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Coordination and Setting of Overcurrent Relays on The PLTMG BMPP Nusantara 1 Generator

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ABSTRACT

The electrical power system can distribute electrical energy optimally if power plants generate electrical energy with high reliability. However, disturbances in the electrical system can affect reliability. Therefore, safety equipment is necessary. In electrical power systems, protection devices are used to minimize disturbances, and protection relays must function properly. One of the protection devices used in generators is an overcurrent relay. To avoid relay failure, it is important to evaluate the overcurrent relay and test the reliability characteristics of the relay. Based on the overcurrent relay coordination test results, the calculation settings show that the relay is capable of handling maximum and minimum short-circuit currents, but with the existing settings, the relay does not function properly at minimum short-circuit currents. The maximum short-circuit current is 17.185A, and the minimum fault current is 13.828A. Comparing the calculation results with the existing settings, there are differences: for the inverse relay, the primary setting current is 494A and the secondary setting current is 0.988A, while for the definite time relay, the primary current is 3.666A and the secondary current is 7.3A with a relay operating time setting of 0.5 seconds. Meanwhile, the primary setting current value for the definite time relay is 526A and the secondary current is 1.05A, while the primary setting current for the definite time relay is 1.173A and the secondary current is 2.34A with an operating time of 0.6s. In the inverse relay, the calculated setting current value is lower than the existing setting. For the definite-time relay, the test results show a faster operating time and a higher setting current compared to the existing conditions, so the calculated results have the potential to improve the reliability of protection against overcurrent faults. By evaluating existing relay settings against calculated minimum and maximum short circuit currents, this study identifies critical gaps in generator protection. The data suggests that current settings lack the necessary sensitivity for low level fault detection. Consequently, we developed more responsive inverse and definite time relay configurations. This approach enhances the overall dependability of the protection scheme and serves as a vital technical guide for engineers tasked with optimizing overcurrent relay coordination in complex power grids."

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I. Introduction

Electricity is one of the most crucial needs in society and industry. A power system is a system consisting of a number of components, including generation, transmission lines, and distribution. With rapid technological development, human dependence on electricity continues to increase, so the power system must be able to distribute energy optimally to customers. The power system consists of several subsystems, including power plants, transmission systems, distribution systems, and customer loads. [1]

A power system can distribute electrical energy optimally if the power plant generates electrical energy with high reliability. However, disturbances in the power system can affect reliability. Therefore, protection equipment is required to protect the system from disturbances. Disturbances can be caused by various factors, such as excessive temperature rise resulting in currents exceeding nominal capacity, failure of the insulation system, and cable installation and device quality that do not meet standards. Electrical disturbances are classified into two main categories, namely symmetrical and asymmetrical faults. [2]. Short circuits frequently occur in power systems. Excess operating current caused by short circuits can damage equipment if protective relays and circuit breakers are not provided to protect each part of the electrical network. [3]. In power systems, protective devices are used to minimize disturbances. Protection relays must function properly without disrupting normal system operation and must have good selectivity, responsiveness, and sensitivity.[4]

Nusantara 1 Floating Power Plant is the first floating power plant built in Indonesia. It is one of the power plants designed to float on the sea surface using a floating vessel. The PLTMG operates with a dual-fuel engine. Because the engine uses two driving power sources, the fuel system must accommodate both fuels. The fuels commonly used are natural gas and diesel oil (HSD/MFO). [5] With this floating power plant design, electricity supply needs in island regions such as Maluku can be met. Nusantara 1 Floating Power Plant has six generator units with an output capacity of 60 MW. To avoid losses due to disturbances, it is important for the electricity supply provider to improve maintenance and repairs, both for main equipment and supporting equipment. Routine maintenance and repairs can maintain operational stability, the reliability of system protection, and prevent fatal damage to power-system equipment.

A generator is a key device that plays an important role in converting mechanical energy into electrical energy. As a source of electrical energy, generators are vulnerable to external and internal disturbances. The most common disturbances on generators are short circuits, overload, loss of excitation, overvoltage, undervoltage, and out-of-step conditions. [6]. Excess current due to disturbances can damage insulation and ultimately cause serious damage to the machine. Fault current capacity is determined not only by the generator reactance but also by the impedance of the overall power system. [7]. Overcurrent protection must consider two overcurrent conditions at minimum and maximum values. Minimum fault current occurs when the load increases and all generators operate in a low-impedance configuration, while maximum fault current occurs when the load is low or only some generators operate in a high-impedance configuration. If a relay is set at only one value (usually the maximum value), selectivity and sensitivity problems will arise [8].

One protection device used on generators is the overcurrent relay. An overcurrent relay measures the fault current and compares it with a predetermined threshold (setting). If the current level rises above the threshold, after a specified time delay a trip command is issued and the appropriate circuit breaker operates to isolate the faulty area [9]. A definite-time overcurrent relay sends a trip signal to the circuit breaker at a specified time. This type of relay is usually used for backup protection. If the main relay does not operate, the backup overcurrent relay must operate and issue a command to the circuit breaker. Definite-time overcurrent protection uses a fixed time delay that must be longer than the normal operating time of the main relay [10] to prevent failure. Therefore, it is important to evaluate overcurrent relays and test their reliability characteristics. Relays may not operate properly due to changes in power-system configuration and load growth, so overcurrent relay settings must be updated. Extreme inverse OCR type (50/51) is a protective relay that is applied and set to operate before the generator armature short-time thermal limit is reached. This can be controlled with a high-dropout instantaneous overcurrent unit that is set higher, approximately 115% of the generator current rating, to avoid operation below the current limit [11].

ETAP (Electrical Transient Analyzer Program) is a power-system analysis software that can be used to simulate protective relay coordination. Through short-circuit fault simulation, the fault current magnitude can be determined so that minimum and maximum Iset can be calculated. In addition, the Star View feature can be used to view current-time characteristic curves so that the appropriate relay operating time can be determined [12].

This study tests the operation of overcurrent relays to protect the PLTMG BMPP Nusantara 1 generator from short-circuit faults. By determining the current threshold, the overcurrent relay will detect the fault current and send a command signal to the tripping device (CB). This study performs overcurrent relay setting calculations and then simulates them using ETAP software. This study aims to answer several questions in the problem formulation: first, to determine the magnitude of the short-circuit current occurring at the generator. Second, to determine the relay current settings and relay operating time on the generator. Third, to determine the relay time multiplier setting (TMS) on the generator. Fourth, to analyze the comparison between the existing OCR settings on the PLTMG BMPP Nusantara 1 generator and the calculation results.

II. Research Methodology

The research method used is descriptive statistics, in which the research stages are closely related to numerical calculations, and the calculation results and available data are analyzed in numerical and graphical forms. The research implementation stages include calculating the generator nominal current, calculating short-circuit current, calculating overcurrent relay settings, then simulating the results using ETAP software and analyzing overcurrent relay performance.

A. Time and Location

This study was conducted at PLTMG BMPP Nusantara, located in Waai Village, Salahutu District, Maluku Province. The study was carried out for three months starting in June 2025.

Figure 1. Research Location

B. Research Flow Diagram

The research flow diagram helps to understand the stages of the research process. The systematic research flow diagram is as follows:

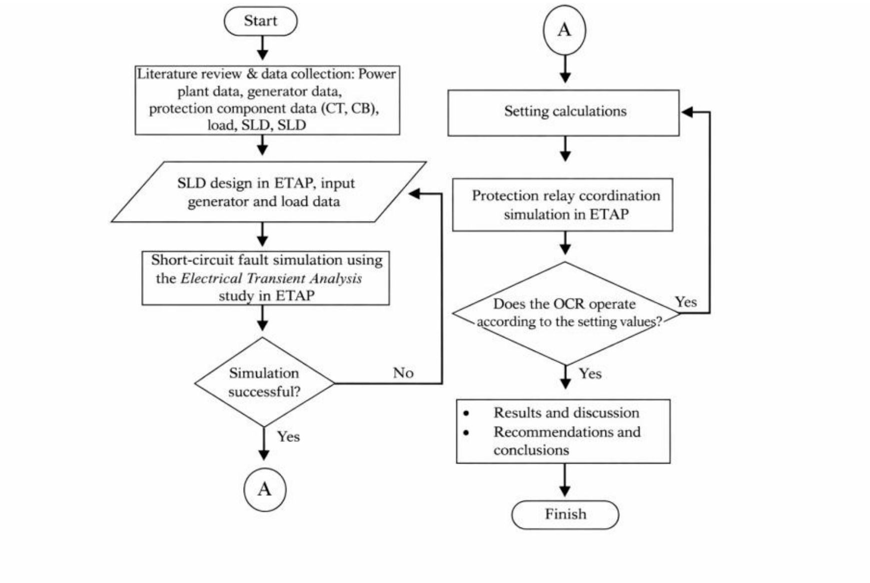

Figure 2. Research Flow Diagram

III. Results and Discussion

A. Short-Circuit Fault Analysis

The maximum three-phase short-circuit fault current test was carried out under peak-load conditions of PLTMG BMPP Nusantara 1. This test was performed to determine the overcurrent relay setting calculation so that the relay can send a command signal to disconnect the power flow through the CB according to the magnitude of the system fault current. Based on ETAP simulation results, the fault current values are as follows:

1) Maximum Three-Phase Short-Circuit Results

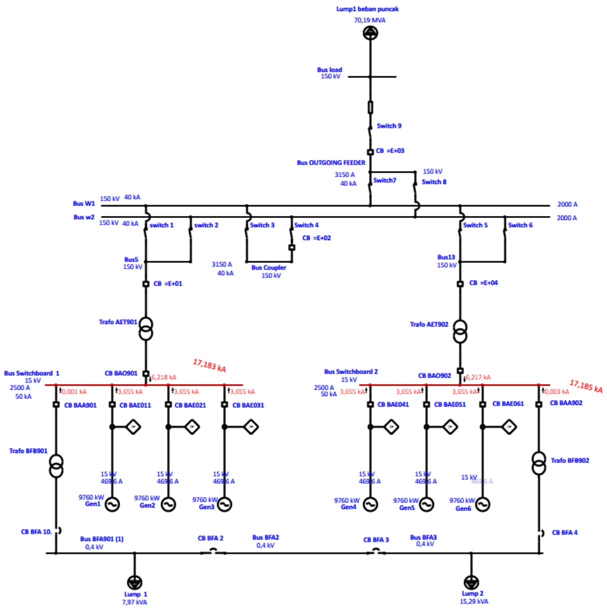

Figure 3. Maximum Three-Phase Short-Circuit Results

Based on the three-phase short-circuit fault simulation results in the power system, the three-phase short-circuit current at the switchboard bus (generator bus) on switchboard 1 is 17,183 kA and on switchboard 2 is 17,185 kA. These values are used to determine the pickup threshold for overcurrent relays on the generator.

B. Overcurrent Relay Setting Calculation

1) Calculation of CB Breaking Capacity

Determining the breaking capacity of the Circuit Breaker (CB) is an important step in designing a power-system protection scheme. The CB breaking capacity must be able to withstand the short-circuit fault current. Therefore, breaking capacity is obtained from ETAP simulation. The simulation results are used as the main reference for determining the selected CB breaking capacity. Proper breaking-capacity selection also aims to avoid oversizing the CB, which can increase equipment procurement costs. The CB breaking capacity is determined from the short-circuit simulation result, taken as 1.2 times the fault current:

$$\mathrm{I_{CB}} = 1{,}2 \times \mathrm{I_{SC}}$$
$$\mathrm{I_{CB}} = 1{,}2 \times 17{,}185$$
$$\mathrm{I_{CB}} = 20{,}622\ \mathrm{KA}$$

2) Nominal Current Calculation (IN)

Nominal current calculation is used to determine the overcurrent relay current setting based on the generator power and voltage values. Therefore, the nominal current (IN) is calculated using Equation (2.1):

$$\mathrm{IN} = \frac{\mathrm{S}}{\sqrt{3} \times \mathrm{V}}$$
$$= \frac{12200}{\sqrt{3} \times 15}$$
$$= \frac{12200}{25{,}98} = 470\ \mathrm{A}$$

3) Inverse-Time OCR Setting Calculation (51)

- Pickup Current Calculation

The primary pickup current calculation is performed to determine the secondary Is value. On the primary side, Equation (2.7) can be used:

$$I_s\ primer = 1{,}05 \times I_n$$
$$= 1{,}05 \times 470$$
$$= 494\ A$$

Overcurrent relay settings use the calculated secondary value based on the current transformer (CT) ratio. The secondary-side value can be calculated using Equation (2.8):

$$I_s\, sekunder) = I_s\ primer \times \frac{CT\ sekunder}{CT\ primer}$$
$$I_s\, sekunder) = 494 \times \frac{1}{500}$$
$$I_s\, sekunder) = 0{,}988 A$$

- OCR Operating-Time Characteristics Using the IEC 60255 Standard

$$t = \frac{TMS \times 0{,}14}{\left(\frac{I_{fault}}{I_{set}}\right)^{0{,}02} - 1}$$
$$t = \frac{02 \times 0{,}14}{\left(\frac{17.185}{494}\right)^{0{,}02} - 1}$$
$$t = \frac{02 \times 0{,}14}{0{,}07}\ ,\ t = 0{,}4\ s$$

4) Definite-Time Overcurrent Relay Setting Calculation (50)

- Pickup Current Calculation (Is)

The primary pickup current is calculated to determine the secondary Is value. On the primary side, the definite-time relay pickup must be higher than the current produced by the generator. The definite-time relay setting formula uses Equation (2.7):

$$I_s\ primer = 7{,}8 \times I_n$$
$$= 7{,}8 \times 470 = 3.666\ A$$

Overcurrent relay settings use the calculated secondary value based on the CT ratio. The secondary-side value can be calculated using Equation (2.8)

$$I_s\ primer = 7{,}8 \times I_n$$
$$= 7{,}8 \times 470$$
$$= 3.666\ A$$

B. Overcurrent Relay Setting Test

PLTMG BMPP Nusantara 1 has six generator units, each connected to switchboard bus 1 & 2. The generator protection uses a combination of inverse-time and definite-time relays with similar settings for all six generators, functioning as an overcurrent protection system for faults such as short circuits and currents exceeding the normal operating current. Therefore, relay settings must be determined accurately and coordinated properly. In the PLTMG BMPP Nusantara 1 generator protection system, the overcurrent relay with the time overcurrent pickup (low set/I>) parameter uses the normal inverse OCR curve (51) as the main protection for lower fault currents, with a variable trip time depending on the fault current magnitude. The definite-time OCR (50) with pickup (high set) is used to detect higher fault currents as backup protection. The definite-time overcurrent relay uses a fixed time delay; therefore, it must be set longer than the operating time of the IDMT relay. The pickup current and time settings for each protection curve are determined based on fault current magnitude to ensure the correct operating sequence and prevent unintended relay operation. To ensure that the relay settings operate properly, OCR testing was carried out using ETAP 19.0.1 software.

Testing of OCR coordination for the existing settings and the calculation results under variations of maximum and minimum three-phase short-circuit currents aims to determine relay performance characteristics based on fault-current variations, including:

a) OCR Coordination on Switchboard Bus 1
b) OCR Coordination on Switchboard Bus 2
c) OCR Coordination on the Generator

Existing-Setting Test for Maximum Three-Phase Short-Circuit Current

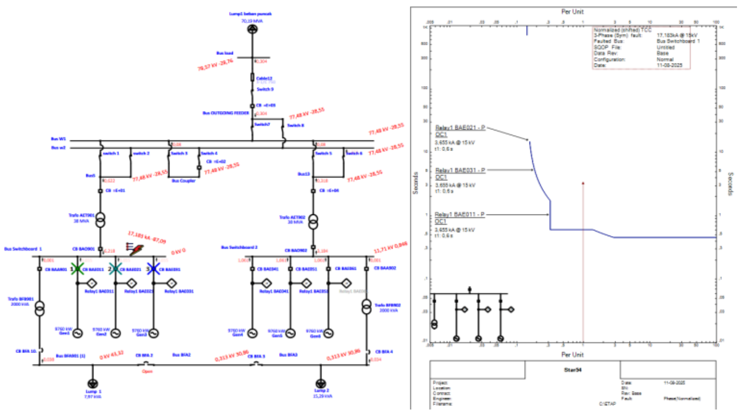

Figure 4. Existing Setting Test on Switchboard Bus 1

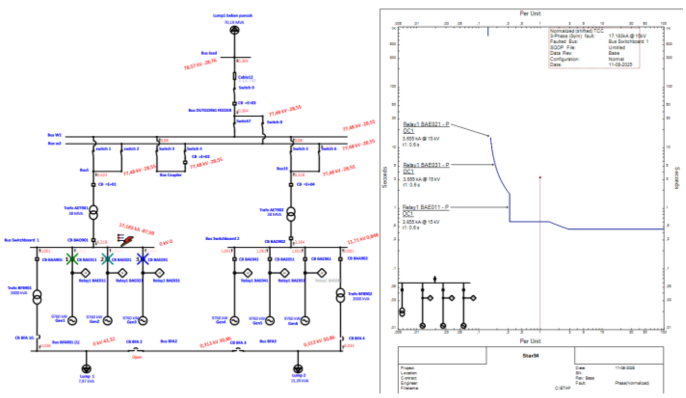

Figure 5. Existing Setting Test on Switchboard Bus 2

The simulation results of OCR coordination with existing settings on switchboard bus 1&2 under maximum short-circuit current show that the relay detects a fault current of 3,655 KA. The definite-time relay (50) sends the trip command first within 0,6 seconds and trips the CB within 0,2 seconds. The TCC results show that the definite-time relay curve operates to protect the generator.

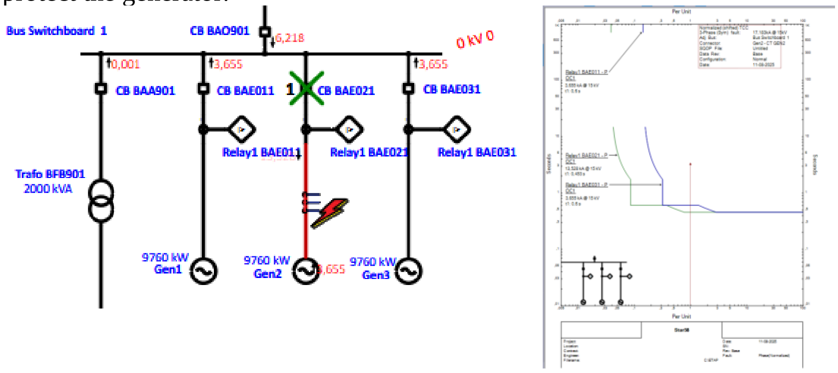

Figure 6. Setting Test on Generator 2

The simulation results of OCR coordination with the existing settings on generator 2 under maximum short-circuit current show that the relay detects a fault current of 13.528 KA. The inverse relay (51) sends the initial trip command within 0,4 seconds and triggers the CB trip within 0,2 seconds. The TCC results show that the inverse relay (51) curve isolates the fault current on generator 2.

Existing-Setting Test for Minimum Three-Phase Short-Circuit Current

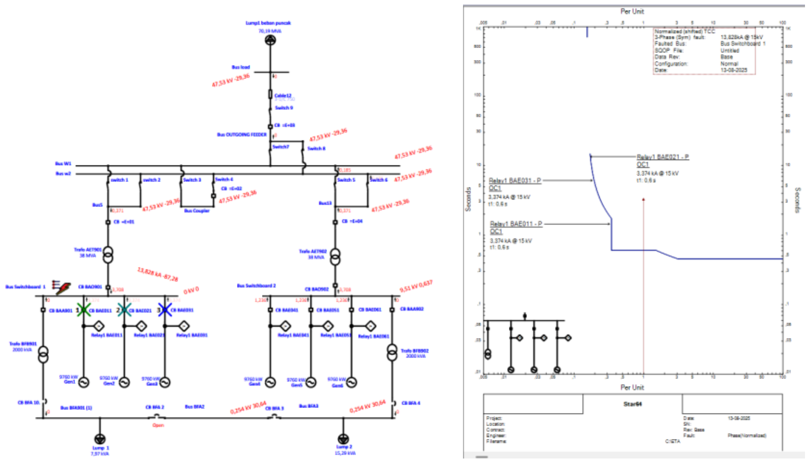

Figure 7. Existing Setting Test on Switchboard Bus 1

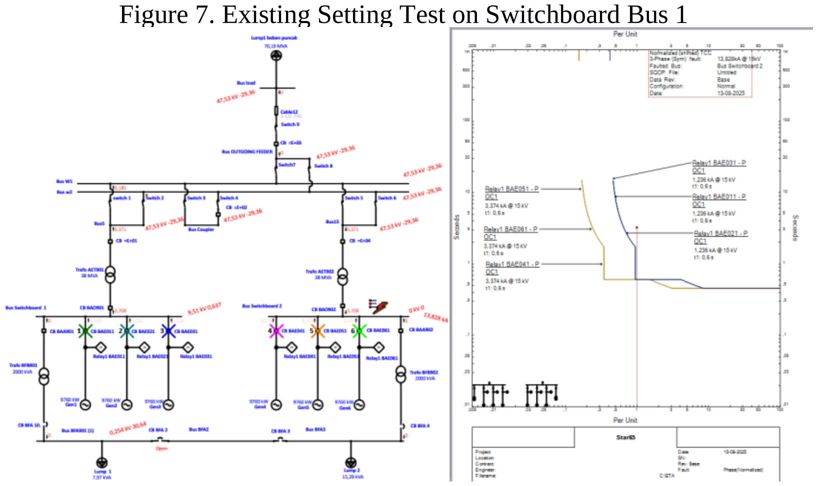

Figure 8. Existing Setting Test on Switchboard Bus 2

The results on switchboard bus 1 show that the TCC of the definite-time relay (50) operates to protect the generator when Ifault is 3.374 A, with an operating time of 0,6s simultaneously. On switchboard bus 2, the TCC shows that the relay operating first is the relay on switchboard bus 1; therefore, it can be concluded that the relay on switchboard bus 2 is not properly coordinated.

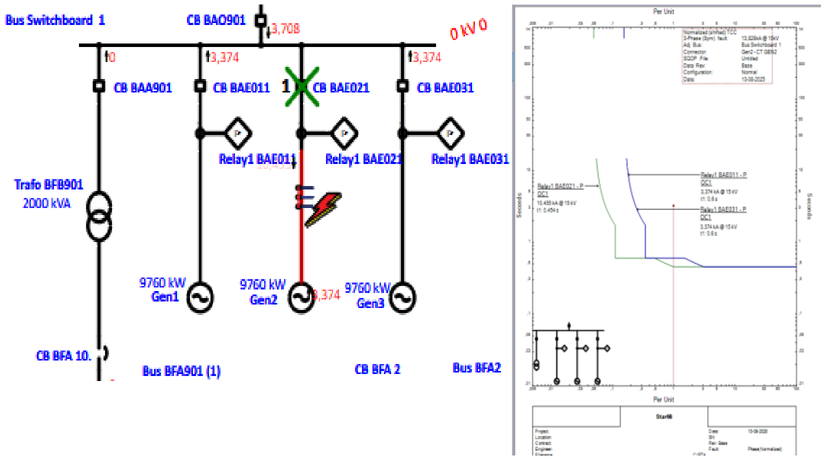

Figure 9. Setting Test on Generator 2

The simulation results of OCR coordination with the existing settings on generator 2 under maximum short-circuit current show that the relay detects a fault current of 10,455KA. The inverse relay (51) sends the initial trip command within 0,4 seconds and triggers the CB trip within 0,2 seconds. The TCC results show that the inverse relay (51) curve isolates the fault current on generator 2

- OCR Setting Test (Calculation Results) for Maximum Three-Phase Short-Circuit Current

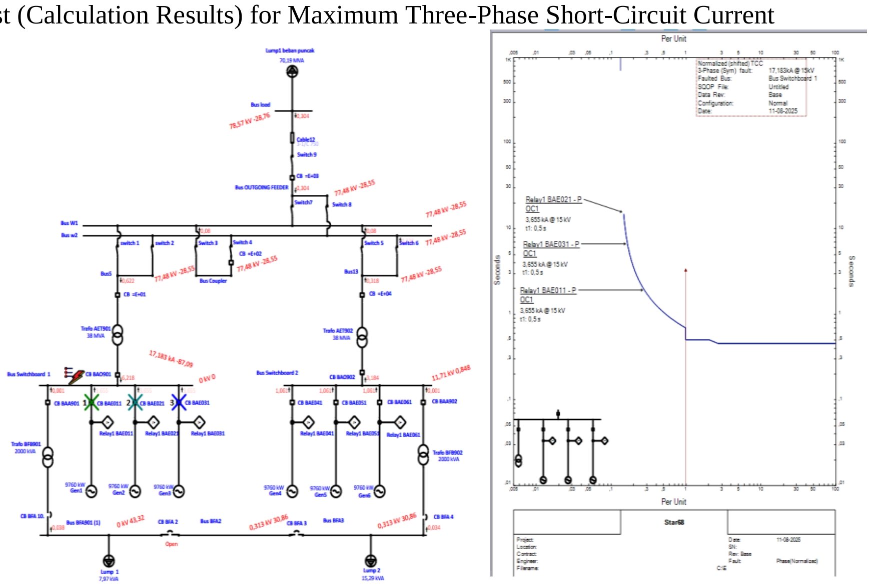

Figure 10. OCR Setting Test (Calculation Results) on Switchboard Bus 1

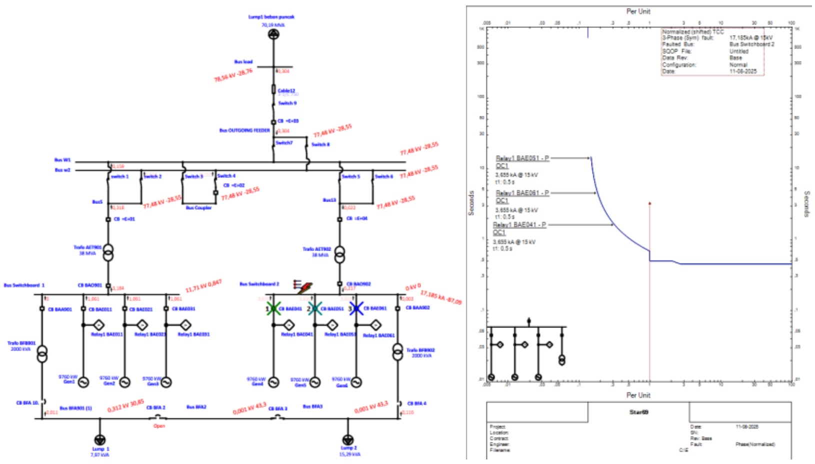

Figure 11. OCR Setting Test (Calculation Results) on Switchboard Bus 2

The switchboard bus 1 & 2 test shows on the TCC that the definite-time relay (50) sends the trip command first and operates at a fault current of 3,655 A within 0,5s, protecting the generator.

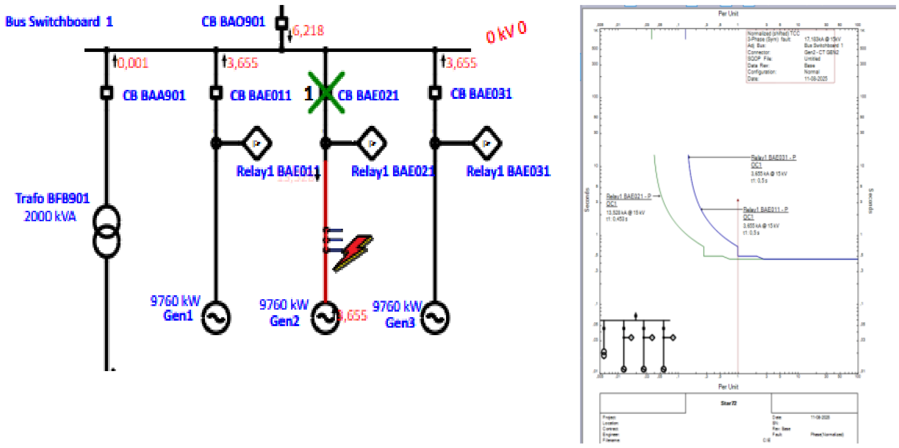

Figure 12. Setting Test on Generator 2

The simulation results of OCR coordination with the existing settings on generator 2 under maximum short-circuit current show that the relay detects a fault current of 13,528 KA. The inverse relay (51) sends the initial trip command within 0,4 seconds and triggers the CB trip within 0,2 seconds. The TCC results show that the inverse relay (51) curve isolates the fault current on generator 2

- OCR Setting Test (Calculation Results) for Minimum Three-Phase Short-Circuit Current

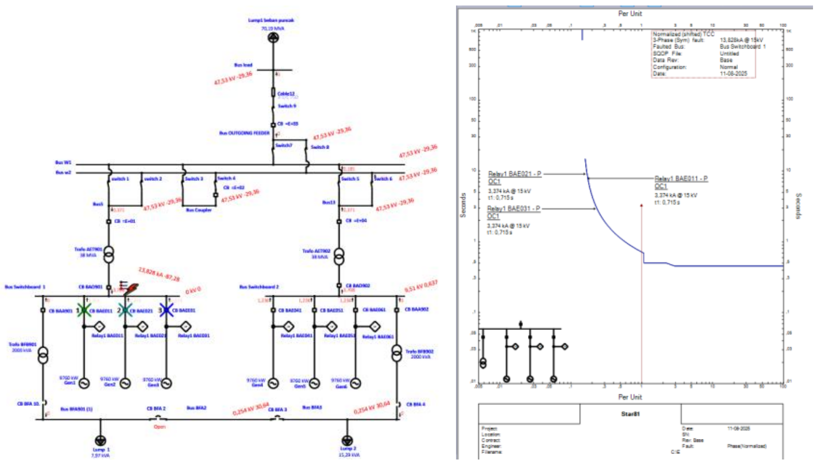

Figure 13. OCR Setting Test (Calculation Results) on Switchboard Bus 1

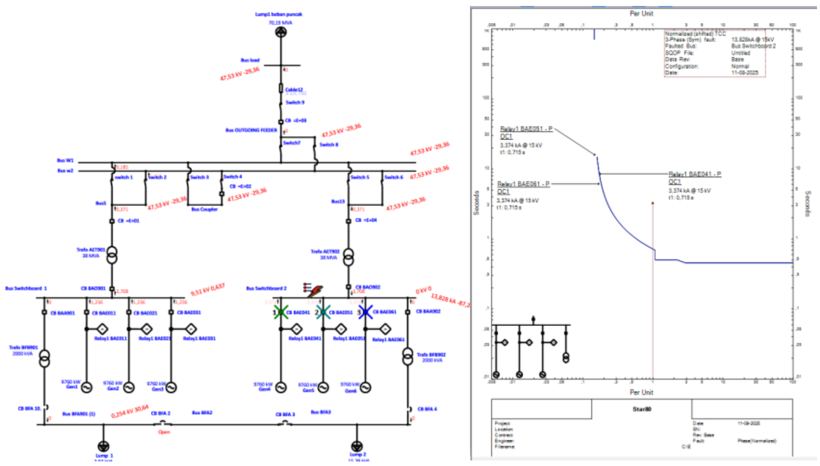

Figure 14. OCR Setting Test (Calculation Results) on Switchboard Bus 2

Based on the simulation results for bus 1 & 2, OCR coordination relays detect a fault current of 3,374 KA. The inverse relay (51) sends the initial trip command within 0,7 seconds and trips the CB within 0,2 seconds. The TCC results show the inverse relay curve operating simultaneously to protect the generator.

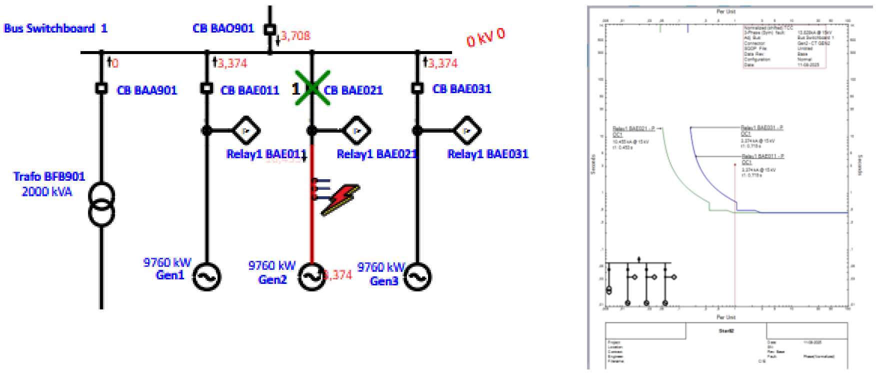

Figure 15. Setting Test on Generator 2

The simulation results of OCR coordination with the existing settings on generator 2 under maximum short-circuit current show that the relay detects a fault current of 10.455 KA. The inverse relay (51) sends the initial trip command within 0,4 seconds and triggers the CB trip within 0,2 seconds. The TCC results show that the inverse relay (51) curve isolates the fault current on the generator

D. *Comparison of Overcurrent Relay Settings*

Table 1 Comparison of Existing Overcurrent Relay Settings with Calculation Results

Curve	Parameter	Existing	Calculated
OCR Normal Inverse	Is primary	526	494
	Iset secondary	1,05	0,988
	TMS	0,2	0,2
OCR Definite Time	Is primary	1.173	3.666
	Iset secondary	2,34	7,3
	Top	0,6	0,5

The comparison of inverse relay (low setting) between the existing settings and the calculation results is quite close. For Ipickup (overload multiplier), the calculation uses the IEC standard of 1,05, resulting in a pickup of 494 A, while the existing setting has an Ipickup of 526 A. In the calculation results, the definite-time pickup is set higher than the inverse relay pickup. When the maximum short-circuit current flows on the switchboard bus, the definite-time relay operates first to clear the fault current; when the minimum fault current flows on the switchboard bus, the inverse relay operates first. In addition, the inverse relay (51) can also operate first for maximum fault current if the maximum fault current is applied directly to the generator.

E. *Overcurrent Relay Setting Test Results*

Based on the overcurrent relay coordination test, the calculated settings show that the relay is capable of protecting maximum and minimum short-circuit currents according to the pickup-setting curve characteristics of each relay. In the generator overcurrent relay combination, the inverse relay (51) uses a low-set setting, while the definite-time relay (50) uses a higher setting. Therefore, the inverse relay will send the trip command earlier, both at maximum and minimum short-circuit currents. Meanwhile, the definite-time relay (50) clears maximum short-circuit currents or high fault currents on switchboard bus 1&2, because the inverse relay (51) acts as the main relay and the definite-time relay (50) acts as a backup to protect the generator from fault currents.

The comparison between the coordination tests of the existing relay settings and the calculated results shows differences. With the existing settings, in the minimum short-circuit current test (as shown in the table or figures) on switchboard bus 2, the inverse relay (51) should operate, not the definite-time relay (50). In the existing case, the definite-time relays (50) BAE 011, 021, and 031 operate first, whereas when a minimum short-circuit current is applied on switchboard bus 2 the relays that should detect it are the inverse relays (51) BAE 041, 051, and 061. The TCC results show that the inverse relay curve and the definite-time relay curve are not properly coordinated. This condition can potentially damage system equipment because the relay does not operate as intended.

This differs from the OCR performance characteristics obtained from the calculation results, where in the minimum short-circuit current test on switchboard bus 1&2 the relays operate correctly, and in the maximum short-circuit current test on generator 2 the inverse relay (51) can operate. The definite-time relay (50) is able to operate for the maximum short-circuit current tested on switchboard bus 1&2. Relay performance follows the closest protected fault current; the TCC results show that in the minimum short-circuit current test the relay that operates first is the inverse relay (51) before the definite-time relay (50).

IV. Conclusion

1) The maximum short-circuit current from the ETAP simulation results is 17,183 kA on switchboard bus 1 and 17,185 kA on switchboard bus 2.
2) The inverse OCR relay (51) setting current from the calculation results has Iset of 0,988 A. The definite-time relay setting current is 7,3 A with a time setting of 0,5 s.
3) The TMS value has been determined according to the operating sequence of the inverse overcurrent relay in the system protection; therefore, TMS is set to 0,2. If the relay TMS is set smaller, the relay operating time to send the trip command will be faster, and conversely, if the relay TMS is set larger, the relay operating time to send the trip command will be longer.
4) The comparison between the calculated OCR settings and the existing settings shows differences. For the calculated OCR Normal inverse (51) curve, the primary Iset is 494 A and the secondary Iset is 0,988 A. For the OCR definite-time (50), the primary Iset is 3,666 A and the secondary Iset is 7,3 A with a relay operating time setting of 0,5 seconds. Meanwhile, the existing OCR Normal inverse (51) settings have a primary Iset of 526 A and a secondary Iset of 1,05 A. For the existing OCR definite-time (50), the primary Iset is 1.173 A and the secondary Iset is 2,34 A with an operating time of 0,6 seconds. In the inverse OCR (51), the calculated Iset value is lower than the existing setting. In the definite-time OCR curve, the test results show a faster operating time and a higher setting current compared to the existing condition, so the calculation results have the potential to improve the reliability of protection against overcurrent faults.
5) Based on these results, the relay settings need to be updated for current rating and operating time so that fault currents below the existing Iset can be protected, with the operating time accelerated by 0,1 seconds, so that the generator OCR on PLTMG BMPP Nusantara 1 can be properly coordinated. Evaluation of OCR coordination on the PLTMG BMPP Nusantara 1 generator should be carried out routinely, especially when load additions occur or there is system reconfiguration.

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