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Calculation of Transmission Lines and Electrical Equipment of 150 kV Main Guluk-Guluk Madura Island East Java, Indonesia

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ABSTRACT

Guluk-Guluk is supplied by a 20 kV system from the Pamekasan GI and Sumenep GI, resulting in a voltage drop of 5 kV. The fall in the voltage on the load side cannot be overcome through the regulation of transformer tapping or the use of bank capacitors, so the possible way is to build a new GI. The construction of GI Guluk-Guluk requires a new transmission line. A good electric power transmission has a low voltage drop, high efficiency and high surge impedance loading (SIL) values. Efforts to improve the voltage by changing the tapping in the power transformer located at the nearest substation only produce a voltage of 166.07 kV. The provision of bank capacitors in Guluk-Guluk produces a voltage of 17,542 kV. The construction of GI Guluk-Guluk requires a new transmission line that connects Pamekasan to Guluk-Guluk, Sampang to Guluk-Guluk and Guluk-Guluk to Sumenep. The construction of a 150 kV network line requires calculations to determine network configurations, conductors, isolators, tower types, and electrical equipment supporting 150 kV transmission systems such as current transformers, voltage transformers, power breakers, and arresters. In this final project, simulation is done with the help of ETAP 12.6 software. The results of calculations and simulations of the transmission line toward Guluk-Guluk give a voltage drop of 4.89 kV, with an efficiency level of 96.74% and a SIL value of 41.225 MW. so these results are sufficient to be used as a reference for GI development in Guluk-Guluk.

Key Words: *Transmission lines, Substation, High voltage equipment, High Voltage Electrical power system, ETAP 12.6.*

1. INTRODUCTION

Transmission and distribution in Madura, especially the Guluk-Guluk area of Sumenep Regency, experienced problems due to the use of a 20 kV system for transmitting electrical energy to the area, resulting in a fairly high voltage drop in the area [1].

In overcoming the stress drop in the Guluk-Guluk area, PT. PLN has made several maneuvers, namely by adjusting the transformer tapping and providing 3 capacitor banks each 1 x 25 MVAR and 1 x 25 MVAR installed on the Pamekasan bus, as well as 1 x 50 MVAR installed on the Sumenep bus [2]. However, the efforts to maneuver PT. PLN is not sufficient to overcome the voltage drop that occurred in the Guluk-Guluk area. So a possible solution is the development of an electric power system, one of which is the construction of substations [3]. The substation development is expected to be able to overcome the stress drop in Guluk-Guluk as well as the demand for additional energy needs.

Substation requires several electrical equipment in order to carry out the process of distributing electric power and become a connection for electricity from the transmission network to the distribution network [4]. Some of these electrical equipment are: conductors, arresters, isolators, circuit breakers (CB), current transformers (CT), and capacitor voltage transormators (CVT) [5]. So it is necessary to evaluate the transmission line planning and electrical equipment for the 150 kV Guluk Guluk substation.

2. METHODOLOGY

In this research, the discussion carried out is the calculation of transmission lines and electrical equipment for the 150 kV Guluk Guluk substation as a solution to the problem of high voltage drop in the Guluk - Guluk area. Some of the evaluations carried out include line configuration, tower configuration, conductors, current transformers (CT), potential transformers (PT), circuit breaker (CB), the insulator and its arrester placement. The values obtained will then be evaluated whether they are in accordance with PLN standards, can be applied reliably, and have good economic value.

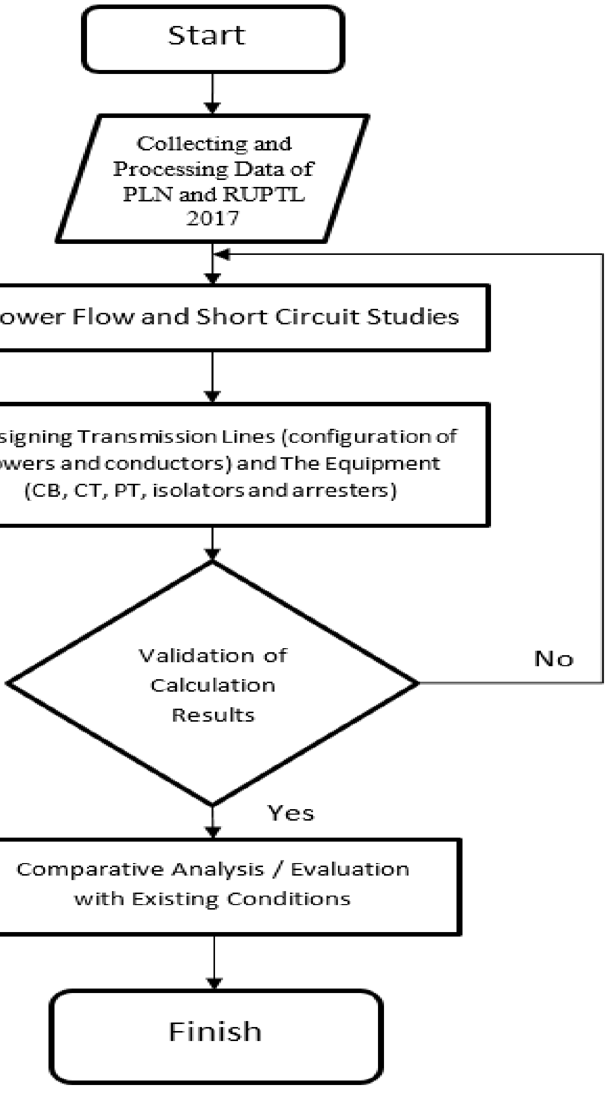

Figure 1: Flowchart

2.1 Transmission Line Design

2.1.1 Determination of Transmission Line Configuration

Determination of the effective and efficient transmission line refers to the lowest voltage drop and losses in the Guluk-Guluk area by simulating the power flow of each of the Madura electrical system configurations [6].

In this power flow analysis using 4 configurations, these four configurations are designed based on a new 150 kV network configuration which allows for the addition of a new substation, namely the 150 kV Guluk Guluk substation, because the Guluk Guluk area is located between Pamekasan and the Sumenep area is located in the tip of the island of Madura. So that the four configurations are the most likely configurations for transmission network construction.

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2.1.2 Design of Transmission Tower

Designing a tower is done by selecting the type of tower, the configuration of the tower based on the phase location, determining the appropriate conductor by taking into account the voltage drop, surge impedance loading (SIL), and line efficiency and paying attention to the location to be built the tower / tower [1].

Selection of the type of transmission tower is based on the location of the tower construction, according to its construction there are 2 types of towers, namely: lattice tower and pole tower [3]. The choice of tower type also considers the number of circuits to be energized, using equation [7]:

$$I = \frac{S}{\sqrt{3}\,Vll} \tag{1}$$

where:

S = apparent power (MVA)
I = nominal current (A)
V_{LL} = line-line voltage (kV)

For tower configuration based on phase location and number of circuits in Indonesia, it is divided into 2 [1], namely delta construction using 1 circuit with a horizontal phase location and pyramid construction using 2 circuits with the phases installed in a vertical parallel arrangement.

2.2 Determination Conductor Size

The choice of conductor type is based on the current conductive strength (KHA), the type of conductor and its compatibility with the tower / tower. The selection of current conductive strength is based on the nominal current flowing in the conductor using equation [8]:

$$I = \frac{S}{\sqrt{3}\,Vll} \tag{2}$$

where:

S = apparent power (MVA)
I = nominal current (A)
V_{LL} = line-line voltage (kV)

2.3 Line Constants

After knowing the configuration of the tower and the conductor used, it is possible to find the Z line based on the tower configuration by looking for the resistance (R) and reactance (X) values. To find the value of resistance (R) you can use equation [8]:

$$R = \frac{\rho\, x\, l}{A} \tag{3}$$

where:

R = resistance (ohm)
ρ = conductor resistance (ohm.m)
l = conductor length (m)
A = area of conductor (m^2)

Meanwhile, to find the value of reactance (X) can use equation [9]:

$$X_L = 2\pi f L \text{ (ohm/km)} \tag{4}$$

$$L = 2.10^{-7} \log\frac{GMD}{GMR} \text{ (H/m)} \tag{5}$$

where:

X_L = inductive reactance (ohms/km)
F = system frequency (Hz)
L = inductance (H/m)
GMD = geometric mean distance
GMR = geometric mean radius

For GMR and GMD values on a double circuit with 3 phases, it can be found by equation [9]:

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$$GMD = \sqrt[3]{Dab\ x\ Dbc\ x\ Dac} \quad (6)$$

$$GMR = (ds^3\ x\ Daa'\ x\ Dbb'\ x\ Dcc')^{\frac{1}{6}} \quad (7)$$

where:

Dxy = the distance from conductor x to conductor y

2.4 Line Effectiveness

To determine the level of efficiency of the tower, it is necessary to calculate the voltage drop, surge impedance loading (SIL) and line efficiency using equation [1]:

- Drop Voltage

$$\Delta V = \sqrt{3}\ x\ I\ x\ (R + jX)\ x\ cos\ \theta \quad (8)$$

where:

ΔV = drop voltage (kV)
I = current (A)
R = resistance (ohm)
X = reactance (ohm)
cos θ = power factor

- Surge Impedance Loading (SIL)

$$Pr = Pn = \frac{|V|^2}{Zo} \quad (9)$$

As for calculating the impedance value using the following equation [10]:

- Tower arm impedance

$$Zak = 60\ \ln(\frac{2h}{Ra}) \quad (10)$$

- Tower surge Impedance

$$Zak = 60 ln\sqrt{2}\frac{2h}{Ra} - 1 \quad (11)$$

where:

Zak = tower arm impedance/surge tower
h = height
r_A = distance between tower arms (m)
Pr = received power (MW)
Pn = natural power or SIL (MW)
Vr = receive voltage (kV)
Zo = surge impedance (ohms)
L = inductance (H)
C = capacitance (F)

- Line efficiency

$$\mu = \frac{Pr}{Ps} x\ 100\% \quad (12)$$

where:

μ = line efficiency
Ps = power sent by the source
= $\sqrt{3}\,.\,Vll(s).\,I(s)\ cos\ \theta(s)$
Pr = power received
= $\sqrt{3}\,.\,Vll(r).\,I(r)\ cos\ \theta(r)$

2.5 Determination of CT and PT

To determine the primary side of the CT using the calculation of the nominal current flowing on the CT. The nominal current flowing on the CT is the same as the nominal current flowing in the conductor, using equation [7]:

$$Inom = \frac{S}{\sqrt{3}\ Vll} \quad (13)$$

$$I_{CT} = Inom$$

where:

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S = apparent power (MVA)
Inom = nominal current (A)
Vll = line-line voltage (kV)
I_{CT} = primary side current of the CT

Meanwhile, to determine the primary side of the PT based on the system voltage.

$$I_{PT} = \frac{Vll}{\sqrt{3}} \tag{14}$$

where:
I_{PT} = voltage on the primary side PT (kV)
Vll = line-line voltage (kV)

Determine the secondary side of CT and PT based on the connected equipment (measuring device and protection device) on the output side of the current transformer (CT) and the potential transformer (PT).

2.6 Determination of the Number of Isolator

Isolators on the transmission line are used to support the conductors on the transmission tower. To determine the number of insulators based on the number of each plate that makes up the insulator. For each plate the insulator usually has the ability to withstand voltage (kV), so we get the equation [11]:

$$Jumlah\ Isolator = \frac{V}{X} \tag{15}$$

where:
V = system working voltage (kV)
X = the ability to hold 1 insulator plate (kV)

2.7 Determination of Arrester Capacity

The selection of lightning arresters is intended to obtain a basic insulation level in accordance with the Basic Insulation Level (BIL) of the equipment being protected. In this study, the protected equipment is a Transformer with a BIL value of 650 kV, to determine the location of the arrester placement. So that you get good and appropriate protection [12].

- Arrester rated voltage [5]

$$Ea = Vll\ x\ 110\%\ x\ grounding\ coefficient \tag{16}$$

$$grounding\ coefficient = \frac{Vm(l-g)}{Vrms} \tag{17}$$

$$Vm(l-g) = \frac{Vm}{\sqrt{3}} \tag{18}$$

$$Vrms = \frac{Vm}{\sqrt{2}} \tag{19}$$

where:
Ea = arrester working voltage (kV)
Vll = system voltage (kV)

- Arrester Placement [5]

$$Ep = Ea + \frac{2AS}{V} \tag{20}$$

$$S = \frac{1}{2}\frac{(Ep-Ea)V}{A} \tag{21}$$

where:
Ep = protected equipment rated voltage (kV)
Ea = arrester working voltage (kV)
A = wave steepness (kV / µs)
v = wave velocity 300 m / µs

- Protection Levels and Protection Factors of Arrester [5]

$$TP = Ea + 10\%\ x\ Ea \tag{22}$$

$$FP = BIL\ Arrester - TP \tag{23}$$

where:
TP = protection level
Ea = arrester working voltage (kV)
FP = protection factor

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Generally protection is considered good when FP> 20% of the TID equipment is protected.

2.8 Determination of CB Capacity

To determine the breaking capacity, it is taken from the highest short circuit current from the simulation results of all the disturbances.

Meanwhile, to determine the withstand capacity, it is seen based on the working time of the relay and the working time of the CB.

$$Withstand\ cap = rele\ working\ time + CB\ working\ time$$

The determination of breaking capacity and withstand capacity is carried out by testing the results using star-protection device coordination available in the ETAP 12.6 software as shown in Figure 3.20 and using the thermal capability equation [1]:

$$W = I^2Rt \quad (24)$$

where:

W = energy (watt)
R = resistance (ohm)
I = current (A)
t = time (s)

If the CB thermal capability value from PT. PLN> CB thermal capability from the calculation results, the CB capacity provided by PT. PLN is in line.

3. RESULT AND ANALYSIS

3.1 Transmission Line Configuration Selection

Based on the power flow analysis with the help of ETAP 12.6 software to determine the voltage drop of each line configuration option, the results of the analysis are shown in table 1.

Table 1: Comparison of voltage drop across all transmission line configurations

No	Transmission Line Configuration	Voltage Drop (kV)
1	Opsi 1	12.375
2	Opsi 2	12.48
3	Opsi 3	13.75
4	Opsi 4	9.435

It can be observed in table 1 that the voltage drop in the transmission line configuration of option 4 is the smallest compared to the other options, which is 9,435 kV. So that the option 4 transmission line configuration is the most effective and most efficient.

For the configuration used by PT. PLN Persero using the configuration as in option 4. So that the results of PT. PLN Persero is appropriate to use the most effective and efficient transmission line configuration.

3.2 Selection of Tower Types

Based on the construction location in the Guluk Guluk area, it is found that the construction site is large, so the tower to be built is a lattice tower type with a vertical parallel phase configuration, because according to SPLN the reliability of 2N-1 so that at least the transmission line uses 2 energized circuits.

3.3 Selection of Number and Size of Conductors

For the determination of the number and size of conductors based on the calculation of the nominal current in the line. The following is the calculation of the flow in the Pamekasan - Guluk Guluk 2 line.

$$I = \frac{60 \ x \ 10^6}{\sqrt{3} \ x \ 150 \ x \ 10^3} = 230{,}94\ A$$

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Table 2: Calculation of the flow of the transmission line

Line	Current (A)
Sampang 1 – Guluk Guluk 1	461.88 A
Pamekasan – Guluk Guluk 2	230.94 A
Guluk Guluk 1 – Sumenep	230.94 A
Guluk Guluk 2 - Sumenep	230.94 A

According to the standards of the state electricity company (SPLN) 41-7: 1981 for aluminum Conductor Steel Reinforced with a minimum cross-sectional area of 240 mm2 (ACSR 240/40). The current conductive strength of the ACSR with a cross-sectional area of 240 mm2 is 638 A, so that all these lines for the size of the conductor can be replaced by the PLN standard, namely conductors with a cross-sectional area of 240 mm2.

For the number of bundle conductors used is one (n = 1), because using 1 bundle conductor can deliver power properly. However, this is not in accordance with what is used by PT PLN. In the conductor configuration, PT. PLN uses 2 bundles, this is done by PT. PLN deals with power distribution capacity and load estimates for the next 10 years. For all PT lines. PLN uses the type of conductor OHL-150 kV Hawk 1x240 mm2.

3.4 Line Impedance

3.4.1 Resistance

Based on data from the characteristics of Aluminum Cable Steel Reinforced, the resistance value of the OHL-150 kV HAWK 1x240 is 0.1342 ohm / km.

3.4.2 Reactance

To calculate the reactance using the GMD and GMR analysis:

a. Geometric Mean Distance (GMD)

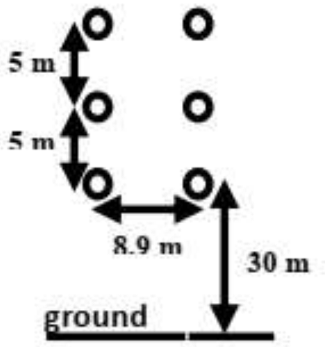

Figure 2: Conductor Configuration

where:

$dab = dbc = da'b' = db'c' = 5\,m$

$dab' = dba' = dcb' = dbc' = \sqrt{5^2 + 8.9^2} = 10.208\,m$

$daa' = dcc' = \sqrt{10^2 + 8.9^2} = 13.387\,m$

$dbb' = dac' = dca' = 8.9\,m$

Then the geometric mean distance (GMD):

$Dab = \sqrt[4]{dab\ x\ dab'\ x\ da'b\ x\ da'b'}$

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$= \sqrt[4]{5\ x\ 10.208\ x\ 10.208\ x\ 5} = 7.1443\ m$

$Dbc = \sqrt[4]{dbc\ x\ dbc'\ x\ db'c\ x\ db'c'}$

$= \sqrt[4]{5\ x\ 10.208\ x\ 10.208\ x\ 5} = 7.1443\ m$

$Dca = \sqrt[4]{dca\ x\ dca'\ x\ dc'a\ x\ dc'a'}$

$= \sqrt[4]{10\ x\ 8.9\ x\ 8.9\ x\ 10} = 9.434\ m$

$GMD = \sqrt[3]{Dab\ x\ Dbc\ x\ Dca}$

$= \sqrt[3]{7.1443\ x\ 7.1443\ x\ 9.434} = 7.838\ m$

While the value of geometric mean radius (GMR):

ds = 0.0289

position aa' = position cc' = $\sqrt{13.387\ x\ 0.0289} = 0.622$

position bb' = $\sqrt{8.9\ x\ 0.0289} = 0.5071$

$GMR = \sqrt[3]{Daa'\ x\ Dbb'\ x\ Dcc'}$

$= \sqrt[3]{0.622\ x\ 0.5071\ x\ 0.622} = 0.581$

For the inductance value (L)

$$L = 2\ x\ 10^{-7} ln \frac{GMD}{GMR}$$

$$L = 2\ x\ 10^{-7} ln \frac{7.838}{0.581} = 5.204\ x\ 10^{-7} ohm/m$$

Reactance value (X_L)

$XL = 2\pi f L$

$XL = 2\pi\ x\ 50\ x\ 5.204\ x\ 10^{-7} = 0.1634\ ohm/km$

These results are not in accordance with the PLN data, where the PLN impedance is 0.137 + 0.397 ohm / km, this is because the GMD and GMR calculations use a 1 bundle configuration and there are other factors that are not reviewed.

3.5 Line Effectiveness

3.5.1 Line Efficiency

The line efficiency is calculated by comparing the power received (Pr) with the power delivered (Ps). For the efficiency of the Pamekasan - Guluk Guluk 2 line with Pr = 53,152 MW and Ps = 54 MW.

Efficiency (µ) $= \frac{Pr}{Ps} x\ 100\%$

$$= \frac{53.152}{54}\ x\ 100\% = 98.43\%$$

Table 3: Calculation of the efficiency of all lines

No	Line	Voltage Drop (kV)
1	Sampang 1 – Guluk Guluk 1	93.944
2	Guluk Guluk 1 – Sumenep	98.873
3	Pamekasan – Guluk Guluk 2	98.4300
4	Guluk Guluk 2 - Sumenep	98.973

3.5.2 Voltage Drop (kV)

The line voltage drop is based on the impedance of each line. For the calculation of the impedance of the Pamekasan - Guluk Guluk 2 line:

Z conductor = (0.1342 + j0.1634)

Z line = (3.736128 + j4.55); line length 27.84 km

ΔV $= \sqrt{3}\ x\ I\ x\ (R + jX)\ x\ cos\ \theta$

$= \sqrt{3}\ x\ 230.94\ A\ x\ (3.736128 + j4.55) x\ 0.9$

$= 2.355\ kV$

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Table 4: Result of the voltage drop

No	Line	Voltage Drop (kV)
1	Sampang 1 – Guluk Guluk 1	9.0837
2	Guluk Guluk 1 – Sumenep	1.54
3	Pamekasan – Guluk Guluk 2	2.355
4	Guluk Guluk 2 - Sumenep	1.54

3.5.3 Surge Impedance Loading (SIL)

The SIL calculation value is based on the received voltage and surge impedance. To determine the SIL value on the Pamekasan - Guluk Guluk 2 line with the received voltage value (Vr) = 147,645 kV with the surge impedance as follows:

For the high value of the phase R (h) = 40 m and the radius of the conductor (r) = 0.010795 mm2. Then the surge impedance value (Zo):

$$Zo = 60 \ln \frac{2h}{r}$$

$$Zo = 60 \ln \frac{2.40\ m}{0.010795}$$

$$= 534.642\ ohm$$

Then the SIL value of the Pamekasan - Guluk Guluk 2 line:

$$SIL = \frac{|V|^2}{Zo}$$

$$= \frac{147.645^2}{534.642}$$

$$= 40.773 \text{ MW}$$

Table 5: Result of the SIL

No	Line	SIL (MW)
1	Sampang 1 – Guluk Guluk 1	37.1415
2	Guluk Guluk 1 – Sumenep	41.225
3	Pamekasan – Guluk Guluk 2	40.773
4	Guluk Guluk 2 - Sumenep	41.225

3.6 Determine the ratio of CT and PT

3.6.1 CT Ratio

In determining the CT ratio, the nominal current is used as the determination of the CT ratio for the primary side, while for the secondary side it is based on the measuring equipment. Can be seen in the table. 1 for the calculation of the nominal current on the line, the CT ratio according to those sold in the market is as follows:

Table 6: CT ratio for all lines

No	Line	CT Ratio	
		Primary	Secondary
1	Sampang 1 – Guluk Guluk 1	500	5/1
2	Guluk Guluk 1 – Sumenep	250	5/1
3	Pamekasan – Guluk Guluk 2	250	5/1
4	Guluk Guluk 2 - Sumenep	250	5/1

The CT ratio value is in accordance with that used by PLN, which has been installed on all lines.

3.6.2 PT Ratio

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Determine the PT ratio based on the working voltage of the electrical system. The working voltage at Pamekasan - Guluk Guluk 2 is 150 kV. hence the PT ratio of the line is $\frac{150\ kV}{\sqrt{3}}$, because PT is attached to each phase.

Table 7: PT ratio for all lines

No	Line	SIL (MW)	
		Primary	Secondary
1	Sampang 1 – Guluk Guluk 1	$150\sqrt{3}$	Adjust
2	Guluk Guluk 1 – Sumenep	$150\sqrt{3}$	Adjust
3	Pamekasan – Guluk Guluk 2	$150\sqrt{3}$	Adjust
4	Guluk Guluk 2 - Sumenep	$150\sqrt{3}$	adjust

The value of the PT ratio is in accordance with that used by PLN, which has been installed on all lines.

3.7 Calculation of the Number of Isolators

To determine the number of interlocking isolators, a working voltage and withstanding strength are required for 1 insulator. This transmission line uses a working voltage of 150 kV with a maximum voltage of 165 kV (110%), while the holding capacity for 1 insulator is 15 kV.

$$Number\ of\ Insulator = \frac{V}{X}$$
$$= \frac{150\ kV + 15\ kV}{15\ kV}$$
$$= 11$$

3.8 Determine Arrester Capacity

In this study determine the rated voltage of the arrester, the placement of the arrester and the level of protection along with the protection factor.

3.8.1 Rated Voltage (Ea)

$$Ea = Vll\ x\ 110\%\ x\ grounding\ coefficient$$
$$Vm\ (L-G) = \frac{Vm}{\sqrt{3}} = \frac{110\%\ x\ 150\ kV}{\sqrt{3}} = 95.2628\ kV$$
$$Vrms = \frac{Vm}{\sqrt{2}} = \frac{110\%\ x\ 150\ kV}{\sqrt{2}} = 116.672\ kV$$
$$grounding\ coefficient = \frac{Vm(lg)}{Vrms} = \frac{95.2628}{116.672} = 0.8165$$

Then the rated voltage of the arrester:

$$Ea = Vll\ x\ 110\%\ x\ grounding\ coefficient$$
$$= 150\ x\ 110\%\ x\ 0.8165$$
$$= 134.7225\ kV$$

From the table regarding the data for determining the isolation of transformers and arresters, the rated voltage close to the above values is 138 kV.

3.8.2 Arrester Placement

To determine the location of the arrester placement required BIL of the protected equipment, namely the transformer and the value of the incident wave steepness. In this study, the BIL of the transformer is 650 kV, based on the table regarding the maximum value of the lightning wave overvoltage price for the arrester with a rating of 138 kV, the value of the wave steepness level is 1030 kV / µs. Then the location of the arrester placement is as follows:

$$S = \frac{1}{2}\frac{(Ep-Ea)V}{A}$$
$$= \frac{1}{2}\frac{(650-460)x\ 300}{1030}$$
$$= 27.67\ m$$

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The minimum distance between the placement of the arrester and the transformer (protected equipment) is 27.67 m before the said equipment. So that the transformer will be safe from disturbance of surges.

3.8.3 Protection Level and Arrester Protection Factor

To find out whether the selection of the rated voltage of the arrester is appropriate or not, by calculating the level and protection factor of the arrester. For the calculation of the protection level (TP) arrester as follows:

TP = Ea + 10% x Ea
= 460 kV +10% x 460 kV
= 506 kV

As for the protection factor (FP) of the arrester:
FP = BIL arrester – TP
= 750 kV – 506 kV
= 244 kV

To find out whether the rated voltage of the arrester is appropriate or not, it can be seen by looking at the FP value that must be greater than 20% of the BIL equipment.
FP > 20% BIL equipment
244 kV > 20% 650 kV
244 kV > 130 kV

From the above calculation, the FP value> 20% of the BIL equipment, namely 244 kV> 130 kV. Then the selection of the 138 kV arrester rated voltage is correct.

3.9 Determine the Capacity of the Circuit Breaker (CB)

In this study, determine the breaking capacity and withstand capacity of the circuit breaker (CB).

3.9.1 Breaking Capacity

For the determination of breaking capacity using a short circuit simulation with the fault located in the working area of the CB. Determination of breaking capacity based on the largest fault current.

Table 8: Short circuit current

No	Line	Ihs (kA)
1	Sampang 1 – Guluk Guluk 1	3.1
2	Pamekasan – Guluk Guluk 2	3.4
3	Guluk Guluk 1 – Sumenep (1km)	3.4
4	Guluk Guluk 2 – Sumenep (1km)	3.1
5	Trafo Bay 150/220 kV	3.1

It can be seen in the table for the short circuit current value. So the minimum breaking capacity in the CB is the Ihs value, for example the breaking capacity value in the CB on the Pamekasan - Guluk Guluk 2 line is 3.4 kA.

However, in the market the available breaking capacities are 12.5 kA, 16 kA, 20 kA, 25 kA, 31.5 kA and 40 kA. The breaking capacity determination also considers the withstand capacity of each CB.

3.9.2 Withstand Capacity

In determining the withstand capacity, it is influenced by the relay working time. For CB25, CB26, CB27 and CB28 the working time is the rele distance from my colleague's research (Indah), while for CB29 it is based on the working time of the OCR / GFR relay from my colleague's research (Rama). Rele distance working time:
Zone 1: 0 s
Zone 2: 0.4 s
Zone 3: 1.6 s
OCR / GFR relay working time:
Overcurrent: 0.3155 s

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Soil disturbance: 0.141 s

In determining the withstand capacity CB25, CB26, CB27 and CB28 using the relay distance working time. The longest working time of the relay distance is 1.6 s, while the opening time of the circuit breaker is 0.1 s. Then the total working time needed by CB25 to solve the disturbance in the Sampang line bay is 1.7 s. For the withstand capacity on CB29 using the OCR / GFR relay working time, where the largest OCR / GFR relay working time is 0.3144 s. Then the total working time required is 0.4144 s.

Table 9: Withstand Capacity

No	CB Location	Withstand Capacity (s)
1	Sampang 1 – Guluk Guluk 1	1.7
2	Pamekasan – Guluk Guluk 2	1.7
3	Guluk Guluk 1 – Sumenep (1km)	1.7
4	Guluk Guluk 2 – Sumenep (1km)	1.7
5	Trafo Bay 150/220 kV	0.4144

To find out whether the breaking capacity and withstand capacity are selected, it is necessary to calculate the thermal capability, which is as follows:

$TC = I^2 x\ R$; where the value of R is assumed to be 1 ohm. For the circuit breaker (CB) on the Pamekasan line is 31.5 kA; 3s. then thermal capability:

$W = I^2\ x\ R\ x\ t$; with assumption R = 1 ohm

W_{PLN} = 31.5^2 kA x 1 x 3 s

= 2976.75 MW

$W_{Calculation}$ = 3.1^2 kA x 1 x 1.7 s

= 16.337 MW

The value of $W_{PLN} > W_{calculation}$, this indicates that the CB capacity on the Pamekasan line is appropriate.

Table 10: Thermal capability comparison of PT. PLN by calculation

CB Location	W_{PLN} (MW)	$W_{Calculation}$ (MW)
Sampang 1 – Guluk Guluk 1	4800	16.337
Pamekasan – Guluk Guluk 2	2976.75	19.652
Guluk Guluk 1 – Sumenep (1km)	2976.75	19.652
Guluk Guluk 2 – Sumenep (1km)	4800	16.337
Trafo Bay 150/220 kV	1600	3.982

In the table above, it can be seen that the thermal capability value of the circuit breaker in the Pamekasan - Guluk Guluk line from PLN is 2976.75 MW, while from the calculation of 19,652 MW, because the thermal capability of PLN is greater than the calculation, the circuit breaker in the Pamekasan – Guluk Guluk line already appropriate. It can be seen in table 10, for CBs that are on other lines from PLN, they also have a thermal capability that is greater than the calculation. So that CBs that are on other lines from PLN have also been completed.

4. CONCLUSION

The construction of a 150 kV Guluk Guluk substation on the island of Madura, East Java Province, has become a solution in overcoming the voltage drop that occurs in the Guluk Guluk area. The 150 kV Guluk Guluk substation gets supplies from 2 other substations, namely the Sampang and Pamekasan substations and the Guluk Guluk substation supplies from the Sumenep substation. The transmission tower used for the transmission network is a type of lattice tower with the conductor configuration is vertical parallel, while the conductor used is 1x240 mm2 ACSR conductor. The configuration of the line and transmission tower and the capacity of the electrical equipment used by PLN is in accordance with the calculation, but the reactance calculation has a different value, because the calculation uses 1 bundle of conductors while PLN uses 2 bundles.

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