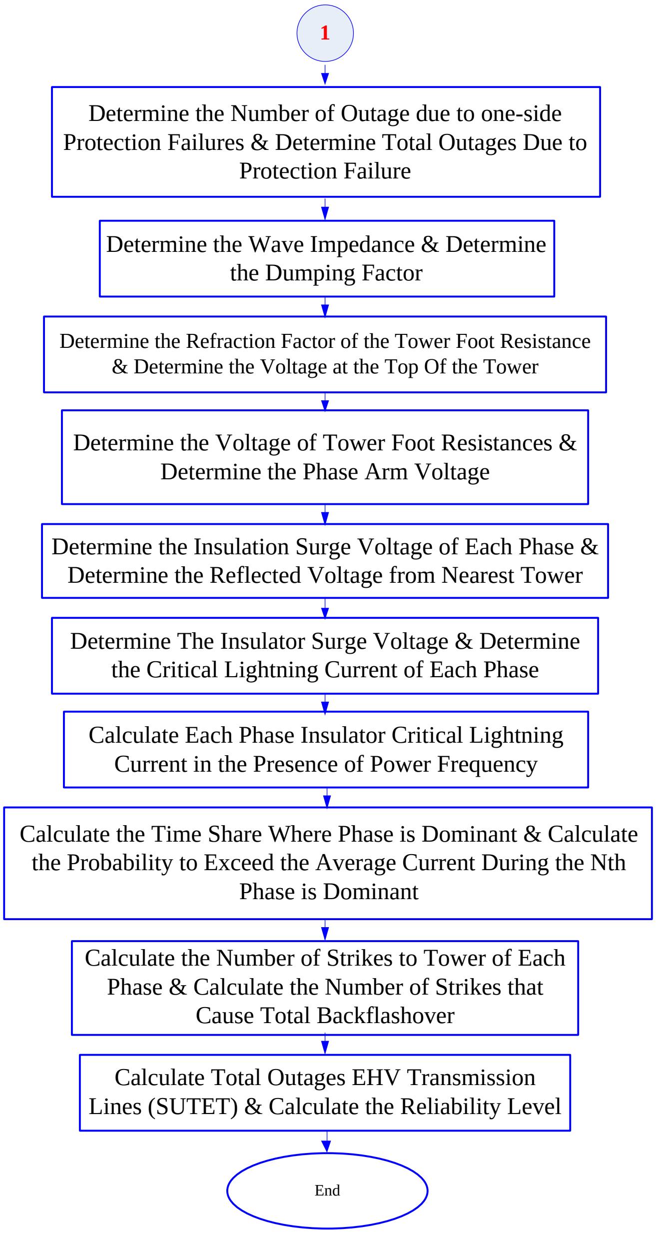

Figure 6. Flowchart of Two-Point Method (cont..)

V. RESULTS AND DISCUSSION

Two-points method yields values which are close to the real disturbances since this method takes into account the existing parameters, i.e.: tower foot resistance, the shape of the tower, and the magnitude of lightning current.

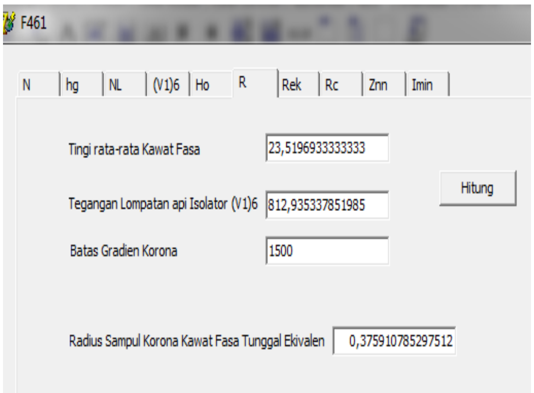

Figure 7. Software display of sheath corona radius calculation of a single equivalent phase conductor

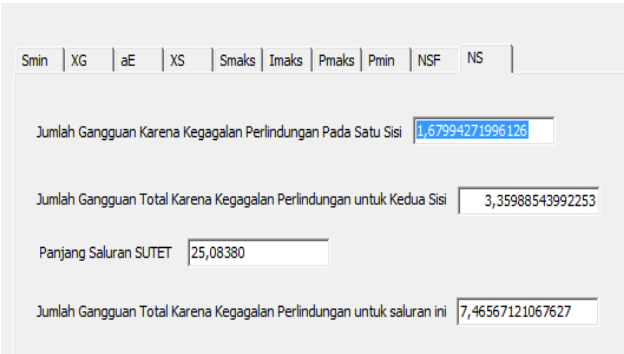

Figure 8. Software display of outage calculation due to line protection failures

Figure 9. Software display of the calculation of mutual surge impedance of phase inductors and ground wires.

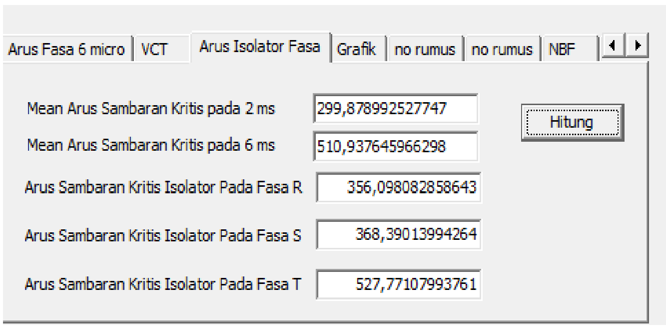

Figure 10. Software display of the calculation of phase insulator-critical lightning current

VI. CONCLUSION

Based on the results of this research, some conclusions can be inferred as follows:

1. The reliability level of two-point method yields the number of outage of 0.341/23.093 km/year.
2. In planning the protection system against lightning strikes, the lightning strike density should be reviewed in advance to determine the quality of protectionthat will be installed. The greater the lightning strike density in an area then the failure of the transmission line protection will be greater.

The realiability of research results are expected can be improved by increasing the number of insulator strings.

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