Fault Current Analysis on 20 Kv Feeder At PLN ULP Sipirok to Determine Fault Location in Order to Accelerate Recovery Time

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Abstract

Disturbances in the electricity distribution system, especially on the 20 kV feeder, can cause significant power outages and impact the continuity of service to customers. This study aims to analyze the fault currents that occur on the 20 kV feeder in the PLN ULP Sipirok working area to determine the fault location more accurately and quickly. The methods used include collecting fault data from protection relays and recording fault currents, as well as calculating the fault location using a current and impedance comparison approach. The analysis results show that identifying the fault location with this approach can increase the speed of fault handling and reduce system recovery time. Thus, a more integrated and effective fault current protection and monitoring system is needed to improve the reliability of the electricity distribution network in the area.

Keywords: ***Fault Current, 20 KV Feeder, Fault Location, Recovery Time, and Electricity Distribution***

Introduction

With the advancement of technology, PLN is not only required to provide electricity but also to ensure its sustainable availability as a key prerequisite for driving economic growth. Without an adequate electricity supply, economic development will not proceed as expected. Furthermore, PLN is required to maintain continuity of service to all its customers. As a state-owned enterprise mandated by the government to manage national electricity, PT PLN (Persero) is obliged to maintain the reliability of electricity supply to avoid blackouts, whether caused by disruptions in generation or distribution.

However, when disruptions occur, PLN must be able to address these challenges through various transformations, improvements, and innovations. At a minimum, the company must minimize recovery time to minimize the impact of outages on customers. Speed in resolving disruptions will directly impact the performance of the SAIDI indicator and ultimately increase public trust in PLN's services.

Recovery time itself is part of the individual employee performance indicators, with a maximum target of 120 minutes per month. Meanwhile, SAIDI, as explained in PT PLN (Persero) Circular Letter No. 0004.E/DIR/2014, is an indicator that measures the average duration of permanent power outages (more than 5 minutes) experienced by customers at a particular service unit within a certain period of time, and is calculated in minutes per customer.

The SAIDI formula can be written as follows:

$$\text{SAIDI} = \frac{\text{Number of permanent customer outages in a given period}}{\text{Total number of customers in one unit}}$$

Information :

a. SAIDI: System Average Interruption Duration Index
b. Number of permanent customer outages in a given period: length of outage x number of outage customers
c. Total number of customers in one unit: clear
d. KPI Type: Negative Polarity (-)
e. Unit: minutes/customer

Based on the formula above, it can be seen that minimizing the SAIDI value can be achieved by minimizing the duration of outages (in this case, outages caused by disruptions to feeder facilities) or by minimizing the number of customers affected by outages. This final project will focus on minimizing recovery time and shortening the duration of outages caused by disruptions.

Literature Review

2.1 Source Impedance Calculation

The source impedance value is obtained using the data contained in the source generator specifications. Generator data is usually expressed as a percentage or per unit of specified power and voltage. The source's secondary reactance can be calculated using the following formula:

$$X_s = \frac{V^2}{P_{sc}}$$

Where:

X_s = Source Reactance (Ω)
V = Source Voltage (V)
P_{sc} = Short Circuit Power (MVA)

The value of Psc itself can be found using the following equation:

$$P_{sc} = \sqrt{3} \text{ x } V_{nominal} \text{ x } I_{sc}$$

Where:
P_{sc} = Short circuit power of source (MVA)
$V_{nominal}$ = Nominal voltage of the source (V)
I_{sc} = Primary side short circuit current at source (A)

2.2 Transformer Impedance

When calculating the impedance value of a transformer, only its reactance value is used, while the resistance value is not taken because the system value is assumed to be in a transient state. The following is the formula for calculating the impedance value of a transformer:

$$XT = \frac{V^2}{P}$$

Where,
XT = Transformer impedance (Ω)
V = Secondary side voltage of the transformer (V)
P = Transformer power capacity (MVA)

1. Positive sequence impedance and negative sequence impedance
   The formula that can be used to calculate the positive sequence impedance and negative sequence impedance values on a transformer is as follows:

   XT1= %known reactance x ZT ………………

2. Zero sequence impedance
   To find the value of zero sequence reactance (XT0) it is necessary to first know the capacity of the delta winding contained in the transformer, if
   a. In a transformer with a ΔY connection where the delta winding capacity in the transformer is the same as the Y winding capacity, then:

      $X_{T0} = X_{T1}$ …

   b. In a power transformer that has a YYΔ winding connection, where the delta winding capacity is usually 1/3 of the Y winding capacity, then:

      $X_{T0} = 3 \times X_{T1}$

   c. In a power transformer that has a YY winding connection and does not have a delta winding in the transformer, then:

      X_{T0}= between 9 to 14 x X_T

   Where :
   X_{T0}= Zero sequence transformer impedance (Ω)
   X_{T1}= Positive and negative sequence transformer impedance (Ω)

Table 1. Resistance (R) and reactance (XL) of 20 kV AAAC conductor (SPLN 64: 1985)

Wide Cross-section (mm2)	2mm fingers	Tendon	GMR (mm)	Positive sequence impedance (Ohm/km)	Zero Sequence Impedance (ohm/km)
16	2,2563	7	1.6380	2.0161 + j0.4036	2,1641+ j1,6911
25	2,8203	7	2.0475	1.2903 + j0.3895	1.4384 + j1.6770
35	3,3371	7	2.4227	0.9217 + j0.3790	1.0697 + j1.6665
50	3,9886	7	2,8957	0.6452 + j0.3678	0.7932 + j1.6553

Wide Cross-section (mm2)	2mm fingers	Tendon	GMR (mm)	Positive sequence impedance (Ohm/km)	Zero Sequence Impedance (ohm/km)
70	4,7193	7	3,4262	0.4608 + j03572	0.6088 + j1.6447
95	5,4979	19	4,1674	0.3096 +j0.3449	0.4876 +j1.6447c
120	6,1791	19	4.6837	0.2688 + j0.3376	0.4168 + j1.6324
150	6,9084	19	5.2365	0.2162 + j0.3305	0.3631 + j1.6180
185	7,6722	19	5,8155	0.1744 + j0.3239	0.3224 + j1.6114
240	8,7386	19	6.6238	0.1344 +j0.3158	0.2824 + j1.6034

2.3 Line Impedance

Positive sequence and negative sequence impedance The formula used to calculate positive sequence impedance and negative sequence impedance is as follows:

$$Z_1 = Z_2 = L \times Z_1 \text{ or } Z_2$$

Where:
Z_1 = Positive sequence impedance (Ω)
Z_2 = Negative sequence impedance (Ω)
L = Length of conductor (km)

Zero Sequence Impedance The formula used to calculate zero impedance is as follows:
$Z_0 = L \times Z_0$
Where:
Z_0 = Zero sequence impedance (Ω)
L = Length of conductor (km)

2.4 Total Impedance

The total impedance of each positive sequence and negative sequence component is Z_1 equivalent and Z_2 equivalent. Where the values of Z_1 equivalent and Z_2 equivalent can be found using the following equation:

Z_1 equivalent = Z_2 equivalent = $Z_{S1} + Z_{T1} + Z_1$feeder

Then to find the equivalent Z_0, which is the total impedance of all zero sequences on each component in the power system up to the fault point, it can be found using the following equation:

Z_0 equivalent = $Z_{T0} + 3_{RN} + Z_0$feeder

Where:
Z_1equivalent = Total positive sequence impedance (Ω)
Z_2equivalent = Total negative sequence impedance (Ω)
Z_0equivalent = Zero sequence total impedance (Ω)
Z_{S1} = Total impedance of positive sequence and negative sequence of source (Ω)
Z_{T1} = Total positive sequence impedance of the power transformer (Ω)
Z_{T0} = Total zero sequence impedance of the transformer (Ω)
R_N = Neutral resistance (grounding) (Ω)
Z_1feeder = Total positive/negative sequence impedance of the cable (Ω)
Z_0feeder = Total impedance of zero cable (Ω)

2.5 Three Phase Short Circuit Fault

Figure 1 shows a schematic of a three-phase fault. A three-phase short circuit is a symmetrical fault, meaning the voltage and current values in each phase remain equal or balanced. Therefore, this three-phase short circuit can be analyzed using only the positive sequence.

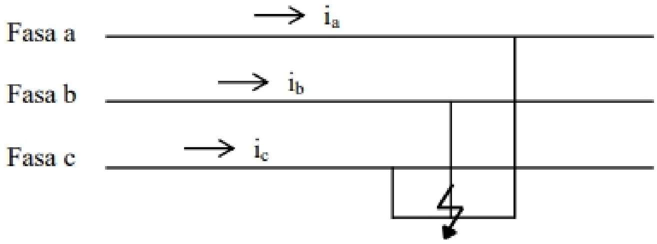


Figure 1. Three Phase Short Circuit Fault

To find the short circuit current value for a three-phase short circuit fault, you can use the following formula:

$$I_{SC}\,3_{\text{ fasa}} = \frac{V_{ph}}{Z_1}$$

Where
V_{ph} = Neutral Phase Voltage (V)
Z_1 = Positive sequence impedance(Ω)

2.6 Two Phase Short Circuit Fault

Figure 2 shows a schematic of a two-phase short circuit. A two-phase short circuit, also known as a phase-to-phase short circuit, is a fault in which one phase is briefly connected to another. In this type of short circuit, the current flowing in the line does not contain a zero-sequence component. This is because there is no fault connected to ground.

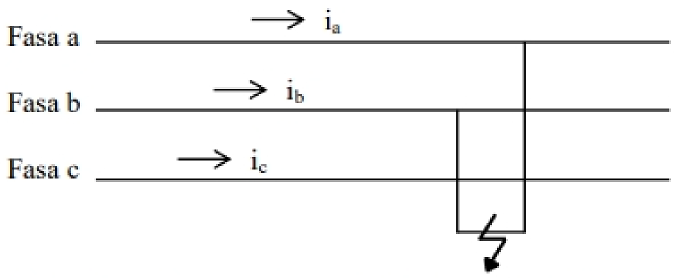


Figure 2. Two Phase Short Circuit Fault

To find the value of the two-phase short circuit current, you can use the equation below.

$$I_{sc}\,2 \text{ Fasa} = \frac{V_f}{Z1+Z2}$$

Where :
V_f = Voltage before the disturbance occurs (V)
Z_1 = Positive sequence impedance (Ω)
Z_2 = Positive negative sequence impedance (Ω)

2.7 Single Phase Short Circuit to Ground Fault

Figure 3 shows a schematic representation of a single-phase to ground short circuit. A single-phase to ground short circuit is a common fault in power systems. This fault is classified as an asymmetrical fault, requiring the use of symmetrical component analysis to analyze the current and voltage at the time of the fault. This fault can be analyzed by shorting all voltage sources in the system and replacing the fault node with a voltage source that has the same magnitude as the voltage just before the fault occurred at the fault point. [15] With this method, unbalance in a three-phase system can be represented using symmetrical component theory, which consists of positive-sequence, negative-sequence, and zero-sequence components. For more details, see the following single-phase to ground short circuit schematic.

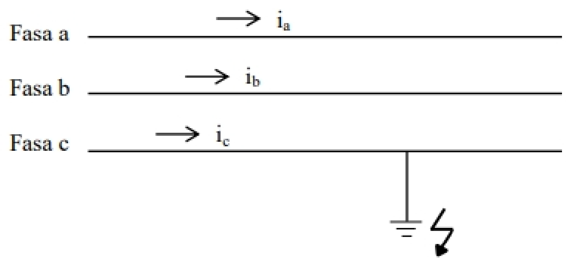


Figure 3. Single Phase Short Circuit to Ground Fault

To calculate the short circuit current from one phase to ground, you can use the following formula:

$$I_{sc}1f_n = \frac{3xVph}{Z1eq+Z2eq+Z0eq}$$

$$I_{sc}1f_n = \frac{3xVph}{Z1eq+Z2eq+Z0eq}$$

Since Z1eq = Z2eq, then :

$$I_{sc}1f_n = \frac{3xVph}{(2\ xZ1eq)+Z0eq}$$

Where:
$I_{SC}\ 1f_n$ = Single phase to ground short circuit current (A)
V_{ph} = System phase – neutral voltage (V)
Z_1eq = Positive sequence impedance (Ohm)
Z_0eq = Zero sequence impedance (Ohm)

Research Methodology

This study uses a descriptive quantitative approach with a fault current analysis method based on field data and simulations. The objective of this method is to determine the characteristics of the fault current and determine the estimated location of the fault on a 20 kV feeder to accelerate the recovery time of the electricity distribution system. The data used in this study were obtained from two main sources:

a. Primary data: in the form of recording results of fault currents and disconnection times from protective devices such as feeder relays, reclosers, as well as data from SCADA at PLN ULP Sipirok.
b. Secondary data: in the form of a single line diagram (SLD), technical data on the distribution network (feeder length, line impedance, network configuration), and historical disruption reports from the service unit.

The steps taken include:

a. Determine the measured fault current value when the fault occurs.
b. Perform line impedance calculations for each 20 kV feeder segment.

c. Using the fault current to impedance ratio formula to determine the estimated location of the fault point based on the distance from the substation.

Commonly used formulas

$$L = \frac{V}{Igangguan . Zperkm}$$

with:

L = distance of fault point from GI (in km)
V = nominal line voltage (20 kV)
I_{fault} = measured fault current
$Z_{per\ km}$ = line impedance per kilometer

To verify the calculation results:

a. ETAP software or Excel-based manual calculations are used to simulate fault current profiles at several network points.
b. Compare the results of the estimated fault point with the actual fault location in the field (data from the operations team).

The estimated fault location results are compared with actual fault handling to determine the accuracy and speed of detection. Then, the method's ability to accelerate recovery time and reduce the System Average Interruption Duration Index (SAIDI) is evaluated.

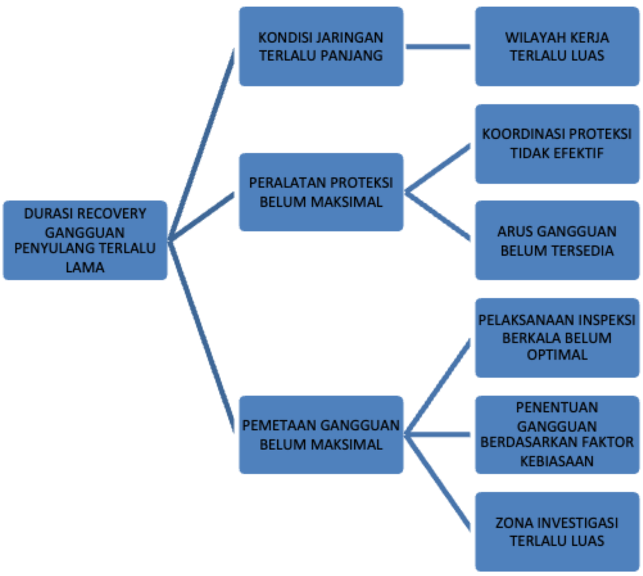


Figure 4. Research flow chart

Table 2. FGD - Determination of Priority Matrix

NO	Opportunities for Improvement	Idea Initiative	Difficulty Level					Impact				
			0	**1**	**2**	**3**	**4**	**0**	**1**	**2**	**3**	**4**
1	Recovery Time Error Repair	Increasing the Number of Office Guard Posts and Officers	v								v	

NO	Opportunities for Improvement	Idea Initiative	Difficulty Level					Impact				
		Replacing Operational Vehicles According to Field Conditions		v						v		
2	Improvement of SAIDI and Operational Communication Quality	Adding and Coordinating Protection Equipment Settings			v					v		
		Building a 20 KV GI and GH SCADA System			v					v		
3	Effectiveness of Disruption Investigation and Acceleration of Disruption Recovery Time	Conducting Upskilling for Technical Service Officers				v		v				
		Creating a Simulation Application for Determining the Location of Disturbances			v						v	

Information :

Difficulty level		**Impact**	
0	Very difficult	0	No impact
1	Difficult	1	Less impactful
2	Currently	2	Currently
3	Easy	3	Impact
4	Very easy	4	Very impactful

Results

4.1 Results of Overcurrent Relay and Ground Fault Relay Settings.

Setting the 20kV side feeder overcurrent relay Calculating the relay installed on the feeder based on the maximum load current. The maximum load current flowing on the PLR13 feeder according to data obtained from APJ is 371.42 A. The inverse relay is usually set between 1.05 – 1.1 x Imax. Relay settings need to pay attention to the current and working time of the relay, the feeder relay must work faster than the incoming relay and then the incoming must work faster than the 150kv side. There is a mutual agreement according to data from PLN (Persero) regarding the relay working time settings that have been set, namely on the feeder side 0.5s, the incoming side 1s, and the 150kv side. 1.5s (Galih, 2017).

I_{burden} = 371.42 Amperes, CT = 800/5

Iset (primary)= 1.05 x I_{burden}

= 1.05 x 371.42

=390A

Table 3. Equivalent Impedance Z1eq (Z2eq)

Long Channel (%)	Feeder Impedance $Z_{1eq}(Z_{2eq})$
25	0.014 + j0.162 pu
50	0.028 + j0.195 pu
75	0.042 + j0.228 pu
100	0.057 + j0.262 pu

Z0eq

= Z0T + 3RN + Z0feeder

= j8.21 + (3 x 1) + Z0feeder

Z0eq in pu

= j8,21 + 36.67
= j1,231 + 0.45 + Z_0feeder

Table 4. Equivalent Impedance Z0

Channel Length (%)	Feeder Impedance Z_0eq
25	0.479 + j1.401 pu
50	0.509 + j1.571 pu
75	0.539 + j1.741 pu
100	0.569 + j1.912 pu

Table 5. Short Circuit Current Calculation Results

Long Channel (%)	Short Circuit Three Phases	Short Circuit Two Phases	Short Circuit One Phase to ground
25	10689.90∠-85 A	9219.43∠ -85 A	1588.24∠-72.4 A

50	8791.63□ -81.8 A	7603□ -81.8 A	1408.11□-73 A
75	7413□-79.5 A	6470.7□-79.5 A	1266.09□-73.5 A
100	6462.09□ -77.7 A	5589.1□-77.7 A	1148.31□-73.9 A

4.2 Setting the Overcurrent Relay and Ground Fault Relay

Setting the 20kV side feeder overcurrent relay Calculating the relay installed on the feeder based on the maximum load current. The maximum load current flowing on the PLR13 feeder according to data obtained from APJ is 371.42 A. The inverse relay is usually set between 1.05 – 1.1 x Imax. Relay settings need to pay attention to the current and working time of the relay, the feeder relay must work faster than the incoming relay and then the incoming must work faster than the 150kv side. There is a mutual agreement according to data from PLN (Persero) regarding the relay working time settings that have been set, namely on the feeder side 0.5s, the incoming side 1s, and the 150kv side. 1.5s (Galih, 2017).

I_{burden} = 371.42 Amperes, CT = 800/5

Iset (primary) = 1.05 x I load

= 1.05 x 371.42

=390A

Table 6. Three Phase Fault Relay Working Time

Location Disturbance	Relay Working Time Incoming	Relay Working Time Feeder	Difference Time
25%	0.970	0.490	0.48
50%	1,093	0.522	0.571
75%	1,227	0.553	0.674

Table 7. Two Phase Fault Relay Working Time

Location Disturbance	Relay Working Time Incoming	Relay Working Time Feeder	Difference Time
25%	1,060	0.514	0.54
50%	1,205	0.548	0.65
75%	1,361	0.581	0.78
100%	1,541	0.614	0.92

Table 8. Comparison of Calculation Results with Existing Data

No	Relay Types	Calculation Result Data	Existing Data
1	OCR (Incoming)	TMS = 0.25 CT ratio = 2500/1 A	TMS = 0.24 CT ratio = 2500/1 A
2	OCR (Feeder))	TMS = 0.244 CT ratio = 800/5 A	TMS = 0.275 CT ratio = 800/5 A
3	GFR (Incoming)	TMS = 0.41 CT ratio = 2500/1 A	TMS = 0.44 CT ratio = 2500/1 A
4	GFR (Feeder)	TMS = 0.192 CT ratio = 800/5 A	TMS = 0.36 CT ratio = 800/5 A

From the calculation results, the distance to the fault location affects the value of the short-circuit current. The closer the fault location, the smaller the short-circuit current value. And based on the calculation data, the largest value of the three-phase short-circuit current is 10689.90□-85 A and the smallest value of single-phase short-circuit current to ground is 1148.31□-73.9 A, and the feeder relay operates faster than the incoming relay according to its settings. The size of the relay time value is influenced by distance, the closer the distance to the area affected by the disturbance, the smaller the relay working time value.

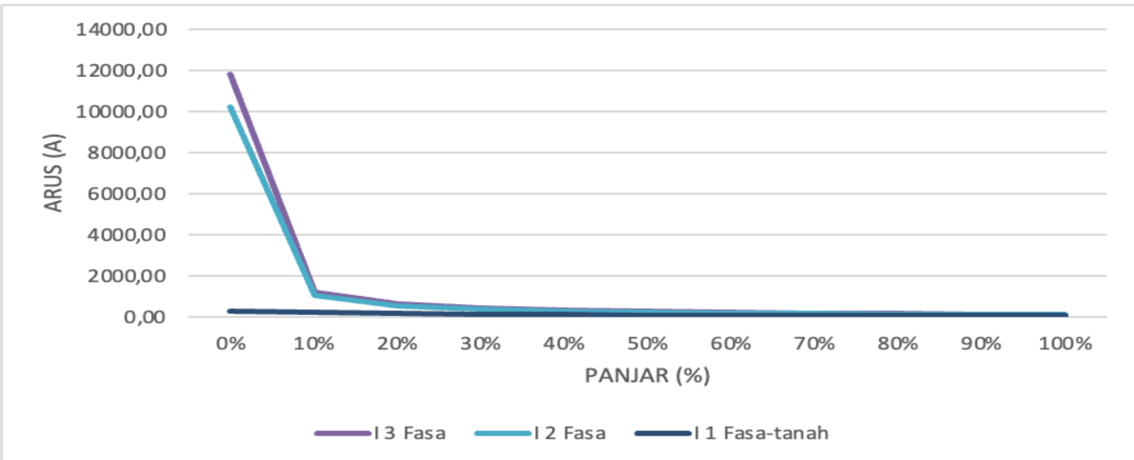
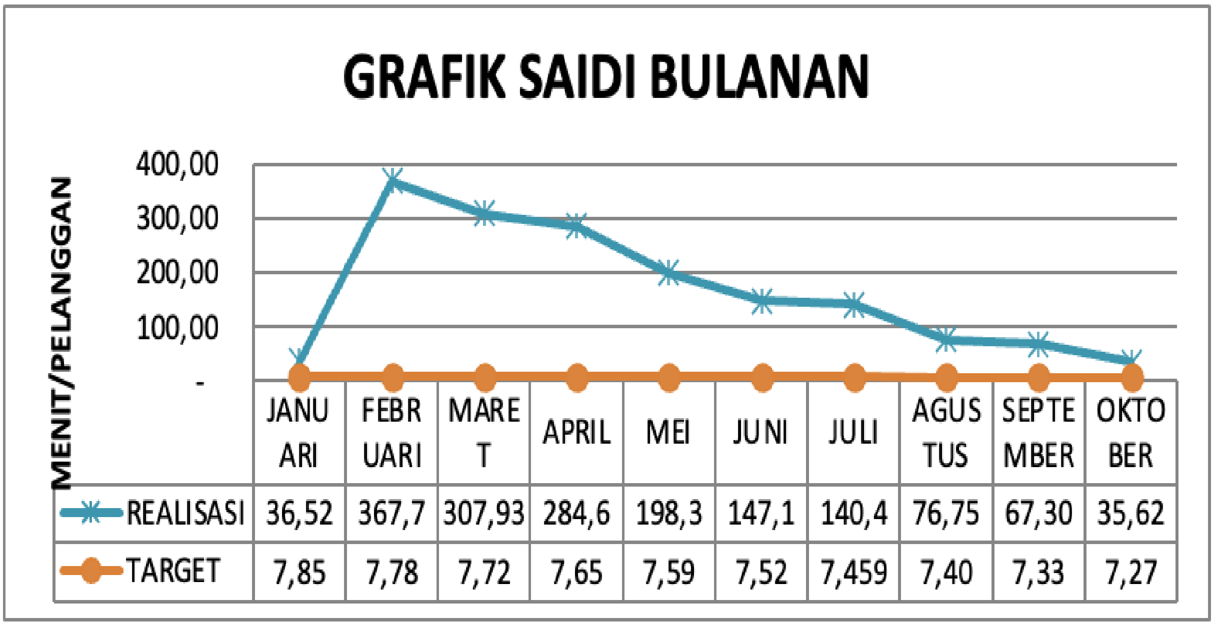


Figure 5. Fault Current Against Fault Distance

From the graph above shows the comparison of the value of the short circuit fault current of 3 phase, 2 phase and 1 phase to the ground to the distance of the fault point, it can be seen that the magnitude of the short circuit current that occurs in the 20 Kv feeder is influenced by the distance of the fault point, the further the distance of the fault point, the smaller the short circuit fault current that occurs and vice versa, the closer the distance of the fault point, the greater the short circuit fault current that occurs. This proves that the magnitude of the fault current depends on the length of the feeder. This is because the magnitude of the conductor impedance depends on the length and type of conductor and the diameter used. It can be seen that the largest magnitude of the short circuit fault current occurs in the 3 phase short circuit fault while the smallest short circuit fault occurs in the 1 phase short circuit fault to the ground

4.3 Feeder Results.

Based on the results of the simulation implementation in the field for 2 months, the following results were obtained where Before the simulation assistance, each feeder that trips/disrupts, then section 1 will be released then tracking/investigation of the cause of the disturbance in section 1. If declared safe, then the feeder may be entered from the main substation/connection substation, and so on until the disturbance can be found. With the help of this application, the feeder that is experiencing disturbance can be directly known the predicted location of the disturbance with the detection radius as we want, thus, the officers in the field only need to release the section closest to the predicted point of the disturbance for further investigation. As well as the average achievement of SAIDI in January - July ULP Sipirok = 211.82 minutes / customer, down by 71.72% from the average realization of SAIDI in August - October 2019 which was 59.89 minutes / customer Based on the results of the calculation of unplanned outages of feeder facilities. Where the average achievement of Recovery Time for January - July of ULP Sipirok = 50.35 minutes, down by 48.54% from the average realization of SAIDI for August - October 2019, which was 25.91 minutes.



	JANUARI	FEBRUARI	MARET	APRIL	MEI	JUNI	JULI	AGUSTUS	SEPTEMBER	OKTOBER
REALISASI	36,52	367,7	307,93	284,6	198,3	147,1	140,4	76,75	67,30	35,62
TARGET	7,85	7,78	7,72	7,65	7,59	7,52	7,459	7,40	7,33	7,27

Figure 6. Monthly SAIDI Realization

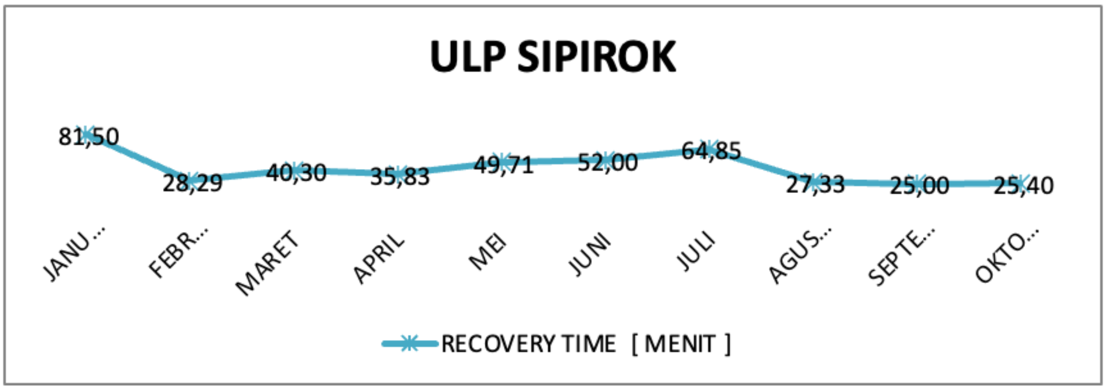


Figure 7. Monthly Recovery Time Realization

From the two figures above, it can be concluded that after the implementation of SAIDI performance and Recovery Time, the dominant improvement occurred from month to month, meaning that the application contributed to the process of improving SAIDI performance, especially at the Sipirok ULP. And the recovery duration of feeders affected by outages caused by disturbances was too long, this was because the disturbance mapping was not optimal and the disturbance investigation zone was too wide.

Conclusion

Based on the results of the fault current analysis that has been carried out on the 20 kV feeder in the PLN ULP Sipirok work area, it can be concluded that:

1. Fault currentThe information recorded by the protection and relay system can be used as the primary parameter in quickly and accurately estimating the location of a fault. By knowing the fault current and line impedance, the fault location can be estimated based on the distance from the source (substation).
2. Fault location calculation method Using a per-kilometer impedance analysis approach has proven effective in providing an initial location of a fault without requiring a thorough inspection of the entire distribution line. This greatly assists the engineering team in making initial decisions in the field.
3. Practical application of this method can speed up outage recovery time by making the location search process more targeted and efficient. This contributes to a reduction in the System Average Interruption Duration Index (SAIDI) and increases the reliability of electricity supply to customers.
4. By implementing a fault current analysis system integrated with historical data and SCADA systems, PLN can improve operational response to disruptions, minimize affected areas, and increase customer confidence in the quality of electricity distribution services.

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