
Coordination Analysis of Overcurrent Relays (OCR) and Directional Ground Relays (DGR) for Transformer Protection at Segoromadu Substation, Gresik

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ABSTRAK

Transformator merupakan komponen vital dalam penyaluran energi listrik yang rentan terhadap gangguan arus lebih dan hubung singkat, terutama pada gardu induk. Dalam penelitian ini, dilakukan analisis koordinasi Over Current Relay (OCR) dan Directional Ground Relay (DGR) untuk melindungi transformator di Gardu Induk Segoromadu, Gresik. Analisis ini bertujuan menentukan setting optimal OCR dan DGR, serta menguji keandalan proteksi menggunakan simulasi perangkat lunak ETAP 19.0.1. Pengukuran dilakukan dengan menghitung arus gangguan hubung singkat tiga fasa, dua fasa, dan satu fasa ke tanah, serta pengaturan waktu relai. Hasil simulasi menunjukkan bahwa setting yang tepat pada OCR dan DGR dapat meningkatkan keandalan dan keamanan sistem proteksi gardu induk dalam menjaga pasokan energi yang stabil. Temuan ini memberikan kontribusi penting dalam meningkatkan performa sistem proteksi dan dapat menjadi acuan untuk pengembangan sistem proteksi di gardu induk lainnya

Kata kunci: Directional Ground Relay (DGR), Over Current Relay (OCR), Proteksi, Transformator

ABSTRACT

Transformers are critical components in power distribution, vulnerable to overcurrent and short-circuit faults, particularly at substations. This study analyzes the coordination of Over Current Relay (OCR) and Directional Ground Relay (DGR) to protect transformers at the Segoromadu Substation in Gresik. The analysis aims to determine the optimal OCR and DGR settings and to test the reliability of the protection system using ETAP 19.0.1 software simulations. Measurements include calculating short-circuit fault currents for three-phase, two-phase, and single-phase-to-ground faults, as well as relay time settings. Simulation results show that accurate settings for OCR and DGR improve the reliability and safety of the substation protection system in maintaining a stable power supply. These findings contribute significantly to enhancing protection system performance and may serve as a reference for developing protection systems in other substations.

Keywords: Directional Ground Relay (DGR), Over Current Relay (OCR), Protection, Transformer

1. INTRODUCTION

The electric power distribution system is a process of sending electric power through several stages starting from the generation, transmission and distribution systems. Each stage uses equipment so that the electric power reaches consumers reliably, safely and efficiently. The components in the electric power distribution process at the substation are equipment that has an important role, one of which is a transformer or commonly called a transformer. Power transformers are one of the sensitive components in the electric energy channel and are susceptible to interference both inside and outside the transformer itself [1]. Transformers are very vital equipment in the distribution of electricity. does not rule out the possibility of interference, especially short circuits caused by excess current. This interference can be in the form of a 3-phase, 2-phase, or 1-phase to ground short circuit. The interference that occurs can be predicted, so that to prevent it, appropriate and reliable safety equipment or protection systems are needed [2]. Protection is a form of protection against equipment to avoid damage and ensure the continuity of a reliable electric power system. The protection system must be able to work to cut off the interference current that appears in the system quickly and

selectively [3]. Protection systems, in addition to securing electrical equipment against interference, also function to localize interference, thereby minimizing the impact on other parts of the system and ensuring reliable operation. Therefore, protection is very necessary in the electric power system [4].

In previous research by Dwiki Prasetyo [5], conducted an analysis on the coordination of the safety system on the 20 kV distribution network for the Orchard Tanglin apartment, discussing the comparison of the calculation of the Over Current Relay (OCR) relay operating time with the existing relay operating time settings for the 20 kV distribution network. The coordination of the OCR relay working time by calculation for the SST, SSO, MVT, MVO, and incoming PLN relays has met the coordination requirements by using a sequential relay working time margin of 0.3 seconds that the longer the network, the faster the relay working time and the smaller the fault current.

Next is a research conducted by Romadhoni Trio Imawan [6] who conducted a study on the coordination of Non-Cascade Overcurrent Relays on Power Transformer III at the 150 kV Tanggul Main Substation, Power Transformer III is equipped with an overcurrent relay protection system which aims to detect fault currents that exceed the specified current setting. This Overcurrent relay has two coordination patterns, namely cascade and non-cascade pattern coordination, with the non-cascade pattern considered more optimal because it is able to cut off faults faster. The non-cascade pattern overcurrent relay setting provides better protection on the incoming and 22kV feeder sides, because the incoming PMT works depending on the overcurrent relay time on the feeder side.

Faisal Irsan Pasaribu [7] also conducted a study on Over Current Relay Analysis in the 20 kV distribution network at PT. Pelindo 1 Belawan Branch, the study obtained calculation results with data in the field that were not in the appropriate condition (there were differences), so it can be concluded that the Over Current Relay setting value at PT. Pelindo 1 was reset, and after the reset, until now the protection relay is still in good condition. Yusmartato [8] conducted a study on the analysis of overcurrent and ground fault relays on feeders at the Lamhotma Main Substation. From his findings, calculations can be seen that the magnitude of the short circuit current is influenced by the distance of the fault point, the further the distance of the fault point, the smaller the short circuit current, and vice versa, the closer the distance of the fault point, the greater the value of the short circuit current.

So from several cases related to the coordination of the safety system, the researcher conducted a research aimed at analyzing the coordination between Overcurrent Relays (OCR) and Directional Ground Relays (DGR) in protecting transformers at the Segoromadu Substation, Gresik. Transformers are vital components in the electric power system, so reliable protection is needed to prevent damage due to overcurrent and ground faults. The methods used in this study include collecting substation technical data, simulations using power system analysis software, and evaluating coordination between relays based on applicable standards. This approach is designed to ensure that OCR and DGR can function optimally in detecting and isolating disturbances without causing unnecessary outages.

2. RESEARCH METHOD

This research focuses on evaluating the coordination of Overcurrent Relays (OCR) and Directional Ground Relays (DGR) to enhance transformer protection at the Segoromadu Substation, Gresik. Given the critical role of transformers in ensuring a stable power supply, effective protection systems are essential to mitigate potential risks from overcurrent and ground faults. The study adopts a systematic approach, including the collection of substation operational data, simulation of relay settings using advanced power system software, and a thorough analysis of relay coordination based on established protection standards. These methods aim to optimize the protection system's performance and ensure minimal disruption in case of faults.

2.1 Impedance Value

Short circuit fault current is a condition where the conductor cable touches another conductor cable or the ground. In this condition, the magnitude of the value due to the disturbance will be calculated. A short circuit fault occurs when the basic insulation between phase wires or between phase wires and the ground is compromised, leading to an overcurrent fault due to the resulting excess current. Such faults can cause significant damage to equipment and disrupt the stability of the power system if not

promptly addressed. Before calculating the fault current, the impedance value is first needed using the following equation:

a. Source Impedance

$$Z_s(\Omega) = \frac{(kV_{L-L})^2}{MVA_{SC}} \quad (1)$$

Where,

- kV_{L-L} : Base Voltage
 Z_s : Source Impedance
 MVA_{SC} : Short Circuit Current on Transformer

b. Power Transformer Impedance

$$Z_{1T} = Z_{2T} \quad (2)$$

$$Z_{0T} = 3 \times Z_{1T} \quad (3)$$

Where,

- Z_1 : Positive Sequence Impedance Transformer
 Z_2 : Negative Sequence Impedance Transformer
 Z_0 : Zero Sequence Impedance Transformer

c. Feeder Impedance

$$Z_{1f} = Z_{2f} = R_1 \times jX_1 \times L \quad (4)$$

$$Z_{0f} = R_0 \times jX_0 \times L \quad (5)$$

Where,

- Z_{1f} : Positive Sequence Impedance Feeder
 Z_{2f} : Negative Sequence Impedance Feeder
 Z_{0f} : Zero Sequence Impedance Feeder
 L : Feeder Length

d. Total Impedance

$$Z_{1total} = Z_{2total} = Z_s + Z_{1T} + Z_{1p} \quad (6)$$

$$Z_{0total} = Z_{0T} + 3Z_n + Z_{0p} \quad (7)$$

$$Z_n = \frac{R_0}{Z_{dasar}} \quad (8)$$

Where,

- Z_{1total} : Positive Sequence Total
 Z_{2total} : Negative Sequence Total
 Z_{0total} : Zero Sequence Total
 Z_n : Grounding Impedance

2.2 Short Circuit Fault Current

After calculating the impedance, the next step is to calculate the fault current using the following equation:

a. 3 Phase Short Circuit Fault

$$I_{SC} = \frac{E_\alpha}{Z_1 + Z_f} \quad (9)$$

b. 2 Phase Short Circuit Fault

$$I_{SC} = \frac{E_\alpha}{Z_1 + Z_2 + Z_f} \quad (10)$$

c. Phase-Earth Short Circuit Fault

$$I_{SC} = \frac{E_a}{Z_1 + Z_2 + Z_0 + Z_f} \quad (11)$$

Where,

- I_{hs} : Short Circuit Current
 Z_1 : Positive Sequence Impedance Total (pu)
 Z_2 : Negative Sequence Impedance Total (pu)
 Z_0 : Zero Sequence Impedance Total (pu)
 Z_f : Short Circuit Impedance
 E_a : base voltage

2.3 Over Current Relay (OCR)

Over Current Relay (OCR) is a protection device that functions to detect excess current, either due to short circuit or overload that can cause damage to equipment in the protected power system. OCR acts as the main or backup protection device. OCR is required to be able to work according to the previously set time [x]. The ability of OCR (Overcurrent Relay) to detect fault current depends on the current transformer, as it accurately measures the current flowing through the system and provides the necessary input for the relay to detect and respond to fault conditions. Furthermore, OCR can give a command to PMT to trip according to the required settings. According to British standards, the calculation of the current setting is 1,05 to 1,3 times the peak current [x].

$$I_{set\ primer} = 1,05\ s/d\ 1,3 \times I_{max}(A) \quad (12)$$

$$I_{set\ secondary} = I_{set\ primer} \frac{1}{n_{CT}} \quad (13)$$

To calculate the trip time, you can use the following equation:

$$TMS = \frac{\left[\left(\frac{I_f}{I_{set}}\right)^\alpha\right]^{-1}}{\beta} \times t \quad (14)$$

$$t = \frac{\beta}{\left[\left(\frac{I_f}{I_{set}}\right)^\alpha\right]^{-1}} \quad (15)$$

Where,

- I_{max} : Peak Current
 t : Time Set to Relay
TMS : Standard Time Settings
 I_f : Maximum Fault Current
 I_{set} : Current Set to Relay

2.4 Directional Ground Relay (DGR)

Ground fault relay, or DGR (Directional Ground Relay), works on a similar principle to OCR, but there are differences in its use. If the OCR relay detects a short circuit between phases, while the DGR detects a short circuit from phase to ground and its direction [x]. When a single-phase to ground fault occurs on the customer side connected to several feeders, analysis can be done quickly using the DGR (Directional Grounding Relay) because this relay is equipped with directional capabilities, allowing it to identify the fault's location and direction of the fault current, facilitating faster fault isolation and protection coordination. To calculate the DGR current setting, the following equation is used:

$$I_{set\ primer} = 0,06\ s/d\ 0,12 \times I_f \quad (16)$$

$$I_{set\ secondary} = I_{set\ primer} \frac{1}{n_{CT}} \quad (17)$$

To calculate the trip time, you can use the following equation:

$$TMS = \frac{\left[\left(\frac{I_f}{I_{set}}\right)^\alpha\right]^{-1}}{\beta} \times t \quad (18)$$

$$t = \frac{\beta}{\left[\left(\frac{I_f}{I_{set}}\right)^\alpha\right]^{-1}} \quad (19)$$

Dimana:

- t : Time Set to Relay
 TMS : Standart Time Settings
 I_f : Smallest Ground Fault Current
 I_{set} : Current Set to Relay

3. RESULT AND ANALYSIS

This section presents the results of the coordination analysis between Overcurrent Relays (OCR) and Directional Ground Relays (DGR) for transformer protection at the Segoromadu Substation, Gresik. The analysis focuses on assessing the effectiveness of the relay settings in detecting and isolating faults while minimizing unnecessary disruptions. The results obtained from the simulations and calculations will be discussed in detail, highlighting the impact of different relay coordination strategies on system reliability and transformer protection. This section also includes a comparison of the theoretical performance with practical outcomes, providing insights into potential improvements for the protection scheme.

3.1 Calculating Source Impedance

Based on the data obtained for the short circuit current on the 150 kV primary side bus at the Segoromadu Main Substation is 37,96 kA, the following calculation can be made:

- a. Primary Side Short Circuit 150 kV

$$\begin{aligned} MVA_{SC} &= \sqrt{3} \times kV \times I_{SC} \\ &= \sqrt{3} \times 150 \text{ kV} \times 37,96 \text{ kA} \\ &= 9862,297 \text{ MVA} \end{aligned}$$

- b. Primary Impedance

$$\begin{aligned} Z_{primer} &= \frac{kV_{(primer)}^2}{MVA_{SC}} \\ &= \frac{150^2}{9862,297} = 2,28 \Omega \end{aligned}$$

- c. Secondary Impedance

$$\begin{aligned} Z_{Sekunder} &= \frac{kV_{(sekunder)}^2}{kV_{(primer)}^2} \times X_{s(primer)} \\ &= \frac{20^2}{150^2} \times 2,28 = 0,04 \Omega \end{aligned}$$

3.2 Calculating Transformer Reactance

In the Transformer specification data, the reactance is known to be 12.408%. Furthermore, to find out the value of positive sequence reactance, negative sequence reactance, and zero sequence reactance in Ohm (Ω), it is necessary to calculate the value of Ohm (Ω) at 100%.

$$\begin{aligned}
 X_{t(100\%)} &= \frac{kV_{(secondary)}^2}{VA_{transformer}} \\
 &= \frac{20^2}{60} = 6,6 \Omega
 \end{aligned}$$

For the transformer reactance value in positive and negative sequence reactance ($X_{t1} = X_{t2}$) can be calculated as follows.

$$\begin{aligned}
 X_{t1} &= X_{t2} = \text{Transformer Reactance (\%)} \times X_{t(100\%)} \\
 &= 12,408\% \times 6,6 \Omega = 0,82 \Omega
 \end{aligned}$$

Because the transformer that supplies the feeder does not have a delta winding in its circuit, namely the YnYnO winding, so the magnitude of X_{t0} ranges from 9 to $14 \times X_{t1}$. So in this calculation the value of X_{t0} is approximately $10 \times X_{t1}$. So for the reactance value of the transformer in the zero sequence (X_{t0}) can be calculated as follows:

$$\begin{aligned}
 X_{t0} &= 10 \times X_{t1} \\
 &= 10 \times 0,82 = 8,2 \Omega
 \end{aligned}$$

3.3 Calculating Feeder Impedance

To calculate the impedance value of the feeder depends on the value of the impedance per kilometer of the feeder, where the value is determined by the configuration used for the distribution network, with impedance consisting of positive sequence impedance (Z_1), negative sequence impedance (Z_2) and zero sequence impedance (Z_0).

Tabel 1. Positive, Negative and Zero Sequence Impedance Value Data

No.	Feeder	Positive and Negative Impedance Sequence	Zero Impedance Sequence
1.	Gramitama 4	0,4866 + 0,6277j	1,4598 + 1,883j
2.	Sentolang	1,2339 + 0,4749j	3,7016 + 1,4246j
3.	Pangsud	1,5378 + 0,4466j	4,6134 + 1,3397j
4.	Gulomantung 2	1,1314 + 0,4621j	3,3943 + 1,3862j
5.	Gramitama 3	0,2922 + 0,3878j	0,8766 + 1,1634j
6.	Gramitama 2	0,2922 + 0,3878j	0,8766 + 1,1634j
7.	Gramitama 1	0,2922 + 0,3878j	0,8766 + 1,1634j

Based on Table 1, the impedance values of the feeders for positive sequence, negative sequence and zero sequence can be calculated for the fault location in the location area with a distance of 0%, 25%, 50%, 75% and 100% of the feeder length, so that the impedance value of each feeder can be calculated as follows:

- a. Positive and Negative Sequence Impedance:

$$Z_1 = Z_2 = \% \text{ feeder length} \times Z/km$$

- b. Zero Sequence Impedance:

$$Z_0 = \% \text{ feeder length} \times Z/km$$

In Table 2 below are the calculation results for the Positive Sequence Impedance, Negative Sequence Impedance, and Zero Sequence Impedance values for the fault location areas at 0%, 25%, 50%, 75%, and 100%. These values represent the impedance measurements at various points along the faulted section, providing essential data for fault analysis and protection coordination in the system. By analyzing the impedance at different fault locations, it becomes possible to determine the fault type, severity, and appropriate protective measures, ensuring the reliability and stability of the electrical network.

Table 2. Positive, Negative and Zero Sequence Impedance Data with Percentage of Feeder Length

No	Feeder	% Length	Z_1 and Z_2	Z_0
1.	Gramitama 4	0	0	0
		25	$0,1217 + 0,1569j$	$0,3649 + 0,4708j$
		50	$0,2433 + 0,3139j$	$0,7299 + 0,9415j$
		75	$0,3649 + 0,4708j$	$1,0948 + 1,4123j$
		100	$0,4866 + 0,6277j$	$1,4598 + 1,8830j$
2.	Sentolang	0	0	0
		25	$0,3085 + 0,1187j$	$0,9254 + 0,3562j$
		50	$0,6169 + 0,2375j$	$1,8508 + 0,7123j$
		75	$0,9254 + 0,3562j$	$2,7762 + 1,0685j$
		100	$1,2339 + 0,4749j$	$3,7016 + 1,4246j$
3.	Pangsud	0	0	0
		25	$0,3845 + 0,1117j$	$1,1533 + 0,3349j$
		50	$0,7689 + 0,2233j$	$2,3067 + 0,6698j$
		75	$1,1534 + 0,3349j$	$3,4601 + 1,0048j$
		100	$1,5378 + 0,4466j$	$4,6134 + 1,3397j$
4.	Gulomantung 2	0	0	0
		25	$0,2829 + 0,1155j$	$0,8486 + 0,3466j$
		50	$0,5657 + 0,2311j$	$1,6972 + 0,6931j$
		75	$0,8486 + 0,3466j$	$2,5457 + 1,0396j$
		100	$1,1314 + 0,4621j$	$3,3943 + 1,3862j$
5.	Gramitama 3	0	0	0
		25	$0,0731 + 0,0969j$	$0,2192 + 0,2909j$
		50	$0,1461 + 0,1939j$	$0,4383 + 0,5817j$
		75	$0,2192 + 0,2908j$	$0,6575 + 0,8725j$
		100	$0,2922 + 0,3878j$	$0,8766 + 1,1634j$
6.	Gramitama 2	0	0	0
		25	$0,0731 + 0,0969j$	$0,2192 + 0,2909j$
		50	$0,1461 + 0,1939j$	$0,4383 + 0,5817j$
		75	$0,2192 + 0,2909j$	$0,6575 + 0,8725j$
		100	$0,2922 + 0,3878j$	$0,8766 + 1,1634j$
7.	Gramitama 1	0	0	0
		25	$0,0731 + 0,0969j$	$0,2192 + 0,2909j$
		50	$0,1461 + 0,1939j$	$0,4383 + 0,5817j$
		75	$0,2192 + 0,2909j$	$0,6575 + 0,8726j$
		100	$0,2922 + 0,3878j$	$0,8766 + 1,1634j$

Based on the data shown in Table 2, it can be seen that the magnitude of the Positive Sequence, Negative Sequence and Zero Sequence impedance values have different impedance values depending on the length of the feeder. The further from the supply voltage, the greater the impedance value, and conversely the closer to the supply voltage, the smaller the impedance value. This impedance value will be used as a reference for calculating the equivalent impedance of the network.

3.4 Calculating Network Equivalent Impedance

The next step is to calculate the magnitude of the equivalent impedance from the point of disturbance to the source. Since the magnitude of the Positive Sequence Equivalent Impedance is equal to that of the Negative Sequence Equivalent Impedance ($Z_{1eq} = Z_{2eq}$), the following equation is applied:

$$\begin{aligned}
 Z_{1eq} = Z_{2eq} &= Z_{secondary(20\text{ kV})} + X_{t1} + Z_{1(feeder)} \\
 &= 0,04j + 0,82j + Z_{1(feeder)} \\
 &= 0,86j + Z_{1(feeder)}
 \end{aligned}$$

To calculate the value of the Zero Sequence Equivalent Impedance (Z_{0eq}) based on the neutral grounding system of the main substation, the value of the grounding resistance is 500Ω , the calculation can be done using the following equation:

$$\begin{aligned}
 Z_{0eq} &= X_{t0} + 3RN + Z_{0(feeder)} \\
 &= 8,2j + (3 \times 500) + Z_{0(feeder)} \\
 &= 8,2j + 1500 + Z_{0(feeder)}
 \end{aligned}$$

Table 3. Network Equivalent Impedance Calculation Result Data

No.	Feeder	%Length	$Z_{1eq} = Z_{2eq}$	Z_{0eq}
1.	Gramitama 4			
		0	0,86j	1500+8,2j
		25	0,1216+1,0169j	1500,3649+8,6707j
		50	0,2433+1,1738j	1500,7299+9,1415j
		75	0,3649+1,3307j	1501,0948+9,6122j
		100	0,4866+1,4877j	1501,4598+10,083j
2.	Sentolang			
		0	0,86j	1500+8,2j
		25	0,3084+0,9787j	1500,9254+8,5561j
		50	0,6169+1,0974j	1501,8508+8,9123j
		75	0,9254+1,2161j	1502,7762+9,2684j
		100	1,2339+1,3349j	1503,7016+9,6246j
3.	Pangsud			
		0	0,86j	1500+8,2j
		25	0,3844+0,9716j	1501,1533+8,5349j
		50	0,7689+1,0833j	1502,3067+8,8698j
		75	1,1533+1,1949j	1503,4600+9,2047j
		100	1,5378+1,3066j	1504,6134+9,5397j
4.	Gulomantung 2			
		0	0,86j	1500+8,2j
		25	0,2828+0,9755j	1500,8485+8,5465j
		50	0,5657+1,0910j	1501,6971+8,8931j
		75	0,8485+1,2065j	1502,5457+9,2396j
		100	1,1314+1,3221j	1503,3943+9,5862j
5.	Gramitama 3			
		0	0,86j	1500+8,2j
		25	0,0730+0,9569j	1500,2191+8,4908j
		50	0,1461+1,0539j	1500,4383+8,7817j
		75	0,2191+1,1508j	1500,6574+9,0725j
		100	0,2922+1,2478j	1500,8766+9,3634j
6.	Gramitama 2			
		0	0,86j	1500+8,2j
		25	0,0730+0,9569j	1500,2191+8,4908j
		50	0,1461+1,0539j	1500,4383+8,7817j
		75	0,2191+1,1508j	1500,6574+9,0725j
		100	0,2922+1,2478j	1500,8766+9,3634j
7.	Gramitama 1			
		0	0,86j	1500+8,2j
		25	0,0730+0,9569j	1500,2191+8,4908j
		50	0,1461+1,0539j	1500,4383+8,7817j
		75	0,2191+1,1508j	1500,6574+9,0725j
		100	0,2922+1,2478j	1500,8766+9,3634j

Based on the calculation data in Table 3, the values of Positive Sequence impedance, Negative Sequence impedance, and Zero Sequence impedance differ. These equivalent impedance values will be used in subsequent calculations to determine the magnitude of the short-circuit current. This step is crucial for accurately assessing the system's response during fault conditions.

3.5 Calculating Short Circuit Fault

a. 3-Phase Short Circuit Fault

To determine a 3-phase short circuit fault using the equation in (9), the current value can be calculated when the fault occurs at 100% of the distance along the Gramitama 4 feeder.

$$I_{SC(3-Phase)} = \frac{11547,005}{\sqrt{0,4866^2 + 1,4877^2}} = 7.377,064 \text{ A}$$

Table 4. Results of Calculation of 3 Phase Short Circuit Current for All Feeders

No.	Feeder	% Length	$Z_{1eq} = Z_2 e q$	$I_{SC(3-Phase)}$
1.	Gramitama 4			
		0	0,86j	13426,7504
		25	0,1216+1,0169j	11274,4416
		50	0,2433+1,1738j	9632,1458
		75	0,3649+1,3307j	8367,9431
		100	0,4866+1,4877j	7377,0647
2.	Sentolang			
		0	0,86j	13426,7504
		25	0,3084+0,9787j	11252,3420
		50	0,6169+1,0974j	9171,7345
		75	0,9254+1,2161j	7555,7935
		100	1,2339+1,3349j	6352,1193
3.	Pangsud			
		0	0,86j	13426,7504
		25	0,3844+0,9716j	11050,3704
		50	0,7689+1,0833j	8692,1708
		75	1,1533+1,1949j	6952,8467
		100	1,5378+1,3066j	5722,2095
6.	Gulomantung 2			
		0	0,86j	13426,7504
		25	0,2828+0,9755j	11368,4829
		50	0,5657+1,0910j	9395,5548
		75	0,8485+1,2065j	7828,0549
		100	1,1314+1,3221j	6635,7559
7.	Gramitama 3			
		0	0,86j	13426,7504
		25	0,0730+0,9569j	12031,4627
		50	0,1461+1,0539j	10852,6671
		75	0,2191+1,1508j	9856,3466
		100	0,2922+1,2478j	9010,1453
8.	Gramitama 2			
		0	0,86j	13426,7504
		25	0,0730+0,9569j	12031,4627
		50	0,1461+1,0539j	10852,6671
		75	0,2191+1,1508j	9856,3466
		100	0,2922+1,2478j	9010,1453
9.	Gramitama 1			
		0	0,86j	13426,7504
		25	0,0730+0,9569j	12031,4627
		50	0,1461+1,0539j	10852,6671
		75	0,2191+1,1508j	9856,3466
		100	0,2922+1,2478j	9010,1453

b. Phase – Earth Short Circuit Fault

To determine a phase-earth short circuit fault using the equation in (11), the current value can be calculated when the fault occurs at 100% of the distance along the Gramitama 4 feeder.

$$I_{SC(phase-earth)} = \frac{3 \times \frac{20000}{\sqrt{3}}}{2 \times (04866 + 1,4877j) + (1501,4598 + 10,083j)} = 23,055 \text{ A}$$

Table 5. Result of Calculation of Phase – Earth Short Circuit Fault

No.	Feeder	% Length	$(2 \times Z_{1eq}) + (Z_{0eq})$	$I_{SC(phase-earth)}$
1.	Gramitama 4			
		0	1500+9,92j	23,0935
		25	1500,6082+10,7046j	23,0840
		50	1501,2165+11,4892j	23,0746
		75	1501,8247+12,2738j	23,0651
		100	1502,4330+13,0584j	23,0557
2.	Sentolang			
		0	1500+9,92j	23,0935
		25	1501,5423+10,5136j	23,0697
		50	1503,0847+11,1072j	23,0459
		75	1504,6270+11,7008j	23,0222
		100	1506,1694+12,2944j	22,9986
3.	Pangsud			
		0	1500+9,92j	23,0935
		25	1501,9222+10,4782j	23,0638
		50	1503,8445+11,0364j	23,0343
		75	1505,7667+11,5946j	23,0048
		100	1507,689+12,1529j	22,9754
4.	Gulomantung 2			
		0	1500+9,92j	23,0935
		25	1501,4142+10,4976j	23,0716
		50	1502,8285+11,0752j	23,04991
		75	1504,2428+11,6528j	23,0281
		100	1505,6571+12,2304j	23,0064
5.	Gramitama 3			
		0	1500+9,92j	23,0935
		25	1500,3652+10,4047j	23,0878
		50	1500,7305+10,8895j	23,0821
		75	1501,0957+11,3742j	23,0764
		100	1501,461+11,859j	23,0708
6.	Gramitama 2			
		0	1500+9,92j	23,0935
		25	1500,3652+10,4047j	23,0878
		50	1500,7305+10,8895j	23,0821
		75	1501,0957+11,3742j	23,0764
		100	1501,461+11,859j	23,0708
7.	Gramitama 1			
		0	1500+9,92j	23,0935
		25	1500,3652+10,4047j	23,0878
		50	1500,7305+10,8895j	23,0821
		75	1501,0957+11,3742j	23,0764
		100	1501,461+11,859j	23,0708

3.6 OCR and DGR Settings

To adjust the current value on the incoming side (20 kV voltage side), first calculate the nominal current value using the following equations (12)-(17):

Table 6. Transformer Rating Specification

Transformer Capacity	60 MVA
Based Voltage	150/20 kV
CT Ratio	2000 : 5

a. Calculating Nominal Current (20 kV Side):

$$\begin{aligned} I_{nom(20\text{ kV})} &= \frac{\text{kVA}}{\sqrt{3} \times \text{kV}} \\ &= \frac{60.000}{\sqrt{3} \times 20} = 1.732,0508 \text{ A} \end{aligned}$$

b. Calculating Current Setting on Primary Side:

$$\begin{aligned} I_{set(\text{primer})} &= 1,05 \times I_{nom} \\ &= 1,05 \times 1.732,0508 = 1.818,65 \text{ A} \end{aligned}$$

c. Calculating Current Setting on Secondary Side:

$$\begin{aligned} I_{set(\text{secondary})} &= I_{set(\text{primer})} \times \frac{1}{\text{CT Ratio}} \\ &= 1.818,65 \times \frac{5}{2000} = 4,5466 \text{ A} \end{aligned}$$

d. Time Multiplier Setting (TMS)

The 3-phase short circuit fault current at the fault location area at 0% of the feeder length is selected as the fault current used to calculate the TMS (Time Multiplier Setting) on the overcurrent relay on the incoming side of the 20 kV power transformer unit 2. The working time of the incoming side overcurrent relay is obtained as the standard working time value, namely +0.4 seconds.

$$t_{\text{incoming}} = 0,3 + 0,4 = 0,7 \text{ second}$$

$$\begin{aligned} \text{TMS} &= \frac{\left[\frac{I_{\text{fault}}}{I_{\text{set}}} \right]^n - 1}{k} \times t \\ &= \frac{\left[\frac{13.426,750}{1.818,65} \right]^{0,02} - 1}{0,14} \times 0,7 = 0,204 \\ t &= \text{TMS} \times \frac{k}{\left(\frac{I_{\text{Fault}}}{I_{\text{set}}} \right)^n - 1} \\ &= 0,204 \times \frac{0,14}{\left(\frac{13.426,750}{1.818,65} \right)^{0,02} - 1} = 0,7 \text{ second} \end{aligned}$$

The overcurrent relay setting on the feeder side is calculated based on the full load current value on each feeder. For the standard inverse relay characteristic, the overcurrent setting value is between 1,05 to 1,3 times the full load current. With a full load current of 281 Ampere and a CT ratio of 400 to 5, the overcurrent setting on the Gramitama 4 feeder side is as follows:

$$\begin{aligned} I_{set(\text{primer})} &= 1,05 \times I_{FL} \\ &= 1,05 \times 281 \text{ A} = 295,05 \text{ A} \end{aligned}$$

The current value of 295,05 Amperes is the setting value on the primary side. If a short-circuit fault current equal to or greater than this value occurs, the overcurrent relay at the feeder position will detect it and issue a command to trip the circuit breaker (CB), thereby protecting other equipment and ensuring safe operation. However, if the short-circuit fault current is below 295,05 Amperes, the overcurrent relay on the feeder side will not activate.

a. Secondary Side Current Setting Value

The calculation of the current setting value $I_{set(sec)}$ for the Gramitama 4 Feeder can be determined using Equation (16), as follows:

$$\begin{aligned} I_{set(sec)} &= I_{set(prim)} \times \frac{1}{CT\ Ratio} \\ I_{set(sec)} &= 295,05 \times \frac{1}{400/5} \\ &= 295,05 \times \frac{5}{400} = 3,69\ A \end{aligned}$$

b. Instant Current Adjustment on the Feeder Side

The instant current setting on the feeder side is obtained based on the value of the full load current on the feeder. The value of the primary instant current and the secondary instant current on the feeder can be calculated using the following equation:

$$\begin{aligned} I_{instan(prim)} &= 1,6 \times I_{FL} \\ &= 1,6 \times 281 = 449,6\ A \\ I_{instan(sec)} &= 449,6 \times \frac{1}{400/5} \\ &= 449,6 \times \frac{5}{400} = 5,62\ A \end{aligned}$$

Table 7. Instant Current Calculation Results Data and Feeder Setting Current

Feeder	$I_{set(prim)}$	$I_{set(sec)}$	$I_{ins(prim)}$	$I_{ins(sec)}$
Gramitama 4	295,05	3,69	449,6	5,62
Sentolang	234,15	2,93	356,8	4,46
Pangsud	149,1	1,86	227,2	2,84
Gulomantung 2	172,2	2,15	262,4	3,28
Gramitama 3	215,25	1,35	328	2,05
Gramitama 2	225,75	1,41	344	2,15
Gramitama 1	218,40	1,37	332,8	2,08

In Table 7, it can be seen that the calculation results above will be used as a basis for calculating TMS (Time Multiplier Setting) and the value of the relay working time on the feeder side. The fault current selected to determine the value of the TMS (Time Multiple Setting) of the 20 kV feeder side overcurrent relay is a three-phase short circuit fault current at a location of 100% of the feeder length, with the relay operating time set at $t = 0,3$ seconds. The calculation of the TMS (Time Multiple Setting) value can use the following equation.

$$\begin{aligned} TMS &= \frac{\left[\frac{I_{fault}}{I_{set}} \right]^n - 1}{k} \times t \\ &= \frac{\left[\frac{9010,15}{218,4} \right]^{0,02} - 1}{0,14} \times 0,3 = 0,165499 \end{aligned}$$

$$\begin{aligned}
 t &= TMS \times \frac{k}{\left(\frac{I_{Fault}}{I_{set}}\right)^n - 1} \\
 &= 0,165499 \times \frac{0,14}{\left(\frac{9010,15}{218,4}\right)^{0,02} - 1} = 0,3 \text{ second}
 \end{aligned}$$

Table 8. Comparative Data of OCR Calculation Results and Existing

Feeder	OCR (Standard Inverse)			
	Current		TMS	
	Existing	Resetting	Existing	Resetting
Gramitama 4	400	295,05	0,15	0,142494
Sentolang	400	234,15	0,15	0,146227
Pangsud	400	149,1	0,15	0,162164
Gulomantung 2	400	172,2	0,15	0,162164
Gramitama 3	400	215,25	0,15	0,166170
Gramitama 2	400	225,75	0,15	0,164382
Gramitama 1	400	218,4	0,15	0,165499

Table 9. Comparative Data of DGR Calculation Results and Existing

Penyulang	DGR (Standard Inverse)			
	Current		TMS	
	Existing	Resetting	Existing	Resetting
Gramitama 4	4	11,5	0,2	0,039884
Sentolang	4	11,5	0,2	0,039884
Pangsud	4	11,5	0,2	0,039884
Gulomantung 2	4	11,5	0,2	0,039884
Gramitama 3	4	11,5	0,2	0,039884
Gramitama 2	4	11,5	0,2	0,039884
Gramitama 1	4	11,5	0,2	0,039884

From Table 8 related to the calculation results and existing, there are several values that are different from the calculation results with existing data. The setting current value on the standard inverse overcurrent relay, the existing data is 400 A, while the data according to the calculation varies for each feeder depending on the size of the full load current on each feeder varying from 149,1 A to 295,05 A. Likewise for the setting current on Instantaneous, there are also differences. The TMS (Time Multiple Setting) value on the existing is 0,15, the same for all feeders, while the calculation data varies between 0,142494 to 0,166170.

From Table 9 which explains the calculation results and existing for the DGR relay, there are several different values from the calculation results with existing data. The setting current value on the DGR standard inverse relay, the existing data is 4 A, while the data according to the calculation has the same value for each feeder of 11,5 A. Likewise for the TMS (Time Multiple Setting) Value, there is also a difference. The TMS (Time Multiple Setting) value on the existing is 0,2 the same for all feeders, while the calculation data obtained a value of 0,039884 the same for each feeder.

4. CONCLUSION

The results of the research that has been done show a significant difference between the existing data and the calculation results in the relay settings. In the standard inverse overcurrent relay, the existing current setting value is 400 A, while the calculation results vary between 149,1 A to 295,05 A, with the existing TMS of 0,15 different from the calculation results ranging from 0,142494 to 0,166170. Meanwhile, in the DGR relay, the existing current setting value of 4 A is different from the calculation results which show a uniform value of 11,5 A, and the existing TMS of 0,2 is also different from the calculation results of 0,039884. This difference indicates a mismatch that can affect the performance of the system protection settings.

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