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Analysis of Determining the Surge Arrester Protective Distance for Protection on 60 MVA Power Transformers at the 150 kV Main Substation in *Surabaya Barat*

Reza Sarwo Widagdo[1], Gatut Budiono[1], Miftachun Nasichin[1]
[1]Department of Electrical Engineering, Faculty of Engineering, Universitas 17 Agustus 1945 Surabaya, Indonesia
Jl. Semolowaru No. 45, Menur Pumpungan, Kec. Sukolilo, Surabaya, Jawa Timur, 60118

Informasi Makalah

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ABSTRACT

Because it provides electrical energy to customers that require protection from lightning interference, the substation is a crucial location. An electrical equipment's defense against lightning strikes is provided by a lighting arrestor. The arrester should be placed as near to the transformer as feasible for optimal protection. In order to restrict the installation of arresters to safeguard equipment, the maximum distance for arrester installation must be established. This study only looks at one 60 MVA transformer in the *Surabaya Barat* Main Substation, and its goal is to determine the minimum amount of error in transformer protection. Based on the maximum possible surge arrester surge arrester jarak with a power transformer at the *Surabaya Barat* Main Substation, the maximum possible surge arrester distance is 8,135 meters. Based on surge arrester capability, the transformer may be protected from over voltage since the maximum voltage that can occur is just 150.83 kV, with the maximum voltage remaining below the transverse impulse drop of around 650 kV.

Author Correspondence:

Reza Sarwo Widagdo
Department of Electrical Engineering,
Universitas 17 Agustus 1945 Surabaya, Indonesia
Jl. Semolowaru No. 45, Menur Pumpungan, Kec. Sukolilo, Surabaya, Jawa Timur, 60118
Email: rezaswidagdo@untag-sby.ac.id

1. Introduction

In this era, human life cannot be separated from all electrical equipment. The need for electricity increases from year to year along with the increase in people's living standards. To meet the need for electric power, it is necessary to improve the quality of the electric power distribution system [1]-[2]. Electricity is generated by power plants, then flows through transmission lines, then distributed, and finally reaches consumers. One of the important components in the electric power transmission system is the substation which has an important role in the electric power distribution system, namely reducing the voltage from 150 kV to 20 kV so that it can be distributed to users. Therefore, to reduce the frequency of damage to electrical equipment, equipment is needed that can prevent interference [3].

Placing arresters at a certain distance can protect equipment from overvoltage disturbances, surge waves or transient electrical energy. When a traveling wave occurs which causes overvoltage on equipment that is located a little far from the arrester, the equipment will remain protected, if the arrester distance is still within the protection working radius. At the 150 kV substation in *Surabaya Barat*, there are power transformers and surge arresters which are placed at a certain distance. The distance between the surge arrester and the protected power transformer influences the amount of voltage arriving at the transformer. If the surge arrester is too far away, the voltage arriving at the transformer can exceed the voltage it can support [4]. Lightning strikes that

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occur can cause dangerous over voltages and traveling waves. The lightning surge wave is a double exponential wave which according to the IEC is a 1.2/50 μs type overvoltage wave [5]. Based on SPLN-7: 1978 for a double circuit system with a voltage of 150 kV, the maximum distance between the arrester and the transformer is 80 m, while for a single circuit it is half that distance. The surge arrester must be placed as close as possible to the device being protect, the aim is to reduce the possibility of impulse voltage propagating on the wire connecting the surge arrester to the equipment being protected [6].

In previous research, Abdul Azis [7] carried out an analysis of the placement of surge arresters. After collecting data in the field, the result was that the distance between the surge arrester and the installed 20 MVA power transformer was 7 m, while from the calculation results it was 5.78 m. The transmission line at the Sungai Juaro Palembang substation is double circuit transmission, and based on SPLN 7: 1978 that for a 66 kV system with double circuit transmission the distance between the lightning catcher and the transformer does not exceed 34 m. This means that the distance between the surge arrester and the 20 MVA power transformer is still within the limits set by SPLN 7: 1978. Toyib [8] in his research conducted research on determining the protective distance of surge arresters in the Harapan Baru 150 kV substation area. After carrying out investigations in the field, the results showed that the layout of the surge arrester for the power transformer unit 1 of the Pakatan Harapan Substation met the standards. It is calculated that the maximum distance between the surge arrester and the power transformer is 10.96 m, while the distance between the on-site surge arrester and the power transformer is 3.2 m, so that the placement of the surge arrester at the Harapan Baru Substation is optimal to protect the impact of surge strikes. Second, the voltage increase that occurs on the transformer is still below the BIL, so it is certain that the equipment can still be protected by a surge arrester because the installation is still below the maximum price or does not exceed the BIL standard.

From several cases previously described, the author carried out an analysis of the protective distance of the surge arrester at the 150 kV *Surabaya Barat* Main Substation. So that the results of discussions and investigations in the field can be used as a reference to determine the type of lightning rod that will be used and it is hoped that it can be applied to other substations. Several analyzes related to determining the protective distance will be taken into account, including the voltage rise on the power transformer and the discharge voltage on the surge arrester.

2. RESEARCH METHODS

In the analysis process, several related parameters will later be taken into account to determine the voltage rise on the power transformer and also the discharge voltage on the surge arrester. The parameters to be calculated are the surge impedance calculation, the rated rating calculation on the surge arrester and the speed of surge wave propagation.

2.1. Determination of Maximum Voltage at Operational Substation

The arrester voltage rating is the maximum alternating voltage allowed at the lightning arrester terminal, where this voltage can break the after current (power follow current) that occurs when the lightning arrester experiences a spark, which in determining this voltage is useful for knowing the highest voltage that can be produced by the substation. The highest system voltage is generally taken to be 110% of the nominal system voltage (V_n). The value can be determined using the following equation [9].

$$V_m = 1{,}1 \times V_n \quad (1)$$

Where,

V_m : Maximum voltage system (Volt)
V_n : Nominal voltage (Volt)

2.2 Surge Arrester Rated Voltage Rating

The rated surge arrester rating or basic arrester voltage can be determined based on the maximum possible system voltage. Arrester rated voltage (V_c) is the most important characteristic for substation protection. The rated voltage of the arrester determines the level of protection of the arrester. If the working voltage of the arrester is below the Basic Insulation Level (BIL) of the protected equipment, then an optimum safety factor for the equipment can be obtained. The basic voltage of the arrester or rated voltage of the arrester can be determined using the equation [9]:

$$V_c = V_m \times C_g \quad (2)$$

Where,

V_c = Voltage rating of surge arrester (Volt)
V_m = Maximum voltage system (Volt)
C_g = Grounding Coefficient (1 or 0,8)

2.3 Determination of Surge Impedance

The surge impedance for air conductors (Z_1) is influenced by the height of the conductor above the ground (h), and the radius of the conductor (r), so it must be determined first. Determination of surge impedance for air conductors is calculated using the following equation [7]

$$Z_1 = 60\, ln\, ln\, \left(\frac{2h}{r}\right) \quad (3)$$

Where,

Z_1 = Surge impedance in the air propagation medium (Ohm)
h = Height of the conductor above the ground (Meter)
r = Radius of the conductor (mm)

Meanwhile, surge impedance for cables is influenced by the outermost wire radius (R), conductor radius (r), and wire permittivity (ϵ), calculated using the following Zc notation [7].

$$Z_c = \left(\frac{60}{\varepsilon}\right) ln\, ln\, \left(\frac{R}{r}\right) \quad (4)$$

Where,

Z_c = Surge impedance in the conductor wire medium (Ohm)
R = Outer wire radius (mm)
r = Conductor radius (mm)
ϵ = Wire permittivity (Alumina Wire : 9.3 – 11.5)

2.4 Propagation Speed of Surge Waves

A wave propagating with constants L and C along a wire, makes the voltage and current waves propagate at the same speed. Apart from that, the propagation speed of the wave is also influenced by a proportional factor, namely the characteristics of the wire being traversed. So the wave propagation speed obtained for the wire in the air medium is as follows [10].

$$v = C_0 \frac{1}{\sqrt{\varepsilon_r}} \quad (5)$$

Where,
v = The speed of propagation of the surge wave ($\frac{m}{s}$)
C_0 = Velocity of light ($\frac{m}{\mu s}$)
ε_r = Relative Permittivity (Air : 1.00085)

2.5 Determination of the Reflection Operator and the Channel Operator

When the surge wave reaches a point that connects two different wave impedances (transition point), it will cause a surge wave that is reflected at that point. Figure 1 shows that the lightning strike wave comes from the left side, after the lightning strike reaches the arrester installation point, part of the wave will be reflected and part will be transmitted. To determine the arrester spark voltage, the reflection operator and line operator must first be determined [11].

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$$a = \frac{z_c - z_1}{z_c + z_1} \qquad b = \frac{z_1 - z_c}{z_1 \mp z_c} \qquad a' = \frac{2z_c}{z_c + z_1} \qquad b' = \frac{2z_1}{z_1 + z_c} \quad (6)$$

Where,

a = Reflection operator for waves coming from the left
a' = Channel operator for waves coming from the left
b = Reflection operator for waves coming from the right
b' = Channel operator for waves coming from the right
Z_1 = Surge impedance in the air propagation medium (Ohm)
Z_C = Surge impedance in the conductor wire medium (Ohm)

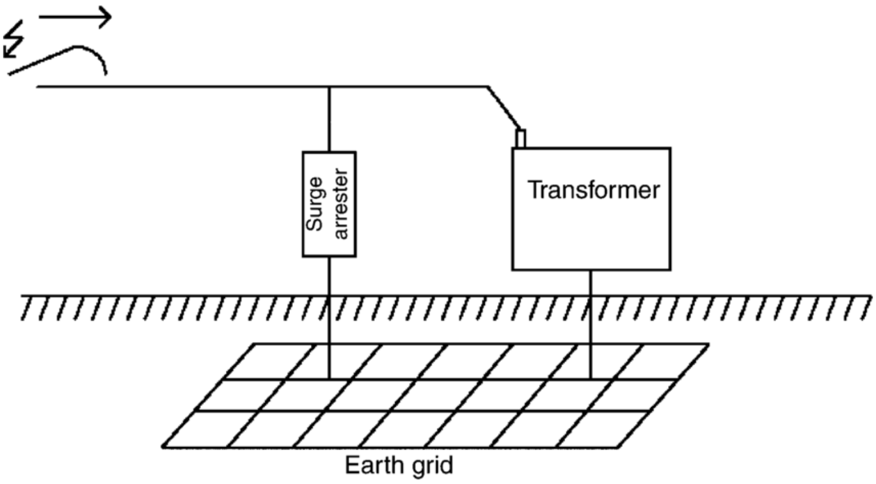

Figure 1. One Channel Equivalent Circuit [12]

For the steepness of the first incident wave, the time of the wave steepness entering the substation or transformer must be determined, and for example the wave steepness time (t) is every 2 µseconds and the lightning surge (A) is 1000 kV, and the damping factor (α) is A × a'.

To determine the voltage value at the overhead wire cable connection point, start at t = 0, and the voltage value at the next time is the sum of the previous voltage value and the damping factor. The voltage value of the reflected wave is the same as the incident wave. So the voltage at the cable-air wire connection point when the lightning arrester is not present for every 2 µsec is:

t = 0 µsec; et = 0 = 0
t = 2 µsec; et = 2 = et = 0 + ($\alpha^1/10^0$)
t = 4 µsec; et = 4 = et = 2
t = 6 µsec; et = 6 = et = 4 + ($\alpha^1/10^0$) + ($\alpha^3/10^4$)
t = 8 µsec; et = 8 = et = 6
t = 10 µsec; et = 10 = et = 8 + ($\alpha^3/10^4$) + ($\alpha^5/10^8$)
t = 12 µsec; et = 12 = et =10

Then the lightning arrester spark time (t_{so}) at the arrester installation location can be determined using the following equation:

$$tso = 8 + \Delta t \quad (7)$$

Where,

t_{so} = Spark over time for surge arrester (μsec)
Δt = The voltage time based on the surge arrester initial time (μsec)

Meanwhile, the voltage time based on the surge arrester initial time (Δt) can be determined using the following equation:

$$\Delta t = (E_a - e_{t=8})/b'(\frac{a^3/10^4}{2}) \quad (8)$$

Where,

Δt = The voltage time based on the surge arrester initial time (μsec)
E_a = Basic insulation level of surge arrester (kV)
$e_{t=8}$ = Voltage at the terminal point at time 8 µsec
b' = Channel operator for waves coming from the right

2.6 Determination of Maximum Distance for Arresters and Power Transformers

The increasing voltage on the transformer is the voltage that arises when a circuit surge occurs. If the voltage that arises is below the basic isolation level of the transformer, the transformer can be protected. The voltage rise on the transformer can be determined using the following equation:

t = 0 µsec; $E_{t=0} = 0$
t = 2 µsec; $E_{t=2} = 0$
t = 4 µsec; $E_{t=4} = E_{t=2} + 2a^1/10^0$
t = 6 µsec; $E_{t=6} = E_{t=4}$
t = 8 µsec; $E_{t=8} = E_{t=6} + 2a^3/10^4$
t = 10 µsec; $E_{t=10} = E_{t=8}$
t = 10 + Δt (µsec); $E_{t=10+\Delta t} = E_{t=10} + (\frac{e_{t=10}+a^5/10^8-e_{t=6}}{2})\,\Delta t$

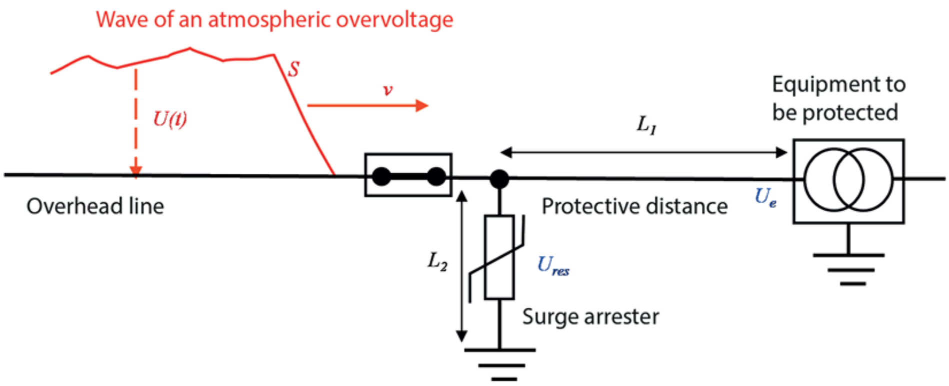

Figure 2. Diagrammatic for Estimating the Protective Distance for an Arrester [13]

The maximum distance between the arrester and the transformer when connected directly to the overhead line and the transformer is considered as an open clamp. Good protection can be obtained if the lightning rod is placed as close as possible to the transformer clamp. However, in practice, the surge arrester must usually be placed at a distance S from the protected transformer. Therefore, this distance must be determined so that proper protection can be carried out [14].

$$S = (E_a - E_T) \times \left(\frac{v}{2A}\right) \quad (9)$$

Where,

S = Protective distance between surge arrester and transformer (m)
v = The speed of propagation of the surge wave ($\frac{m}{s}$)
A = The steepness of the surge wave (kV)
E_a = Basic insulation level of surge arrester (kV)
E_t = Increasing voltage on the transformer (kV)

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2.7 Insulator Breakdown Voltage in Air

The amount of voltage that arises on the transmission insulator depends on the two lightning parameters, namely the peak and the steepness of the surge wave. Not all lightning strikes can result in a flashover on the insulator because it also depends on the amount of voltage that arises and does not exceed the breakdown voltage on the insulator ($E_{50\%}$) [15].

$$E_{50\%} = \left(K_1 + \frac{K_2}{\Delta t^{0,75}}\right) \times 10^3 \quad (10)$$

Where,

$E_{50\%}$ = Breakdown voltage of insulator (kV)
K_1 = 0.3 × Insulator span length
K_2 = 0.7 × Insulator span length
Δt = Sparkover time (μsec)

Nominal discharge current is a current with a certain peak value and wave shape which is used to determine the class of surge arrester according to its current capability and protective characteristics. The discharge current in a traveling wave event can be determined using the following equation [15]:

$$I_a = \frac{2 \cdot E_{50\%} - E_a}{Z_1} \quad (11)$$

Where,

I_a = Current discharge surge arrester (kA)
$E_{50\%}$ = Breakdown voltage of Insulator (kV)
E_a = Basic insulation level of surge arrester (kV)
Z_1 = Surge impedance in the air propagation medium (Ohm)

2.8 Protection Factor of Surge Arrester (FP)

The protection factor is the voltage difference between the BIL of the protected equipment and the working voltage of the arrester. When determining the level of protection for equipment protected by an arrester, a price is generally taken that is 10% above the working voltage of the arrester, the aim is to overcome the increase in voltage on the connecting wire and factory tolerance. This protection factor is generally 20% of the equipment BIL for arresters installed near the protected equipment. Protection Factor (FP) can be determined using the following equation [16]:

$$FP(\%) = \frac{BIL - Protection\ Level\ of\ Surge\ Arrester}{BIL} \times 100\% \quad (12)$$

$$Protection\ Level\ of\ Surge\ Arrester = E_a + 10\%\ (wire\ length\ +\ factory\ tolerance) \quad (13)$$

3. RESULT AND ANALYSIS

The research began by observing the research location, then collecting operational data in the form of power transformer data, surge arrester data, tower height data and transmission lines. The data that has been obtained is then analyzed and then processed so that it can be used in calculations to obtain surge impedance, surge arrester operator value, voltage rise on the power transformer, distance of the surge arrester to the power transformer, breakdown voltage of the air insulator, and protection factors.

3.1 Power Transformer, Surge Arrester, and Transmission Wire Data

The transformer used at the 150 kV *Surabaya Barat* main substation is the SALOCR type which has a power of 60 MVA and has a primary voltage versus a secondary voltage of 150kV versus 20 kV with a frequency of 50Hz. Apart from that, the impedance value is 12.46% with a basic isolation level of 650 kV. Regarding the completeness of the parameters of the transformer, it has been explained in Table 1 regarding the operational parameters of the transformer. Then the surge arrester used is the SORESTER brand with type ZSE-E1Z which has a nominal voltage of 150 kV, operational current of 10 kA and frequency of 50 Hz.

Table 1. Parameter of Power Transformer at *Surabaya Barat* Main Substation

Parameter	Unit
Transformer Capacity	60 [MVA]
Primary Voltage	150 [kV]
Secondary Voltage	20 [kV]
Impedance	12,46%
Basic Insulation Level (BIL)	650 [kV]
Frequency	50 [Hz]

Table 2. Parameter of Surge Arrester at *Surabaya Barat* Main Substation

Parameter	Unit
Transformer Capacity	60 [MVA]
Primary Voltage	150 [kV]
Secondary Voltage	20 [kV]
Impedance	12,46%
Basic Insulation Level (BIL)	650 [kV]
Frequency	50 [Hz]

The conductor used is type ACSR (Aluminum Conductor Steel-Reinforced) 340/30 mm^2 with a diameter of 24.99 mm. ACSR transmission wire has aluminum conductors on the outside that provide electrical current conductivity, while steel retaining walls on the inside provide mechanical and structural strength to the wire. This combination gives ACSR transmission wire good strength and conductivity. Table 3 is material data for ACSR type transmission, this data is used to determine the wire impedance value.

Table 3. Parameter of Transmission Wire at *Surabaya Barat* Main Substation

Parameter	Unit
Type of Wire	ACSR
Size	340/30 [mm^2]
Cross-sectional area	369,14 [mm^2]
Diameter (d)	25 [mm]
Radius (r)	125 [mm]
Minimum Pull Strength	9,44 [Kg]

3.2 Determination of Maximum Voltage at Operational Substation

The typical approach is to consider the highest system voltage as 110% of the nominal system voltage. This determination is valuable for understanding the maximum voltage achievable by the substation. One can ensure the maximum system voltage using the following method.

$$V_m = 1{,}1 \times V_n$$

$$V_m = 1{,}1 \times 150\ [kV] = 165\ [kV]$$

3.3 Surge Arrester Rated Voltage Rating

Based on the highest possible system voltage, the rated arrester rating or fundamental arrester voltage may be determined. Determine the following figures to determine the arrester's rated voltage.

$$V_c = V_m \times Grounding\ Coefficient$$

$$V_c = 165\ [kV] \times 0{,}8 = 132\ [kV]$$

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For a direct grounding system, the grounding coefficient is 0.8, which means that this kind of surge arrester is called an 80% surge arrester. Systems that are not directly connected to ground have a ground factor of 1.0 so this kind of arrester is called a 100% surge arrester. The meaning of direct grounding system and indirect grounding system is as follows. From the calculation results, it is obtained that the rated voltage of the surge arrester *Vc* = 132 kV, which means that the working voltage of the arrester is below the Basic Insulation Voltage (BIL) of the protected equipment, so that an optimum safety factor for the equipment can be obtained.

3.4 Determination of Surge Impedance

Determination of surge impedance for air conductors can be calculated using the following equation.

$$Z_1 = 60\ ln\left(\frac{2h}{r}\right)$$

$$Z_1 = 60\ ln\left(\frac{2(35)}{0{,}0125}\right)$$

$$Z_1 = 517{,}831\ [\Omega]$$

The surge impedance for overhead wires = 400 – 600 ohms, and for cables = 20 – 60 ohms. The working voltage of the lightning rod will increase with the value of the discharge current, but this increase is very limited by the linear resistance of the lightning rod. So the Zc value can be calculated as follows.

$$Z_c = \left(\frac{60}{\varepsilon}\right) ln\left(\frac{R}{r}\right)$$

$$Z_c = \left(\frac{60}{9}\right) ln\left(\frac{12{,}5}{1{,}5}\right)$$

$$Z_c = 20\ [\Omega]$$

3.5 Propagation Speed of Surge Waves

From an energy perspective, it can be said that a surge in the cable is caused by a sudden injection of energy into the cable. This energy flows through cables consisting of current and voltage. The propagation speed of the traveling wave depends on the wire constant. The propagation speed of traveling waves in transmission lines can be determined using the following equation.

$$v = C_0 \frac{1}{\sqrt{\varepsilon_r}} = 300[m/\mu sec] \times \frac{1}{\sqrt{1}} = 300\ [m/\mu sec]$$

3.6 Determination of the Reflection Operator and the Channel Operator

To determine the increase in time required for a surge wave to cross a channel, the reflection and channel operators must first be determined. Through the Z1 and Zc values, the operator values can be determined using equation (6) so that the results are explained in Table 4.

Table 3. Reflection and Channel Operator

Parameter	Value
Z_1	517,83 [Ω]
Z_c	20 [Ω]
a'	0,0743
a	−0,9256
b	0,9256
b'	0,0743

For the steepness of the first incident wave, the time of wave steepness entering the substation or transformer must be determined, and the following value must be obtained.

$t = 2\ [\mu sec]$

$A = 1000\ [kV]$

$\alpha = A.a' = 1000 \times 0{,}0743 = 74{,}3$

Next, determine the voltage value at the overhead wire cable connection point. The voltage starts at t=0, and the voltage value at the next time is the sum of the previous voltage value and the damping factor. The voltage value of the reflected wave is the same as the incident wave. So the voltage at the cable-air wire connection point when the lightning arrester is not present for every 2 µseconds is:

Table 3. Reflection and Channel Operator

Duration $[\mu sec]$	$e_t\ [kV]$
0	0
2	74,3
4	74,3
6	198,8
8	198,8
10	262,45
12	262,45

Then the strike time based on the initial time of the lightning arrester wave (Δt) can be determined using the following equation:

$$\Delta t = (E_a - e_{t=8})/b'(\frac{\alpha^3/10^4}{2})$$

$$\Delta t = (500 - 198{,}8)/0{,}0743(\frac{74{,}3^3/10^4}{2})$$

$$\Delta t = 0{,}197\ [\mu sec]$$

The lightning arrester spark time (t_{so}) at the arrester installation location can be determined using the following equation:

$$t_{s0} = 8 + \Delta t = 8 + 0{,}197 = 8{,}197\ [\mu sec]$$

Next, the discharge voltage or working voltage (e_(t=8.197)) of the lightning arrester can be determined using the following equation.

$$t = 8{,}197\ \mu detik;$$

$$E_{t=8{,}197} = e_{t=8} + \left(\frac{e_{t=10} - e_{t=8}}{2}\right)\Delta t$$

$$E_{t=8{,}197} = 198{,}8 + \left(\frac{262{,}45 - 198{,}8}{2}\right) \times 0{,}197$$

$$E_{t=8{,}197} = 205{,}069\ [kV]$$

3.7 Determination of Maximum Distance for Arresters and Power Transformers

A surge or lightning strike can cause a voltage spike in the transformer. This is caused by induced voltage that occurs when lightning causes a sudden change in the electromagnetic field around the transformer. These voltage spikes can damage electrical equipment connected to the transformer and even disrupt the entire electrical system. The voltage rise value on the transformer is calculated based on time in μsec, starting from 0 - 10 μsec. Later, the value of the voltage rise on the transformer will be used to determine the protective distance between the surge arrester and the transformer.

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This value is calculated as follows,

t = 0 µdetik; $e_{t=0} = 0$
t = 2 µdetik; $e_{t=2} = 0$
t = 4 µdetik; $e_{t=4} = e_{t=2} + 2a^1/10^0 = 0 + 2 \times 74{,}3^1/10^0 = 148{,}6\ [kV]$
t = 6 µdetik; $e_{t=6} = e_{t=4} = 148{,}6\ [kV]$
t = 8 µdetik; $e_{t=8} = e_{t=6} + 2\alpha^3/10^4 = 148{,}6 + 2 \times 74{,}3^3/10^0 = 230{,}63\ [kV]$
t = 10 µdetik; $e_{t=10} = e_{t=8} = 148{,}6\ [kV]$
t = 10 + Δt µdetik

$$e_{t=10{,}197} = e_{t=10} + (\frac{e_{t=10}+\alpha^5/10^8-e_{t=6}}{2})\ \Delta t = 148{,}6 + (\frac{148{,}6+74{,}3^5/10^8-148{,}6}{2}) \times 0{,}197$$

$$e_{t=10{,}197} = 150{,}83\ [kV]$$

The protective distance of the surge arrester to the power transformer can be determined using the following equation,

$$S = (E_A - E_T)\frac{V}{2A}$$

$$S = (205{,}069 - 150{,}83) \times \frac{300}{2 \times 100}$$

$$S = 8{,}135\ [m]$$

Based on actual data in the field, the percentage error in the protection distance is,

$$\%Error = \left|\frac{Actual\ Distance - Calculated\ Distance}{Actual\ Distance}\right| \times 100\%$$

$$\%Error = \left[\frac{8\ [m] - 8{,}135\ [m]}{8\ [m]}\right] \times 100\% = 1{,}68\%$$

3.8 Insulator Breakdown Voltage in Air

The amount of voltage that arises on the transmission insulator depends on the two lightning parameters, namely the peak and the steepness of the lightning wave front. Not all lightning strikes can result in a flashover on the insulator because it also depends on the amount of voltage that arises and does not exceed the breakdown voltage of the insulator ($V_{50\%}$). To determine the breakdown voltage, the following equation is used.

$$E_{50\%} = \left(K_1 + \frac{K_2}{\Delta t^{0,75}}\right) \times 10^3$$

$$E_{50\%} = \left(0{,}3 \times 1{,}5 + \frac{0{,}7 \times 1{,}5}{0{,}197^{0,75}}\right) \times 10^3$$

$$E_{50\%} = 572\ [kV]$$

Nominal discharge current is a current with a certain peak value and wave shape which is used to determine the class of arrester according to its current capability and protective characteristics. The discharge current in a traveling wave event can be determined using the following equation.

$$I_a = \frac{2E_{50\%} - E_a}{Z_1}$$

$$I_a = \frac{2 \times 572 - 205{,}069}{517{,}831} = 1{,}81\ [kA]$$

3.9 Protection Factor of Surge Arrester (FP)

The lightning arrester protection factor for power transformers can be determined using the following equation.

$$FP(\%) = \frac{BIL - Protection\ Level\ of\ Surge\ Arrester}{BIL} \times 100\%$$

$$= \frac{500-(205{,}069+205{,}069\times 10\%)}{500} \times 100\%$$

$$= 54{,}8\%$$

From the results of the analysis that has been carried out, the distance between the surge arrester and the installed 60 MVA power transformer is 8 m, while from the calculation results it is 8.135 m. Based on SPLN 7: 1978 [17], for a 150 kV system the distance between the surge arrester and transformer does not exceed 34 m. The distance between the surge arrester and the 60 MVA power transformer is still within the limits set by PT. PLN. Then, the voltage increase that occurs on the transformer is still below the BIL, thus it can be determined that the equipment can still be protected by a lighting arrester because the installation is still below the maximum price or has not exceeded the BIL standard. Judging from the effect of distance on the abnormal voltage reaching the power transformer, the closer the distance, the better the surge arrester protection effect, because the less voltage reaches the surge arrester.

4. CONCLUSION

Based on the results of the analysis and discussion, it can be concluded that the protective distance of the surge arrester for the 60 MVA West Surabaya main substation power transformer unit meets the standards. It is calculated that the maximum distance between the surge arrester and the power transformer is 8,135 meters, while the distance between the surge arrester in the field and the power transformer is 8 meters, so the placement of the surge arrester in the West Surabaya main substation is optimal to protect against lightning strikes. Power transformers are not affected by surge waves and surge currents because the voltage increase that occurs on the transformer is still below the BIL with a value of 650 kV, whereas based on calculations the voltage surge is only 150,83 kV, so it is certain that the equipment can still be protected by a surge arrester because the installation is still below the maximum value or not exceeding the BIL standard.

REFERENCE

[1] Widagdo, R. S., & Andriawan, A. H. (2023). Analysis of Losses Due to Load Unbalance in a 2000 kVA Transformer at Supermall Mansion 2 Tower Tanglin Surabaya. *Journal of Engineering and Scientific Research*, *5*(2), 78-84.

[2] Widagdo, R. S., & Andriawan, A. H. (2023). Prediction of Age Loss on 160 KVA Transformer PT. PLN ULP Kenjeran Surabaya using The Linear Regression Method. *Jurnal Riset Rekayasa Elektro*, *5*(2), 83-92.

[3] Marlanfar, M., Yusmartato, Y., Yusniati, Y., & Pelawi, Z. (2020). Analisa Penempatan Lightning Arester Pada Gardu Induk Tanjung Morawa. *Buletin Utama Teknik*, *15*(3), 229-233.

[4] Ridal, Y. (2022). Studi Analisis Kemampuan Lightning Arrester Sebagai Proteksi Transformator Daya pada Gardu Induk Padang Luar ULTG Bukit Tinggi. *Jurnal Teknik Industri Terintegrasi (JUTIN)*, *5*(2), 270-275.

[5] Manihuruk, J., Simorangkir, T., & Sitanggang, N. L. (2021). Studi Kemampuan Arrester Untuk Pengaman Transformator Pada Gardu Induk Tanjung Morawa 150 KV. *Jurnal ELPOTECS*, *4*(1), 16-25.

[6] Asna, I. M., Suriana, I. W., Sugarayasa, I. W., Sutama, W., Pancane, I. W. D., Adrama, I. N. G., & Sariana, I. M. (2021). Analisis Konstruksi Posisi Lightning Arrester Di Gardu Distribusi Km 0003 Penyulang Subagan Wilayah Kerja PT PLN (Persero) ULP Karangasem. *Jurnal Ilmiah Telsinas Elektro, Sipil dan Teknik Informasi*, *4*(1), 46-55.

[7] Azis, A., & Alimin Nurdin, H.). Analisa Jarak Lindung Lighting Arrester Terhadap Transformator Daya 20 Mva Gardu Induk Sungai Juaro Palembang. *TEKNIKA: Jurnal Teknik*, *7*(1), 106-120.

[8] Zainuddin, M., & Bima, L. (2023). Jarak Penempatan Lightning Arrester sebagai Pelindung Transformator terhadap Tegangan Lebih pada Gardu Induk 150 Kv Harapan Baru. *Mutiara: Jurnal Ilmiah Multidisiplin Indonesia*, *1*(2), 164-185.

[9] Wirawan, H. Y., Al-Amin, M. S., & Emidiana, E. (2021). Kemampuan Arrester Sebagai Pengaman Transformator. *Jurnal Tekno*, *18*(1), 72-78.

[10] Rao, M. M., Lanjewar, A., & Tiwari, N. (2022). Analytical and experimental studies on 245 kV gas insulated surge arrester. *Electric Power Systems Research*, *204*, 107713.

.

[11] Shariatinasab, R., & Azimi, R. (2020). A methodology for optimal design of transmission lines to protection against lightning surges in presence of arresters. *Advanced Electromagnetics*, *9*(1), 105-110.

[12] Boumous, S., Boumous, Z., Latréche, S., & Nouri, H. (2023). Influence of the lightning arrester position on protection of the 220KV Overhead transmission line. *Przeglad Elektrotechniczny*, *99*(5).

[13] Castro, W. S., Lopes, I. J., Missé, S. L., & Vasconcelos, J. A. (2022). Optimal placement of surge arresters for transmission lines lightning performance improvement. *Electric Power Systems Research*, *202*, 107583.

[14] Datsios, Z. G., Mikropoulos, P. N., Tsovilis, T. E., Thalassinakis, E., & Pagonis, G. (2022). Investigation of line surge arresters application to the 150 kV system of Rhodes. *Electric Power Systems Research*, *213*, 108763.

[15] Olesz, M., Litzbarski, L. S., & Redlarski, G. (2023). Leakage Current Measurements of Surge Arresters. *Energies*, *16*(18), 6480.

[16] Visacro, S., Silveira, F. H., Pereira, B., & Gomes, R. M. (2020). Constraints on the use of surge arresters for improving the backflashover rate of transmission lines. *Electric Power Systems Research*, *180*, 106064.

[17] Handoko, S. R. (2023). Analisa Peralatan Lightning Arrester Pada Gardu Induk 150 kV PLTU Rembang. *JETI (Jurnal Elektro dan Teknologi Informasi)*, *2*(1), 17-21.