Short-Circuit Analysis Of The Saparua Distribution Feeder Network

Elisabeth Tansiana Mbitu[1*], Ferdiaztha Rendy Sahusilawane[2], Marselin Jamlaay[3]

[1,2,3] Department of Electrical Engineering, Ambon State Polytechnic, Ambon, Maluku 20155, Indonesia.
[*]Corresponding Author:
Email: elisabethtansianambitu@gmail.com

Abstract.

Short-circuit faults are a type of disturbance that impedes the transmission of electrical energy. To protect equipment from the impact of such faults, short-circuit analysis is conducted. In this study, the magnitudes of phase-to-phase and phase-to-ground short-circuit currents are calculated, along with the determination of overcurrent relay and circuit breaker ratings on the distribution network of PT PLN Saparua Rayon, Maluku. The analysis is carried out using ETAP software on generator busbars and feeders at various fault locations. PT PLN (Persero) Saparua Rayon operates four feeders: Saparua, Pohar, Tenggara (Southeast), and Hatawano. Simulation results show that the Saparua feeder has the highest fault current at bus 6 under an L-L-G fault condition, while the Tenggara, Hatawano, and Pohar feeders exhibit their highest fault currents at the generator bus under an L-G fault. It is evident that the L-L-G (double line-to-ground) fault consistently generates the highest short-circuit current when compared to other types of faults such as L-L (line-to-line) and three-phase faults. This type of fault involves a direct connection between two phases and the ground, resulting in a larger fault current due to lower overall impedance at the fault point. Furthermore, it was observed that the magnitude of the short-circuit current decreases progressively with increasing distance from the power source. This behavior is primarily due to the increase in line impedance along the distribution path, which naturally limits the fault current as it travels farther from the generation point. In summary, the farther the location of the fault from the generator, the lower the resulting short-circuit current, which highlights the critical role of impedance in fault current behavior across the distribution network.

Keywords: *Short Circuit; Feeder; Fault and Current.*

I. INTRODUCTION

An electrical power system must be designed with a high level of reliability and quality to ensure the continuous delivery of electrical energy from the power plant to the end users. A power system is considered reliable if it can effectively handle disturbances, whether they originate from within the equipment (permanent faults) or from external factors (temporary faults), in a fast, safe, and selective manner without causing a total blackout. To prevent such disturbances, a protection system is required to safeguard all equipment installed within the power system [1].The electrical power distribution system plays a vital role in delivering electrical energy from the power generation center to end consumers. One of the most common issues in 20 kV distribution systems is short-circuit faults [2]. These faults can cause current levels significantly higher than normal operating currents. If such faults are allowed to persist for an extended period within the power system, they can lead to a reduction in the system's stability margin, damage to equipment near the fault location, and widespread power outages across the network [3].Short-circuit analysis is essential to determine the appropriate fault current values.

This is done to protect devices and equipment within the distribution system from the negative impacts of load disturbances, and it serves as the basis for setting protection devices [4, 5]. When a short circuit occurs, it can cause either temporary or permanent faults. Permanent faults typically result from three-phase short circuits, two-phase-to-ground faults, phase-to-phase faults, or single-phase-to-ground faults. On the other hand, temporary faults are generally caused by flashovers between conductors and the ground, between conductors and poles, or between conductors and ground wires, as well as other similar conditions [1]. A short-circuit fault will generate a very large current and can damage or endanger electrical equipment [6]. Short-circuit faults can also occur due to insulation breakdown or damage caused by overvoltage, whether originating internally or externally (such as from lightning strikes) [7].

Analysis and calculation of short-circuit current are carried out to determine the magnitude of the fault current that may occur in a power network, allowing for the determination of the appropriate rating for the equipment installed in the system. In addition, short-circuit analysis is conducted to identify potential issues within the system, thereby aiding in system planning and protection coordination settings [8, 9].The Saparua Rayon distribution network is a medium-voltage 20 kV system. PT PLN Saparua Rayon (Maluku) operates four feeders: Saparua feeder (2.71 km), Pohar feeder (13.77 km), Tenggara feeder (21.31 km), and Hatawano feeder (32.96 km). Each feeder has indications of potential faults. With the total length of the Saparua Rayon distribution network reaching 70.75 km, there is a significant possibility of short-circuit faults occurring either in the distribution lines or at the transformers. Each feeder in a distribution system has the potential for faults to occur. This also applies to UPT Rayon Saparua in Maluku, which has four feeders with varying distribution line lengths. Therefore, this study performs calculations of short-circuit current magnitudes for both phase-to-phase and phase-to-ground faults in order to obtain accurate data as a basis for protection system analysis.

II. METHODS

This research is quantitative in nature, developing and utilizing mathematical models, theories, or hypotheses related to natural phenomena or the object of study. The object being examined is the short-circuit fault in the distribution network of PT. PLN (Persero) Saparua Rayon. The stages of the research are illustrated in Figure 1.

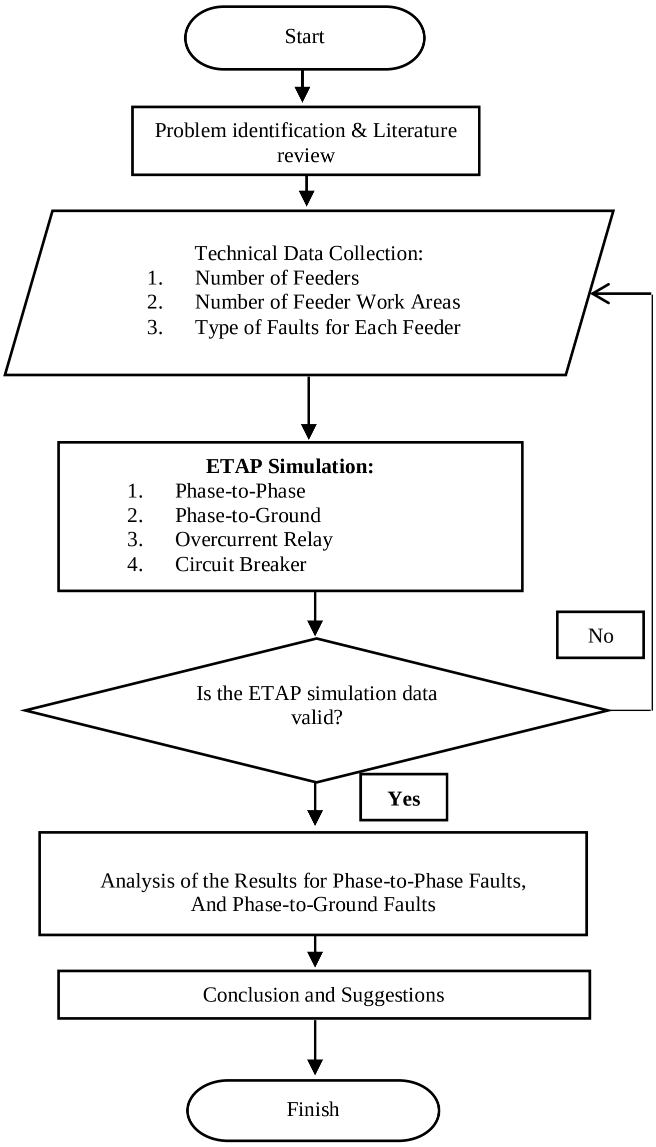


Fig 1. Research Flowchart

III. RESULT AND DISCUSSION

Single Line Diagram Design Using ETAP Software

This research begins with the design of a Single Line Diagram (SLD). The author designed the SLD using ETAP software based on the actual SLD of PT. PLN (Persero) Saparua Rayon. The following figure presents the complete Single Line Diagram of PT. PLN (Persero) Saparua Rayon as modeled in ETAP (Figure 2).

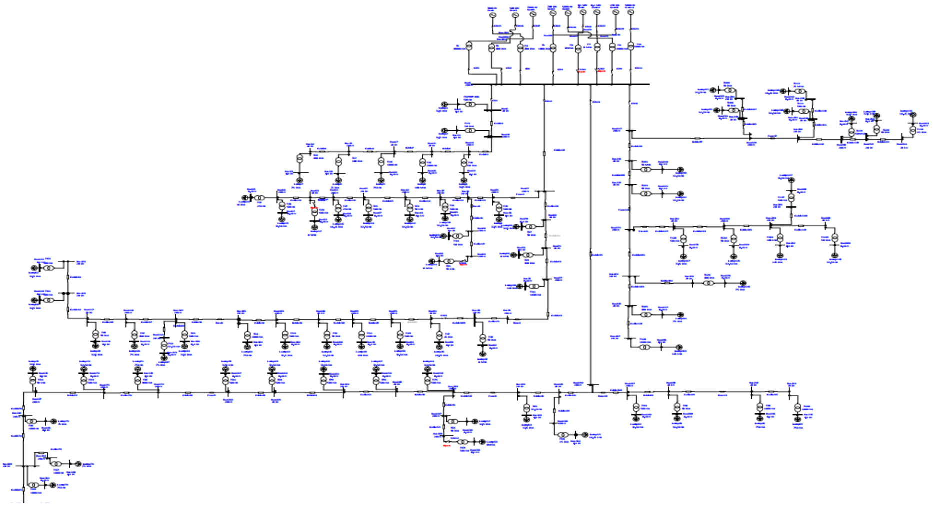


Fig 2. Single Line Diagram of ULP Saparua Using ETAP

Short Circuit Analysis

The next step is to perform a short-circuit analysis on the busbars, specifically on the generator busbar and the feeder busbars. Short-circuit fault currents in an electric power distribution system are categorized into three types: three-phase short-circuit current, two-phase short-circuit current, and single-phase-to-ground short-circuit current [10]. The analysis is conducted at four locations for each feeder (Saparua, Pohar, Tenggara, and Hatawano), namely at the generator busbar and one selected busbar along each feeder. These locations are illustrated in Figure 3.After designing the Single Line Diagram (SLD) in ETAP and inputting parameters for each component—such as generators, transformers, cables, and loads—the next step is to perform a short-circuit simulation based on IEC standards. The simulation is conducted at the generator bus and at five fault location points, namely: the generator bus, bus 6 (Saparua feeder), bus 67 (Tenggara feeder), bus 194 (Hatawano feeder), and bus 217 (Pohar feeder). The types of short-circuit faults analyzed include three-phase (3φ) faults, single line-to-ground (L-G) faults, line-to-line (L-L) faults, and double line-to-ground (L-L-G) faults.

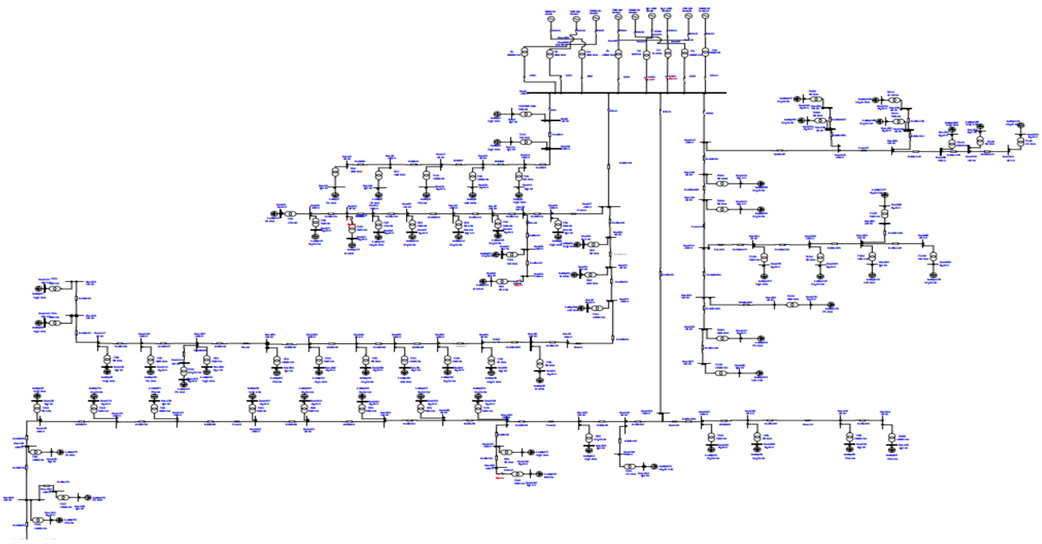
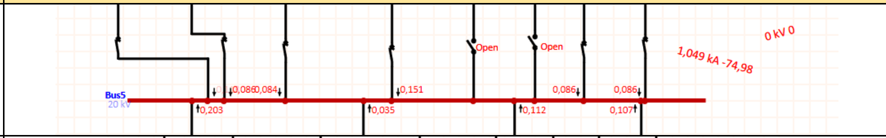
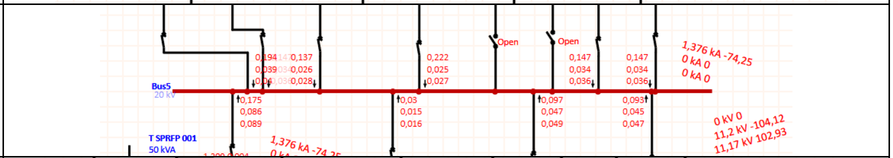
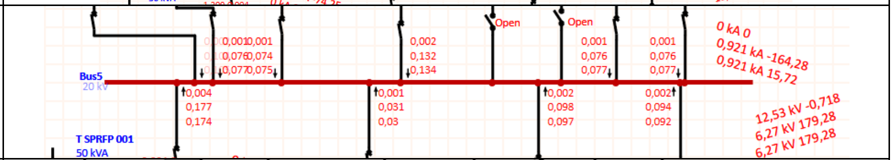
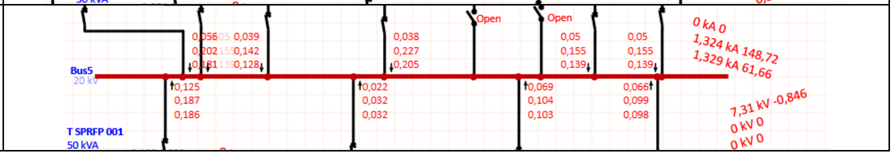


Fig 3. Short-Circuit Fault Locations in the Medium Voltage Network

Short-Circuit Analysis at the Generator Bus

Table 1. Short-Circuit Simulation Results at the Generator Bus

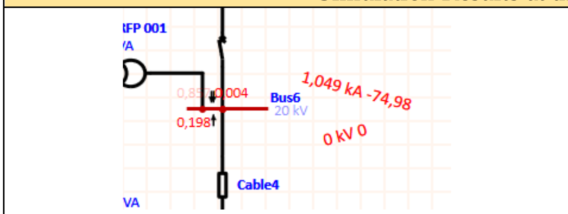
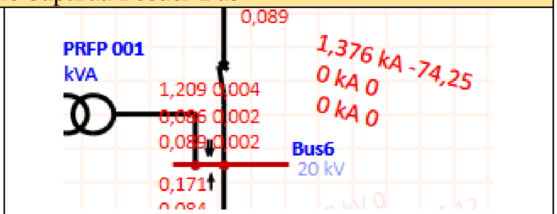
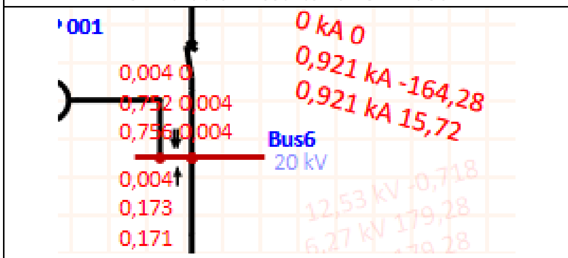
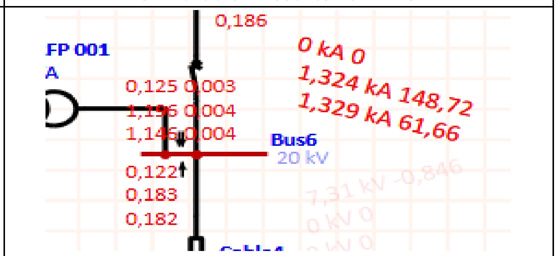
Short-Circuit Fault	**Short-Circuit Simulation Results**
3 phase	
L-G (1 Phase)	
L-L(Phasa – Phasa)	
L-L-G (2 Phasa)	

As shown in Table 1, the magnitude of the short-circuit current varies for each type of fault. For the three-phase fault, the fault current is 1.049 kA; for the line-to-ground (L-G) fault, the fault current is 1.376 kA; for the line-to-line (L-L) fault, it is 0.921 kA; and for the double line-to-ground (L-L-G) fault, the fault current is 1.329 kA.

Short-Circuit Analysis at the Saparua Feeder Bus

The simulation result of short-circuit analysis at Saparua Feeder is shown in Table 2.

Table 2. Simulation Results at Bus-6

Simulation Results at the Saparua Feeder Bus	
 Simulation results for 3-Phase	 Simulation results for L-G
 Simulation results for L-L	 Simulation results for L-L-G

As shown in Table 2, the magnitude of short-circuit current at Bus 6 of the Saparua feeder varies depending on the type of fault. For the three-phase fault, the fault current is 1.049 kA; for the line-to-ground (L-G) fault, the current is 1.376 kA; for the line-to-line (L-L) fault, it is 0.921 kA; and for the double line-to-ground (L-L-G) fault, the fault currents are 1.329 kA and 1.324 kA.

Short-Circuit Analysis at the Tenggara Feeder Bus

The simulation result of short-circuit analysis at Tenggara Feeder is shown in Table 3.

As shown in Table 3, the magnitude of short-circuit current at Bus 67 of the Tenggara feeder varies depending on the type of fault. For the three-phase fault, the fault current is 0.996 kA; for the line-to-ground (L-G) fault, it is 1.23 kA; for the line-to-line (L-L) fault, it is 0.873 kA; and for the double line-to-ground (L-L-G) fault, the fault currents are 1.236 kA and 1.088 kA.

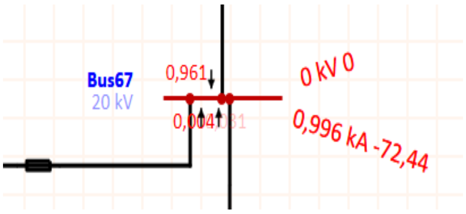
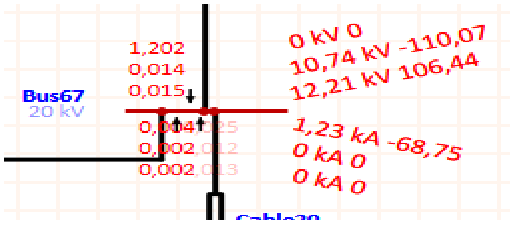
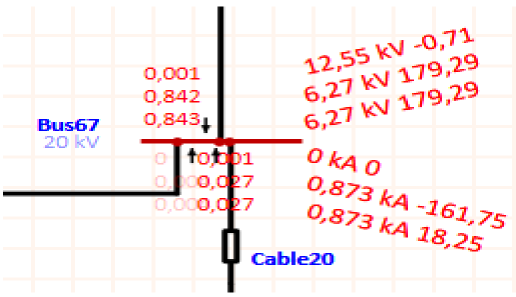
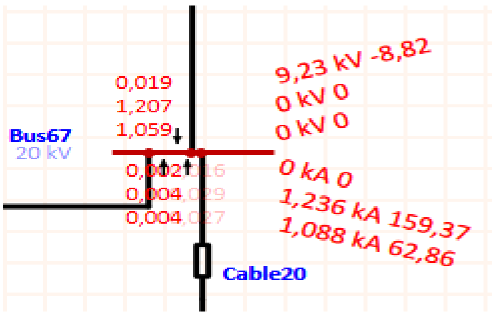
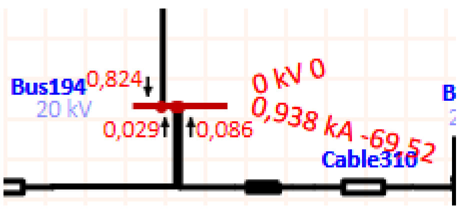
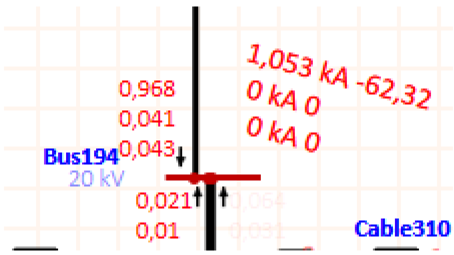
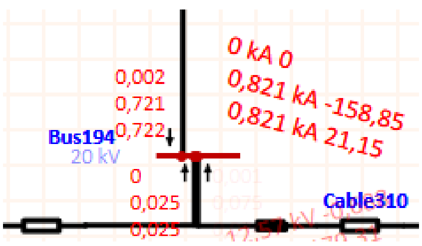
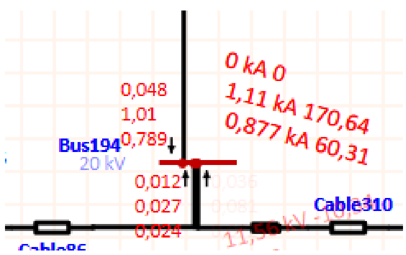
Simulation Results at the Tenggara Feeder Bus	
 Simulation results for 3-Phase	 Simulation results for L-G
 Simulation results for L-L	 Simulation results for 3-Phase L-L-G

Table 3. Simulation Results at Bus-67

Short-Circuit Analysis at the Hatawano Feeder Bus

The simulation result of short-circuit analysis at Hatawano Feeder is shown in Table 4.

Table 4. Simulation Results at Bus-194

Simulation Results at the Hatawano Feeder Bus	
 Simulation results for 3-Phase	 Simulation results for L-G
 Simulation results for L-L	 Simulation results for L-L-G

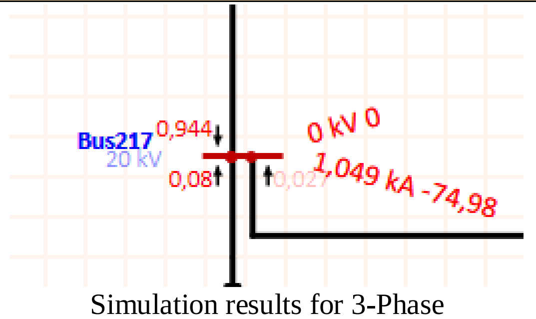
As shown in Table 4, the magnitude of short-circuit current at Bus 194 of the Hatawano feeder varies depending on the type of fault. For the three-phase fault, the fault current is 0.938 kA; for the line-to-ground (L-G) fault, it is 1.053 kA; for the line-to-line (L-L) fault, it is 0.821 kA; and for the double line-to-ground (L-L-G) fault, the fault currents are 1.110 kA and 0.877 kA.

Short-Circuit Analysis at the Pohar Feeder Bus

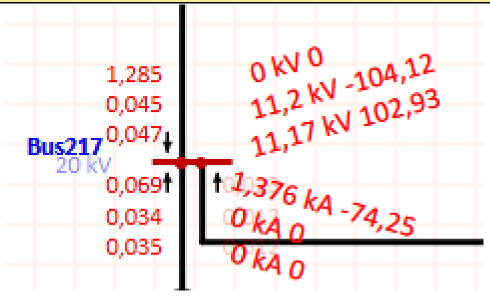
The simulation result of short-circuit analysis at Pohar Feeder is shown in Table 5.

Table 5. Simulation Results at Bus-217

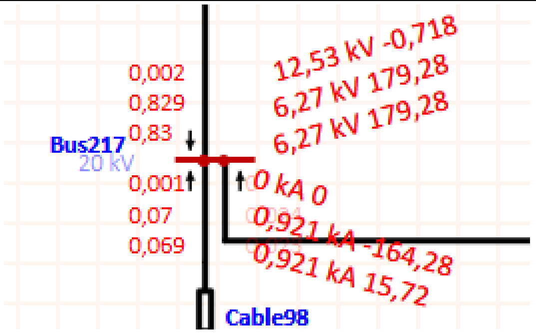
Simulation Results at the Pohar Feeder Bus



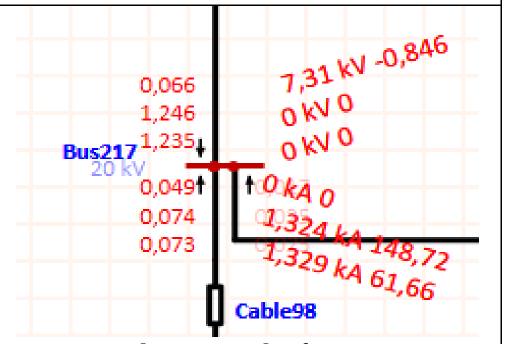
Simulation results for 3-Phase



Simulation results for L-G



Simulation results for L-L



Simulation results for L-L-G

As shown in Table 5, the magnitude of short-circuit current at Bus 217 of the Pohar feeder varies depending on the type of fault. For the three-phase fault, the fault current is 1.049 kA; for the line-to-ground (L-G) fault, it is 1.376 kA; for the line-to-line (L-L) fault, it is 0.921 kA; and for the double line-to-ground (L-L-G) fault, the fault currents are 1.329 kA and 1.324 kA.

Results Discussion

To determine the presence of short-circuit faults, it is first necessary to identify the magnitude of fault current within the distribution system of PT. PLN (Persero) Saparua Rayon. Therefore, short-circuit analysis was carried out using ETAP software. The analysis was conducted at the generator busbar and at one initial location on each feeder busbar, at specific distances from the source. The simulation covered various fault types, including three-phase faults, line-to-ground (L-G) faults, line-to-line (L-L) faults, and double line-to-ground (L-L-G) faults. The simulation results indicate that the magnitude of fault current varies depending on the type of fault, as shown in several analysis tables. Table 6 is a summary of the short-circuit analysis results for the Saparua distribution system.

Table 6. Short-Circuit Fault on the Saparua Feeder

Bus	**Short-Circuit Fault on the Saparua Feeder (kA)**			
	3-Phase (Phase R)	**L-G (Phase R-G)**	**L-L (Phase ST & TR)**	**L-L-G (Phase ST-G & TR-G)**
Power Plant	1,049 kA	1,376 kA	0,921 kA	1,324 & 1,329 kA
Bus 6	1,049 kA	1,376 kA	0,921 kA	1,324 & 1,329 kA

As shown in Table 6 for the Saparua feeder, the highest fault current occurs during the L-L-G (double line-to-ground) fault, compared to other types of faults. This is due to one phase being directly connected to the ground. Meanwhile, the lowest fault current is observed during the L-L (line-to-line) fault.

Table 7. Short-Circuit Fault on the Tenggara Feeder

Bus	**Short-Circuit Fault on the Tenggara Feeder (kA)**			
	3-Phase (Phase R)	**L-G (Phase R-G)**	**L-L (Phase ST & TR)**	**L-L-G (Phase ST-G & TR-G)**
Power Plant	1,049 kA	1,376 kA	0,921 kA	1,329 & 1,324 kA
Bus 67	0,996 kA	1,23 kA	0,873 kA	1,236 & 1,088 kA

As shown in Table 7 for the Tenggara feeder, the highest fault current occurs during the L-L-G (double line-to-ground) fault compared to the other types of faults. This is due to one phase being directly connected to the ground. Meanwhile, the lowest fault current is observed during the L-L (line-to-line) fault. Table 8 shown the summary of short-circuit fault on the Hatawano Feeder. As shown in Table 8 for the Hatawano feeder, the highest fault current occurs during the L-L-G (double line-to-ground) fault compared to the other types of faults. This is due to one phase being directly connected to the ground. Meanwhile, the lowest fault current is observed during the L-L (line-to-line) fault.

Table 8. Short-Circuit Fault on the Hatawano Feeder

Bus	**Short-Circuit Fault on the Hatawano Feeder (kA)**			
	3-Phase (Phase R)	**L-G (Phase R-G)**	**L-L (Phase ST & TR)**	**L-L-G (Phase ST-G & TR-G)**
Power Plant	1,049 kA	1,376 kA	0,921 kA	1,329 & 1,324 kA
Bus 194	0,938 kA	1,053 kA	0,821 kA	1,110 & 0,877 kA

Table 9. Short-Circuit Fault on the Hatawano Feeder

Bus	**Short-Circuit Fault on the Pohar Feeder (kA)**			
	3-Phase (Phase R)	**L-G (Phase R-G)**	**L-L (Phase ST & TR)**	**L-L-G (Phase ST-G & TR-G)**
Power Plant	1.049 kA	1.376 kA	0.921 kA	1,329 & 1,324 kA
Bus 217	1.049 kA	1.376 kA	0.921 kA	1,324 & 1.329 kA

As shown in Table 9 for the Pohar feeder, the highest fault current occurs during the L-L-G (double line-to-ground) fault compared to the other types of faults. This is due to one phase being directly connected to the ground. Meanwhile, the lowest fault current is observed during the L-L (line-to-line) fault. Based on Tables 6 through 9, it can be concluded that the highest fault current occurs at the generator bus. This is because the power plant, acting as the main power source, has very low impedance, resulting in a significantly higher fault current. Conversely, the farther the fault location is from the power source, the lower the fault current becomes, due to the increasing network impedance and distance.The L-L-G short-circuit consistently shows the highest fault current across the four bus locations (Saparua feeder, Tenggara feeder, Hatawano feeder, and Pohar feeder), while the L-L short-circuit consistently produces the lowest fault current. Therefore, it can be concluded that the farther the fault is from the power source (generator), the lower the resulting short-circuit current will be.Figure 4 presents a graph of short-circuit current magnitudes at Bus 6 of the Saparua feeder, Bus 67 of the Tenggara feeder, Bus 194 of the Hatawano feeder, and Bus 217 of the Pohar feeder, under four different fault conditions.

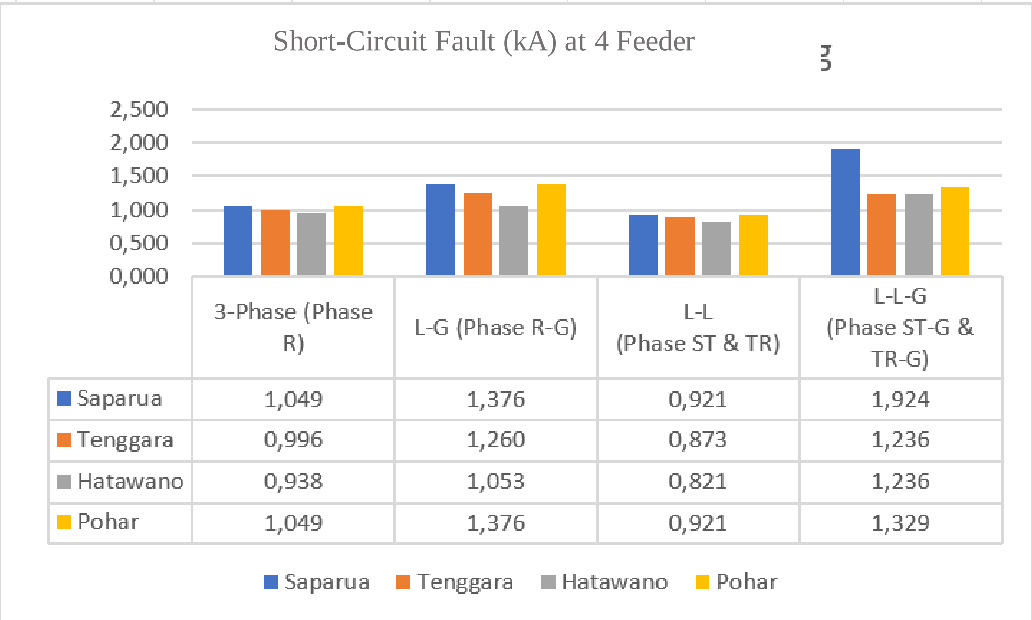


Fig 4. Graph of Short-Circuit Fault Currents Under Four Phase Conditions Across Four Feeders

The Customer Service Unit (ULP) Saparua is a power generation facility located in Negeri Tiow and operates under the UP3 Ambon sub-unit. The ULP is equipped with 9 generator units, 7 of which are active and 2 inactive, with a total capacity of 3,860 kW. The system includes four feeders: The Saparua feeder, supplying 7 distribution transformers. The Tenggara feeder, supplying 26 distribution transformers. The Hatawano feeder, supplying 20 distribution transformers (including 1 inactive transformer). Therefore, ULP Saparua plays a vital role in efficiently supplying electrical energy to the surrounding communities.

IV. CONCLUSION

Based on all the simulation results presented, it can be concluded that:

1. the L-L-G (double line-to-ground) fault consistently produces the highest fault current compared to other types of faults such as L-L and three-phase faults.
2. the fault current tends to decrease as the distance from the power source increases, due to the rising impedance of the distribution network.
3. The farther the distance from the power source (generator), the smaller the resulting short-circuit current will be.

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