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Distance relay protection study using etap software at the Langsa substation on 150 kV transmission line

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ABSTRACT

The reliability of an electric power system is strongly influenced by the ability of its protection system to detect and isolate faults quickly, selectively, and reliably. One of the protection devices used on transmission lines is the distance relay, which operates based on the measurement of impedance between the relay location and the fault point. This study aims to evaluate the suitability of distance relay settings on the 150 kV Langsa Substation–Tualang Cut Substation transmission line and to analyze coordination among protection zones using Electrical Transient Analysis Program (ETAP) software. The study was conducted by comparing the existing relay settings with theoretical calculation results and three-phase fault simulation results. The research objects consisted of Tualang Cut 1, with a line length of 22.1 km, and Tualang Cut 2, with a length of 88.7 km. The results show that the existing settings for Tualang Cut 1 remain relatively suitable. However, Tualang Cut 2 exhibited underreach conditions of 21.7% in Zone 1, 32.6% in Zone 2, and 83.6% in Zone 3. Based on the evaluation results, new settings of 15.8 Ω for Zone 1, 23.7 Ω for Zone 2, and 43.4 Ω for Zone 3 are recommended. Simulation results indicate that the recommended settings provide graded protection coordination.

Keywords: Distance Relay, Protection System, 150 kV Transmission, ETAP, Protection Coordination.

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1. INTRODUCTION

A modern electric power system is an integrated system connecting generating units, transmission systems, and distribution systems, together with their protection systems, to deliver electrical energy from sources to customers or consumers [1]. The electricity supply system of PT PLN (Persero) consists of three main business processes: generation, transmission, and distribution. Transmission lines are essential for connecting generation centers to load centers. The use of high voltage is important for reducing power losses during transmission because generating stations, particularly those with low operating costs, are generally located far from consumers [2].

Transmission lines are crucial components of electric power systems because they transfer electrical energy from generating sources to load locations. Faults on transmission lines can

affect service continuity and threaten system reliability; therefore, the protection system must be able to detect and isolate only the affected section selectively [3].

The protection system on transmission lines must be designed to operate properly in coordination with all protection devices installed in the system. When a network fault occurs, only the affected section should be isolated. This means that the damaged section must be disconnected without affecting other parts of the network that are still operating properly [4].

Distance relays are commonly used to protect transmission lines. Their operating principle is based on the apparent impedance between the relay location and the fault point. Protection is generally divided into several zones with different reaches and operating times, allowing Zone 1 to provide primary protection while Zones 2 and 3 provide backup protection with time delays [5][6].

Previous studies have evaluated distance relay settings, relay coordination, fault-location estimation, and adaptive protection under changing network conditions [7]. Tayeb and Utomo showed that reconductoring of the 150 kV Babat–Lamongan line changed the line impedance, so that settings based on outdated parameters left Zone 1 of the adjacent Ngimbang–Babat relay covering only 72.84% of the line, below the 80% criterion [2]. Shodik and Hajar evaluated the existing distance relay settings of a 150 kV line against IEEE C37.113 using DIgSILENT PowerFactory [3], Ulum and Utomo analyzed the distance relay coordination settings of the 150 kV PLTMG Baubau–Baubau–Raha system [4], Adi and Muljono evaluated relay performance through protection testing at the Sengkol–Kuta line bay [5], and Utami et al. simulated protection coordination using ETAP [6]. These studies show that the performance of each relay depends on the actual line impedance, line length, network configuration, and existing setting parameters [8]. However, most of them evaluate the settings either by calculation or by simulation alone, and few quantify the agreement between the theoretical impedance used to derive the settings and the apparent impedance obtained from the simulation.

This study evaluates two circuits within the 150 kV Langsa–Tualang Cut corridor, namely Tualang Cut 1 (22.1 km) and Tualang Cut 2 (88.7 km). Although Tualang Cut 2 is four times longer, its existing Zone 1 and Zone 2 settings are also only about four times those of Tualang Cut 1; in other words, they correspond to the same impedance per kilometer as the short circuit and not to the actual impedance of the 88.7 km line. This indicates that the Tualang Cut 2 settings were not recalculated from the actual line parameters, which causes a significant underreach. The contribution of this work is the identification of this inadequate protection reach by comparing existing settings, theoretical impedance calculations, and ETAP fault simulations, followed by proposed revisions to the zone settings and their validation through a comparison between theoretical and simulated impedances [9].

ETAP software is used to design and simulate electric power network systems. In addition to power-flow analysis, ETAP can also be used to analyze problems such as unbalanced power flow, short circuits, arc flash, motor starting, harmonics, protection coordination, transient stability, and others [10].

2. RESEARCH METHOD

2.1. Research Location and Object

The study was conducted on the 150 kV transmission system from Langsa Substation to Tualang Cut Substation. The analyzed system consists of two transmission lines:

1. 1. Tualang Cut 1 with a line length of 22.1 km.
2. 2. Tualang Cut 2 with a line length of 88.7 km.

This study aims to analyze the performance of distance relays at the Langsa Substation 150 kV line using ETAP 19.0.1 simulations based on the IEC 60909 standard. The results are expected to provide technical insight for improving protection-system reliability and reducing the need for circuit-breaker replacement on electric power transmission lines [11].

The system parameters used in this study include line length, conductor impedance, CT and PT data, and existing distance relay settings [12].

2.2. Research Stages

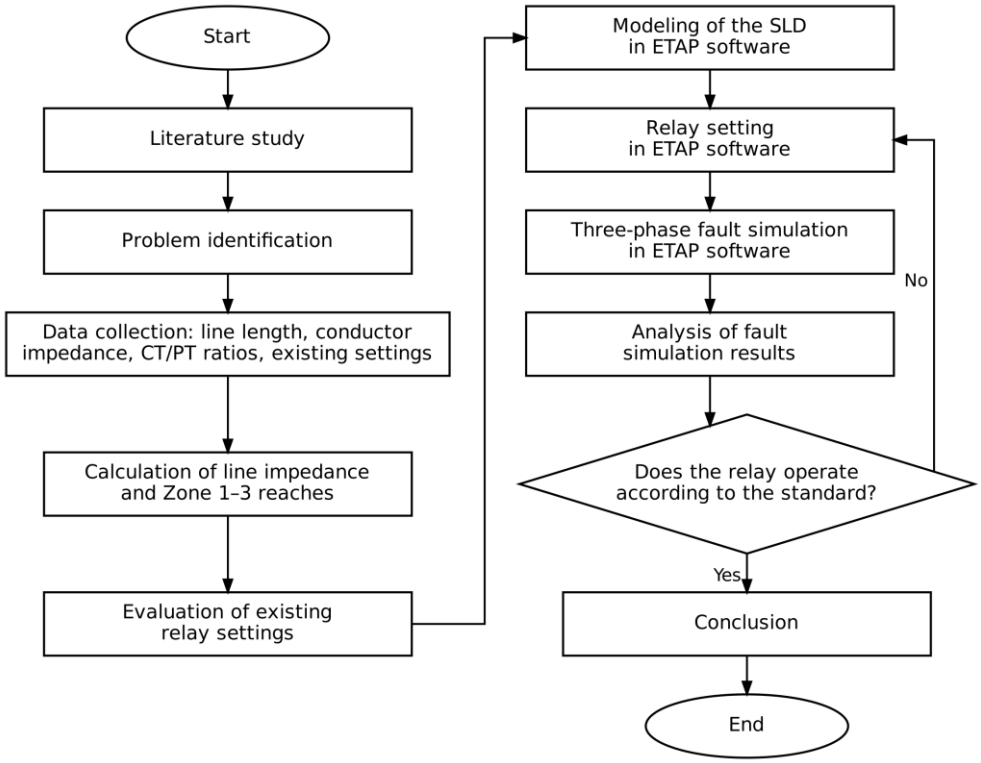


Figure 1. Research flowchart

The research was carried out systematically following the stages in Figure 1. First, a literature study was conducted on distance protection principles and setting criteria. Second, the problem was identified by examining the existing relay settings of both circuits. Third, the system data were collected, including line length, conductor impedance, CT and PT ratios, and the existing distance relay settings. Fourth, the line impedance and the required reaches of Zones 1–3 were calculated using Eqs. (1)–(6). Fifth, the existing settings were evaluated by comparing them with the calculated reaches. Sixth, the 150 kV system was modeled as a single-line diagram (SLD) in ETAP. Seventh, the distance relay settings were entered into the ETAP Star-Z module. Eighth, three-phase faults were simulated at several locations along the line. Ninth, the simulation results were analyzed and compared with the theoretical calculation. If the relay did not operate according to the zone and time criteria, the settings were revised and the simulation was repeated; otherwise, conclusions were drawn.

2.3 Impedance Reach Calculation

The total line impedance is determined from the impedance per unit length and the line length: ZL = z × l. The calculated impedance is used to evaluate the required reaches of Zones 1, 2, and 3. The existing settings are compared with the calculated requirements and validated through simulation [2].

Line impedance is calculated using the power-system formula:

$$Z_L = (r + jx) \times L \quad (1)$$

$$Z_{primer} = R + jX\ (\Omega) \quad (2)$$

where R and X are the total resistance and reactance of the line on the primary side (Ω).

Application of the relay secondary impedance ratio (Zsecondary):

$$Z_{sekunder} = Z_{primer} \times \frac{\text{Rasio CT}}{\text{Rasio PT}} \quad (3)$$

where Z_{primer} is the line impedance on the primary side (Ω), Z_{sekunder} is the impedance seen by the relay on the secondary side (Ω), Rasio CT = $I_{\text{primary}}/I_{\text{secondary}}$ is the current-transformer ratio, and Rasio PT = $V_{\text{primary}}/V_{\text{secondary}}$ is the potential-transformer ratio. Because the relay measures voltage and current through the PT and CT, a primary impedance is converted into relay (secondary) ohms by multiplying it by Rasio CT/Rasio PT, and a secondary setting is converted into primary ohms by dividing it by the same factor. The R–X diagrams of ETAP used in this study are expressed in primary ohms (Ω-Prim); therefore, the recommended settings must be converted using Eq. (3) before they are entered into the relay.

The protection-zone formulation is determined according to the SPLN reference:
Zone 1:

$$Zona\ 1 = 0{,}80 \times Z_{L1} \quad (4)$$

Zone 1 is designed to provide instantaneous fault clearing without a time delay. To avoid overreach, in which the relay trips for faults occurring outside the protected transmission line due to CT/VT tolerances, uncertainty in line parameters, and transient dynamics, Zone 1 is set to cover only 80% to 85% of the total length of the main transmission line.

Zone 2:

$$Zona\ 2 = 1{,}20 \times Z_{L1} \quad (5)$$

Zone 2 functions to protect the remaining 15%–20% of the transmission-line end section not reached by Zone 1, while also serving as backup protection for Zone 1. The Zone 2 setting must overlap with Zone 1 at the next substation but must not exceed the Zone 1 reach on the subsequent line.

Zone 3:

$$Zona\ 3 = 1{,}20 \times (\ Z_{L1} + 0{,}8\ \times Z_{L2}) \quad (6)$$

Zone 3 is designed as remote backup protection for the entire main line and the entire subsequent transmission line connected to the adjacent bus.

2.4 Simulation Procedure

The procedure consists of data collection, impedance calculation, zone-setting evaluation, ETAP modeling, three-phase fault simulation, and comparison of the resulting protection coverage. Faults are evaluated at locations of 0%, 50%, 80%, 100%, and approximately 110% of the protected line [13].

The 150 kV Langsa Substation power system was modeled using ETAP (Electrical Transient Analyzer Program) through the Star-Z Distance Protection (StarZ) module. This modeling aims to build a digital representation of the system topology so that short-circuit faults can be simulated at various points and locations along the transmission line to observe the distance relay performance response.

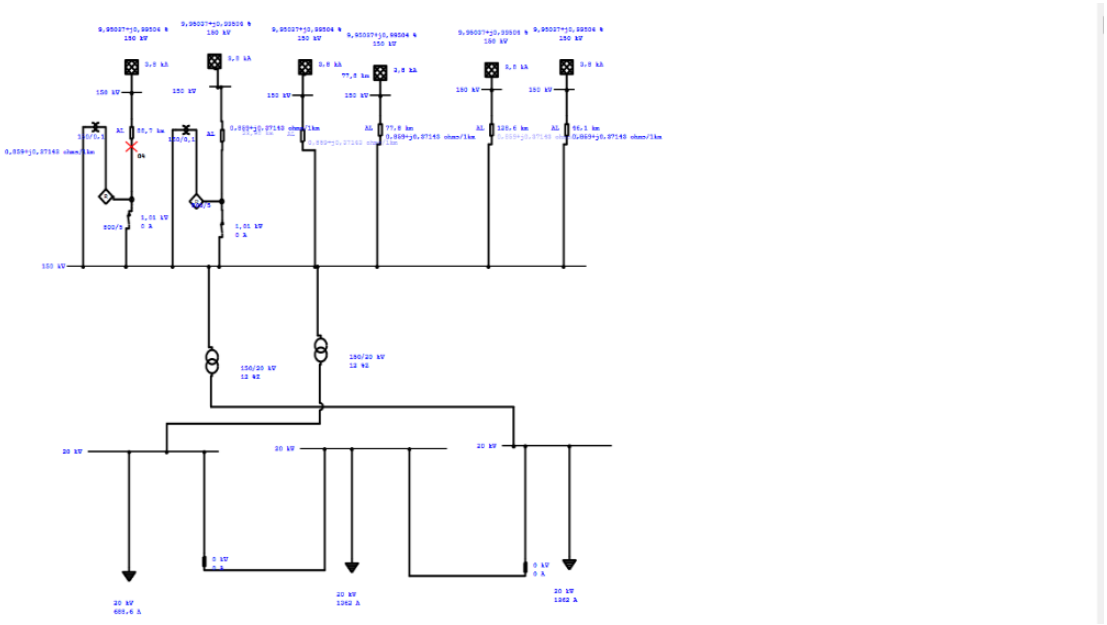


Figure 2. Single-line diagram (SLD) in ETAP software

3. RESULTS AND DISCUSSION

3.1 Existing Distance Relay Settings

Table 1. Existing distance relay settings

Line	Z1 (Ω)	tZ1 (s)	Z2 (Ω)	tZ2 (s)	Z3 (Ω)	tZ3 (s)
Tualang Cut 1	1.07	0	1.62	0.4	2.72	1.2
Tualang Cut 2	4.35	0	6.53	0.4	16.76	1.2

Table 1 indicates that both lines apply similar time settings but have considerably different impedance reaches. Because the second line is longer, its reach must be evaluated based on actual line characteristics rather than solely on the numerical values of the existing settings.

3.2 Comparison of Reach Between Existing Settings and Calculation Results

Table 2. Comparison of reach between existing settings and calculation results

Line	Zone	Existing (Ω)	Calculated (Ω)	Coverage	Evaluation
TC 1	Z1	1.07	0.86	99.6%	Relatively suitable
TC 1	Z2	1.62	1.29	150.7%	Suitable for backup
TC 1	Z3	2.72	2.36	253.1%	Suitable for backup
TC 2	Z1	4.35	16.04	21.7%	Underreach
TC 2	Z2	6.53	24.05	32.6%	Underreach
TC 2	Z3	16.76	44.10	83.6%	Underreach

For Tualang Cut 1, the calculated requirements are 0.86 Ω, 1.29 Ω, and 2.36 Ω, indicating relatively suitable coverage. For Tualang Cut 2, the calculated requirements are 16.04 Ω, 24.05

Ω, and 44.10 Ω. The evaluated reaches are approximately 21.7% for Zone 1, 32.6% for Zone 2, and 83.6% for Zone 3, indicating underreach. Similar studies have reported that changes in line characteristics and network conditions can significantly affect distance relay reach and coordination [5].

The existing settings of Tualang Cut 2 are far below the SPLN criterion of 80% because they do not correspond to the actual impedance of the 88.7 km line. The existing Zone 1 and Zone 2 settings of Tualang Cut 2 (4.35 Ω and 6.53 Ω) are 4.07 and 4.03 times those of Tualang Cut 1 (1.07 Ω and 1.62 Ω), which is practically equal to the ratio of the line lengths (88.7/22.1 = 4.01). Dividing the line impedance implied by the existing Zone 1 setting (Z1/0.8) by the line length gives approximately 0.061 Ω/km for both circuits, whereas the calculated impedance of Tualang Cut 2 corresponds to 20.05/88.7 ≈ 0.226 Ω/km. This indicates that the existing Tualang Cut 2 settings were derived from the impedance per kilometer of the shorter circuit instead of from the actual parameters of the 88.7 km line. As a consequence, Zone 1 operates instantaneously only for faults in roughly the first fifth of the line, faults on most of the line are cleared only by Zone 3 after 1.2 s, and the end section of the line is not covered by Zone 2. A similar condition was reported in [2], where settings based on outdated line parameters left Zone 1 below the 80% criterion, confirming that distance relay settings must be recalculated whenever the line parameters change.

3.3 ETAP Fault Simulation Results

- **Fault Scenario at 50%**

The fault point was placed at 50% of the TLCUT2 line length (±44.35 km from Langsa Substation). The measured fault impedance was Zf = 11.16 ∠ 62.29° Ω, which on the R-X diagram falls within the Zone 1 characteristic (Z1 = 15.8 Ω). This result agrees with the theoretical prediction: a fault at 50% of the line produces an impedance of approximately 50% × Zline ≈ 9.87 Ω, which is below the Z1 threshold; therefore, the relay operates instantaneously (t = 0 s) without a time delay.

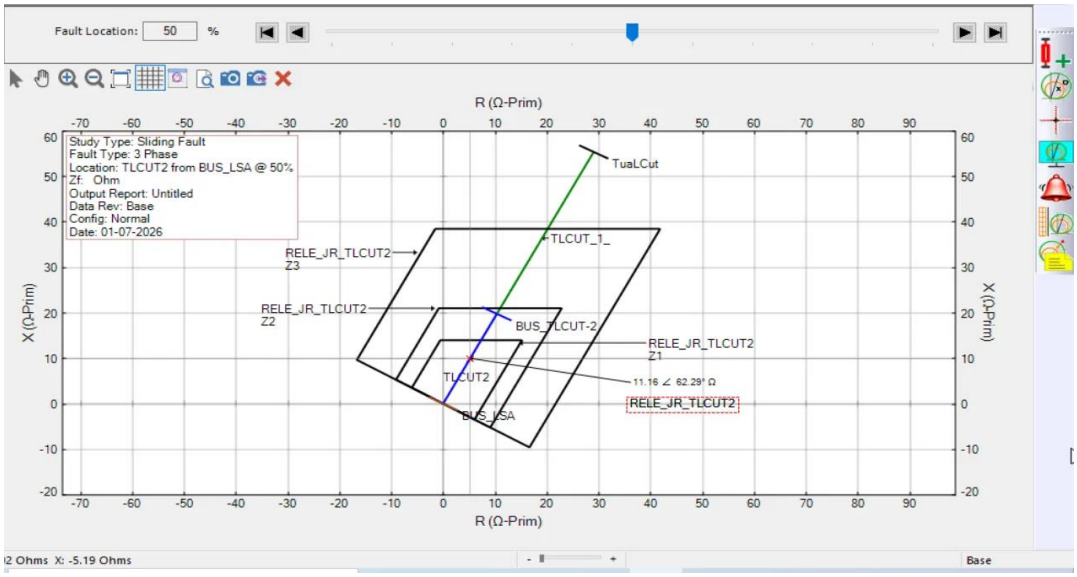


Figure 3. R-X diagram of the 50% line fault simulation result

- **Fault Scenario at 80%**

The fault point was placed at 80% of the TLCUT2 line length (±70.96 km from Langsa Substation), which theoretically represents the Z1 reach limit. The measured fault impedance was Zf = 17.87 ∠ 62.25° Ω, which on the R-X diagram falls within the Zone 2 characteristic (outside Z1 = 15.8 Ω but still within Z2 = 23.7 Ω). The relay operates with a time delay of t = 0.4 s.

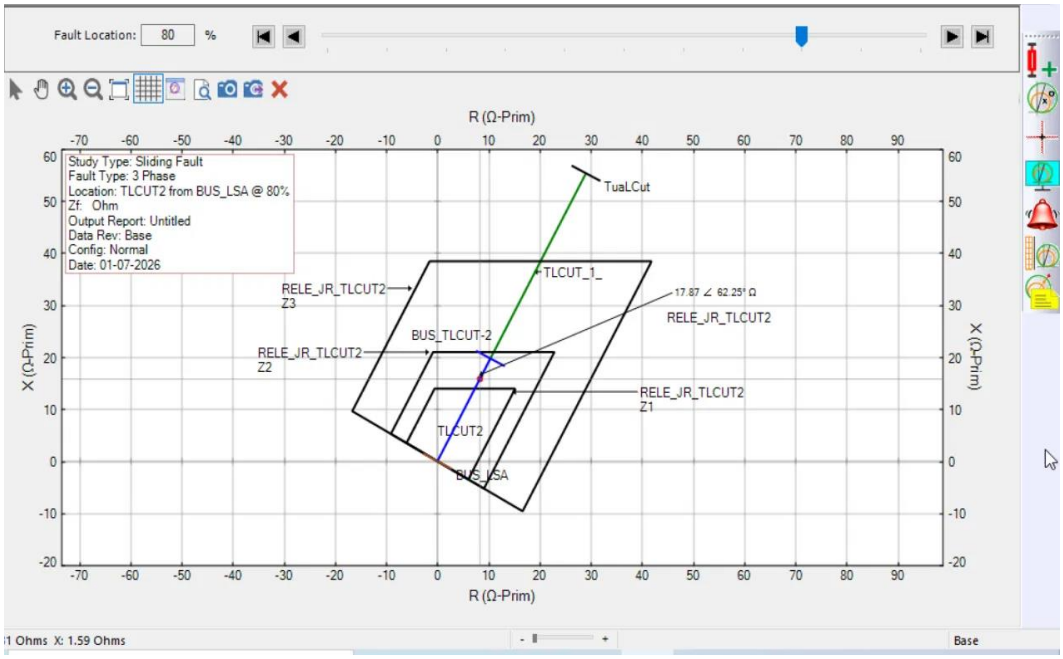


Figure 4. R-X diagram of the 80% line fault simulation result

- **Fault Scenario at 100%**

The fault point was placed precisely at BUS_TLCUT-2 (the end of the TLCUT2 line, 100%), representing a fault occurring directly at the Tualang Cut Substation bus. The measured fault impedance was Zf = 22.37 ∠ 62.22° Ω (R = 10.43 Ω, X = 19.79 Ω), which on the R-X diagram falls within the Zone 2 characteristic (Z1 = 15.8 Ω < Zf = 22.37 Ω < Z2 = 23.7 Ω), very close to the upper boundary of Zone 2. The relay operates with a time delay of t = 0.4 s.

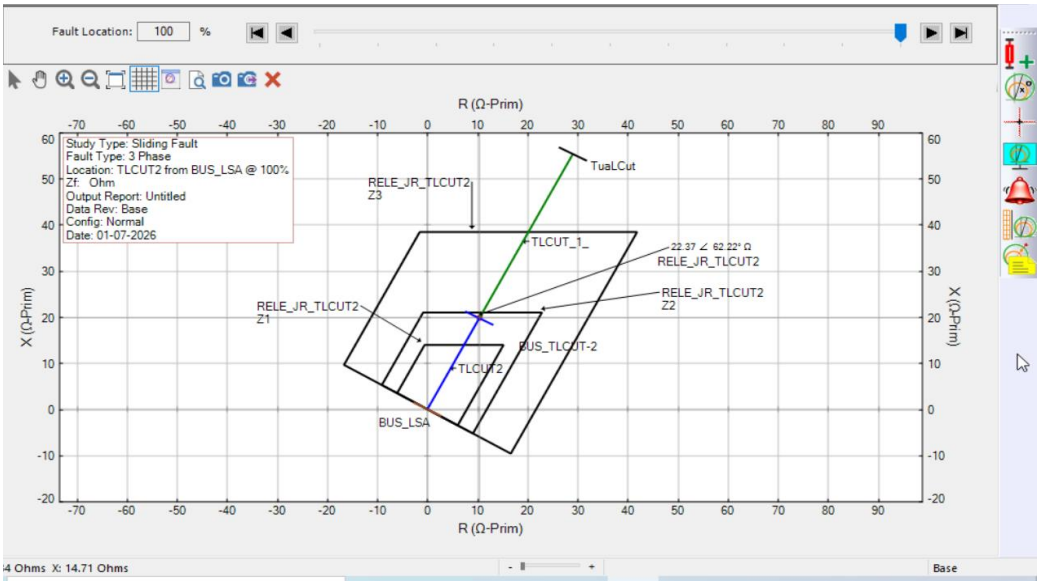


Figure 5. R-X diagram of the 100% line fault simulation result

Table 3. Tualang Cut 2 simulation results

Fault location	Impedance (Ω)	Active zone	Operating time
0%	0	Outside zone	No trip
50%	11.16	Zone 1	0 s
80%	17.87	Zone 2	0.4 s

100%	22.37	Zone 2	0.4 s
110%	32.74	Zone 3	1.2 s

The simulation shows that a fault at 50% distance is detected within Zone 1 and triggers instantaneous operation. At 80% and 100%, the measured impedance falls within Zone 2 coverage and the relay operates after 0.4 seconds. At approximately 110%, the fault is handled by Zone 3 with a time delay of 1.2 seconds. The progression of operation from Zone 1 to Zone 3 indicates that the proposed reach and time settings provide selective backup characteristics.

Based on the simulation results, the operating characteristics of the distance relay on the Tualang Cut 2 line can be analyzed through changes in the impedance values measured at each fault location. The farther the fault location is from the relay installation point, the greater the impedance seen by the relay. These changes in impedance determine the protection zone that will operate.

For faults at approximately 50% of the line length, the impedance value of 11.16 Ω lies within the operating region of Zone 1, so the relay operates without a time delay. When the fault location is at 80% and 100%, the impedance increases to 17.87 Ω and 22.37 Ω, respectively, causing operation to shift to Zone 2 with a 0.4-second delay. At approximately 110%, an impedance of 32.74 Ω is handled by Zone 3 with a 1.2-second delay. These results show a graded shift in operation as the fault distance increases.

3.4 Proposed Relay Settings

Table 4. Proposed relay settings

Parameter	**Existing**	**Recommended**
Zone 1	4.35 Ω	15.8 Ω
t Zone 1	0 s	0 s
Zone 2	6.53 Ω	23.7 Ω
t Zone 2	0.4 s	0.4 s
Zone 3	16.76 Ω	43.4 Ω
t Zone 3	1.2 s	1.2 s

These proposed values provide reaches that are closer to the calculated protection requirements while maintaining coordinated backup operation [14]. Adjusting the impedance values from the existing settings to the recommended ones aligns the protection coverage of each zone more closely with the results of calculations and fault simulations. Furthermore, maintaining a graded timing scheme ensures that the protection system operates selectively based on the fault location.

The recommended values in Table 4 are slightly lower (about 1.5%) than the calculated requirements in Table 2 (15.8 versus 16.04 Ω, 23.7 versus 24.05 Ω, and 43.4 versus 44.10 Ω). The ratio between the two sets is practically constant for all zones (0.984–0.985), which shows that the difference is not caused by zone-specific safety factors or by the relay characteristic angle, but by the line impedance used as the basis of the calculation. Table 2 is based on a line impedance of 20.05 Ω, whereas the recommended settings are based on a line impedance of approximately 19.74 Ω (0.8 × 19.74 ≈ 15.8 Ω and 1.2 × 19.74 ≈ 23.7 Ω), which is the same value used for the theoretical check of the simulation (50% × Zline ≈ 9.87 Ω). A slightly shorter reach is conservative for Zone 1 because it increases the margin against overreach caused by CT/PT errors and uncertainty in the line parameters.

By implementing the recommended settings, the distance relay is expected to detect faults more optimally at various locations along the line as well as in the zone beyond the line end, serving as a backup protection function. Therefore, these proposed settings serve not only to rectify the underreach condition identified in the existing settings but also to enhance the reliability and coordination of the protection system for the Tualang Cut 2 150 kV transmission line.

3.5 Comparison Between Theoretical Calculation and ETAP Simulation Results

To validate the research findings, the apparent impedance obtained from ETAP was compared with the theoretical impedance of a fault located at a fraction p of the line length, $Z_{th} = p \times Z_{L1}$, using the line impedance on which the recommended settings are based (Z_{L1} = 19.74 Ω). The deviation was calculated as $\delta = (Z_{ETAP} - Z_{th})/Z_{th} \times 100\%$. The results are presented in Table 5.

Table 5. Comparison between theoretical calculation and ETAP simulation results for Tualang Cut 2

Fault location	Theoretical (Ω)	ETAP (Ω)	Deviation	Zone (theoretical)	Zone (ETAP)
50%	9.87	11.16	+13.1%	Zone 1	Zone 1
80%	15.79	17.87	+13.2%	Zone 1 reach limit	Zone 2
100%	19.74	22.37	+13.3%	Zone 2	Zone 2
110%	21.71	32.74	+50.8%	Zone 2	Zone 3

Table 5 shows that, within the protected line (50–100%), the impedances obtained from ETAP are consistently 13.1–13.3% higher than the theoretical values. Because the deviation is almost constant, it is systematic rather than random and indicates that the line impedance represented in the ETAP model (22.37 Ω at the remote bus) is higher than the impedance used to derive the settings. The zones predicted by the calculation agree with the ETAP results at 50% and 100%. At 80%, the theoretical impedance (15.79 Ω) lies exactly at the Zone 1 reach limit, as intended by Eq. (4), whereas ETAP places the fault in Zone 2. Beyond the remote bus (110%), the deviation increases to 50.8% and the fault is detected by Zone 3. This larger deviation is consistent with the infeed effect, in which the fault current contributed by other sources at the remote bus increases the apparent impedance seen by the relay. Differences between impedance-based estimates and actual fault locations have also been reported on other 150 kV lines [15]. Overall, the comparison confirms the graded zone sequence predicted by the calculation; however, because the 100% fault lies close to the Zone 2 boundary (22.37 Ω versus 23.7 Ω), the final settings should be verified against the actual line parameters before implementation.

3.6 Analysis of Time Coordination Between Zones

Time coordination is an important part of a protection system because each zone must have a clear operating sequence. Zone 1 operates as the primary protection with an operating time of 0 seconds. If the fault is outside the reach of Zone 1, protection is continued by Zone 2 with a time delay of 0.4 seconds. Zone 3 has an operating time of 1.2 seconds because it functions as backup protection for more distant areas. These time differences allow the primary protection to operate first before backup protection takes action. Based on the simulation results, the operating sequence from Zone 1 to Zone 2 and then Zone 3 demonstrates selective coordination.

Based on the simulation results, the variation in operating times across zones demonstrates a graded protection system. Zone 1 serves as the primary protection, operating instantaneously; faults within the Zone 1 reach are isolated immediately, without any time delay. This is evident in the simulation of a fault at 50% of the Tualang Cut 2 line length, where the fault impedance of 11.16 Ω falls within the Zone 1 operating region, prompting the relay to issue a trip command with an operating time of 0 seconds.

For faults located further along the line—specifically at 80% and 100% of the line length—the measured impedance values were 17.87 Ω and 22.37 Ω, respectively. While these values lie outside the Zone 1 reach, they fall within the Zone 2 operating region. Consequently, the relay does not trip immediately but operates after a time delay of 0.4 seconds. This delay allows the primary protection system located closer to the fault point the opportunity to act first; if the primary protection clears the fault within this period, the relay in the backup zone does not need to trip.

3.7 Analysis of Distance Relay Performance Based on Fault Location Changes

Based on the calculations and simulations performed, changes in the fault location on the Tualang Cut 2 line directly affect the impedance value detected by the distance relay. This is

evident from simulation results at three fault points: 50%, 80%, and 100% of the line length. The further the fault location is from the Langsa Substation—where the relay is installed—the higher the impedance value detected by the relay. This condition causes the relay's operation to shift from Zone 1 to Zone 2, and subsequently to Zone 3.

For a fault occurring at 50% of the line length, the detected impedance is 11.16 Ω. This value falls within the Zone 1 reach, allowing the relay to operate instantaneously without a time delay. This demonstrates that Zone 1 functions effectively as the primary protection for faults occurring between the beginning and the midpoint of the line. Instantaneous operation is crucial for accelerating fault isolation, thereby preventing the fault from escalating and minimizing its impact on the stability of the electrical power system.

When the fault location shifts to approximately 80% of the line length, the detected impedance rises to 17.87 Ω. This value exceeds the Zone 1 limit but remains within the Zone 2 reach; consequently, the relay operates with a time delay of 0.4 seconds. This operational shift illustrates the clear sequence of operation defined by the Zone 1 and Zone 2 boundaries. Zone 2 serves as both extended protection and backup coverage for faults located at the far end of the line or in instances where the primary protection fails to operate correctly.

At the 100% fault point—the end of the line—the detected impedance is 22.37 Ω, which remains within the Zone 2 reach. These results indicate that the Zone 2 setting of 23.7 Ω provides coverage extending to the very end of the line. Fault impedance values falling close to the Zone 2 boundary indicate that settings must be precisely determined to ensure adequate protection without causing overreach. Thus, the proposed settings strike a balance between protection requirements and operational selectivity.

4. CONCLUSION

Based on the results of data analysis, theoretical calculations, and ETAP software simulations in the distance relay protection study on the 150 kV transmission line from Langsa Substation to Tualang Cut Substation, the following conclusions can be drawn. The existing distance relay settings at the Tualang Cut 1 Bay generally meet PLN protection criteria and standards, with Zone 1 reach of 1.07 Ω (99.6%), Zone 2 reach of 1.62 Ω (150.7%), and Zone 3 reach of 2.72 Ω (253.1%) relative to line reactance. These values are highly adequate for protecting the short 22.1 km line. The Sliding Fault simulation results in ETAP Star-Z Distance Protection demonstrate that applying the recommended setting values (Zone 1 = 15.8 Ω, Zone 2 = 23.7 Ω, and Zone 3 = 43.4 Ω) successfully restores protection performance optimally. The distance relay can clear three-phase faults at the 50% position instantaneously (t = 0 s), faults at 80% and 100% in Zone 2 (t = 0.4 s), and faults beyond the remote substation in Zone 3 (t = 1.2 s) selectively and accurately. The simulation results show that the distance relay can detect and identify fault locations based on the characteristic region of each zone. Faults within the reach of Zone 1 can be responded to directly, whereas faults entering Zones 2 and 3 are responded to according to their predetermined time delays.

Thus, the combination of existing-setting evaluation, theoretical calculations, and ETAP simulations has proven effective for identifying inadequate relay reach and developing a more appropriate coordination scheme. Future research may expand the analysis by including additional fault types and coordination with adjacent transmission protection systems.

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REFERENCES

[1] M. J. Ashari, "The impact of biogas power plant penetration on power system stability in the 20 kV distribution network of Tanjung Pura," J. Geuthee Eng. Energy, vol. 4, no. 1, pp. 34–48, 2025, doi: 10.52626/joge.v4i1.49.

[2] A. A. Y. Tayeb and S. B. Utomo, "Analysis of Distance Relay Settings and Coordination After Reconductoring SUTT 150 kV Babat-Lamongan," J. Tek. Elektro dan Komputasi, vol. 8, no.

1, pp. 129–138, 2026, doi: 10.32528/elkom.v8i1.5290.
[3] I. H. Muchmad Jafar Shodik, “Evaluation of Distance Relay Setting Values for 150 kV High-Voltage Overhead Line Protection Using DIgSILENT PowerFactory,” vol. 14, no. 1, pp. 1–13, 2024, [Online]. Available: https://doi.org/10.33322/sutet.v14i1.2291
[4] M. N. Ulum and S. B. Utomo, “Analysis of Distance Relay Coordination Setting in 150 kV Transmission Line Protection System PLTMG BAUBAU Substation - BAUBAU Substation - RAHA Substation,” Eduvest - J. Univers. Stud., vol. 6, no. 1, pp. 1125–1133, 2026, doi: 10.59188/eduvest.v6i1.52129.
[5] H. S. Adi and A. B. Muljono, “Analysis of Transmission Line Protection Testing Using a Distance Relay at the Sengkol–Kuta Line Bay of Sengkol 150 kV Substation,” J. Inform. dan Tek. Elektro Terap., vol. 13, no. 3, 2023.
[6] M. F. P. Utami, Y. Volta, “Simulation Of Electric Power System Protection Coordination Using Etap,” Med. Trada J. Tek. Elektromedik Polbitrada, vol. 5, no. 1, pp. 25–34, 2024.
[7] Z. Xie et al., “Error analysis and improved method of time-domain distance protection for wind power transmission lines,” Int. J. Electr. Power Energy Syst., vol. 160, no. February, p. 110081, 2024, doi: 10.1016/j.ijepes.2024.110081.
[8] Y. Simamora, M. S. Dewy, and A. I. Silitonga, “Analysis of Overcurrent Relay Coordination in the Jelok Hydroelectric Power Plant Protection System for the Electric Power System Protection Course,” J. Teknol. Inf. Komun. Dalam Pendidik., vol. 11, no. 1, 2024, doi: 10.24114/jtikp.v11i1.60288.
[9] Reza Sarwo Widagdo, G. Budiono, Aris Heri Andriawan, Puji Slamet, and R. W. Putra, “Analysis of Fault Locations Using the Impedance Method on the GIS 150 kV Transmission Line Karang Pilang Surabaya,” J. Poli-Teknologi, vol. 23, no. 2, pp. 83–92, 2024, doi: 10.32722/pt.v23i2.6837.
[10] N. N. Fitrah, M. Syukri, A. Info, and G. Hubung, “Seimbang Pada Jaringan Distribusi Sistem Radial Feeder Lk 07 Sistem Kelistrikan,” vol. 1, no. 1, pp. 12–20, 2022.
[11] R. H. Siregar, A. Farras, and S. Syahrizal, “Short circuit current limitation using series reactors in 20 kV distribution feeder,” J. Geuthee Eng. Energy, vol. 5, no. 1, pp. 62–74, 2026, doi: 10.52626/joge.v5i1.94.
[12] D. Romdhani, Supriyatna, and A. B. Muljono, “Distance relay protection on high voltage transmission line 150 kV from Ampenan Substation to Lombok Energy Dynamic steam power plant,” *Dielektrika*, vol. 8, no. 1, pp. 36–43, Feb. 2021, doi: 10.29303/dielektrika.v8i1.263.
[13] I. F. Pasaribu and D. Fauziah, “Analysis of Distance Relay Settings on the 150 kV Bay 1 Kiaracondong–South Bandung Substation Transmission Line,” Pros. Disem. FTI Gen. 2021/2022, pp. 1–9, 2021.
[14] D. Aminarti, “Analysis of Distance Relay Settings for the 150 kV Sunyaragi Substation Transmission Line,” vol. 3, no. 2, pp. 58–63, 2025.
[15] J. Arifin, H. Yamashika, and A. Dwiharzandis, “Comparison of Fault Location Determination Between a Fault Locator and Distance Relay on the 150 kV Teluk Kuantan Line,” vol. 9, no. 2, pp. 182–184, 2026.