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Analysis of Distance Relay Coordination Setting in 150 kV Transmission Line Protection System PLTMG BAUBAU Substation - BAUBAU Substation - RAHA Substation

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ABSTRACT

The electric power transmission system requires a reliable protection mechanism to ensure continuity and dependability, particularly in 150 kV transmission lines. One of the key protection devices used is the distance relay, which detects and isolates faults based on impedance measurements. This study was initiated following a fault on the PLTMG Baubau–Raha transmission segment, which caused a power outage of 8.7 MW lasting 2 hours and 23 minutes. The objective of this research is to analyze the coordination settings of distance relays and evaluate the performance of the teleprotection system in responding to disturbances, as well as to estimate energy loss and its economic impact. The methodology includes collecting primary data from PT PLN (Persero) and simulating fault conditions based on the actual relay settings installed at three substations: PLTMG Baubau, Baubau, and Raha. The analysis revealed that the relay zone settings and timing delays were functioning correctly, and the Permissive Underreach Transfer Trip (PUTT) teleprotection scheme successfully accelerated fault isolation in a selective manner. Simulations also confirmed that the system accurately identified fault locations based on impedance values detected by the relays. Additionally, calculations showed a total energy loss of 20,732.1 kWh, equivalent to IDR 29,939,622.4. This study emphasizes the importance of proper relay coordination and teleprotection systems in enhancing the reliability of power transmission networks.

KEYWORDS *Distance relay, Protection system, 150 kV transmission line, Teleprotection, Fault impedance*

INTRODUCTION

The power transmission system serves as the main link between power plants and load centres, making it a crucial component in maintaining the reliability and continuity of electrical power delivery (Brown, 2017; Ruiz-Romero et al., 2014). In order for this system to remain reliable, it requires protection devices that are able to work quickly, precisely, and selectively in responding to various types of disturbances. One of the main devices used in the 150 kV transmission line protection system is the distance relay, which plays an important role in detecting and securing the system from disturbances such as short circuits or ground faults that have the potential to damage equipment and cause blackouts (Al Kazzaz et al., 2020; Ogar, 2023; Pujari & Alam, 2025).

Distance relays have the advantage of being able to determine the location of the fault based on impedance measurements between the relay point and the fault point. To support its effectiveness, this relay is arranged in several protection zones (zone 1, zone 2, and zone 3), each with different impedance settings and working times. However, if the relay settings are not done properly, the relay may fail to work optimally, causing a delay in disconnecting the faulted part of the system.

Previous research has demonstrated the importance of proper distance relay coordination in transmission line protection systems (Mohamed et al., 2021; Wu et al., 2016; Zheng et al., 2021). Several studies have examined distance relay settings in Indonesia's 150 kV transmission networks and identified critical gaps between actual settings and international standards (Alamshah, 2020; Saleem, 2015). Priambodo, Sukmadi, and Facta (2018) analyzed distance relay settings on the 150 kV Ungaran-Krapyak-Srondol transmission line using DigSILENT software and found that the initial setting of zone 1 did not meet Alstom's NPAG standard. After recalculation, the range was adjusted to 85% according to the standard, demonstrating the importance of simulation to improve the reliability of transmission system protection (Priambodo et al., 2018).

Similarly, Nugroho, Karnoto, and Facta (2017) conducted research on 150 kV line protection and showed that the initial distance relay settings at GI Pandean Lamper did not comply with IEEE standards. After zone adjustment, relay performance improved significantly, confirming the importance of setting coordination for protection system reliability (Nugroho et al., 2017). Mu'tashim (2017) investigated the use of distance relays in the transmission system between 150 kV Jajar Substation and 150 kV Banyudono Substation, showing that impedance differences in each zone allow identification of fault locations, thereby increasing the reliability and efficiency of the transmission system (Mu’tashim, 2017).

Furthermore, Sudrajat, Saodah, and Waluyo (2014) analyzed distance relay tuning as main protection on the 150 kV high voltage air line between South Bandung and Cigereleng. Their study demonstrated that distance relay tuning is performed by dividing the protection area into three zones (Zone 1, Zone 2, and Zone 3), each with specific impedance and working time settings. This zoning principle ensures selective protection while maintaining system stability (Sudrajat et al., 2014).

The protection pattern in power systems must be designed to fit and harmonize with all protection equipment installed in the system. The disconnection of the network due to interference must be done as selectively as possible, meaning only the faulted section should be isolated without affecting other parts that are still functioning normally. In addition to selectivity, the protection system must also have high sensitivity, capable of detecting disturbances accurately. In each system operating condition, the protection device must respond quickly so that faults can be isolated immediately and do not spread, while maintaining a high level of reliability (Jamaah, 2014).

The components in the High Voltage Air Line (SUTT) protection system consist of several critical devices: current transformers (CT), voltage transformers (PT or CVT), protection relays, power breakers (PMT), power supply sources, wiring circuits, and teleprotection systems. Each of these elements plays a specific role in ensuring the protection system can work effectively in detecting and isolating disturbances (Jamaah, 2014).

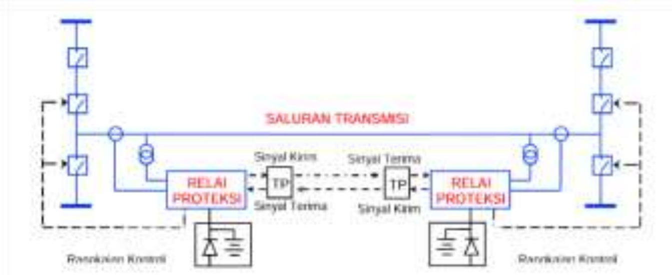

Fig. 1. SUTT Protection Components

Distance relays are the primary protection device on transmission lines. It operates by measuring voltage and current to obtain the impedance value of the line to be protected. If the measured impedance value is below the predetermined setting value, the relay will activate. It is called a distance relay because the impedance value is proportional to the length of the transmission line. This relay divides the protection area into several zones, namely Zone-1, Zone-2, and Zone-3. In addition, the system is equipped with teleprotection (TP) to ensure that the relay can work quickly and selectively within the predetermined protection area (Jamaah, 2014).

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Distance relay protection zones are configured based on specific principles. Zone 1, considering the possibility of errors in line data, CTs, PTs, and other supporting devices of 10% to 20%, is usually set at 80% of the total line length to be protected. The primary zone-1 impedance setting is formulated as $Z1P = 0.8 \times ZL1\ \Omega$ (Primary) and $Z1S = Z1P \times n\ \Omega$ (Secondary), where n represents the CT/PT ratio. The working time of the relay in this zone is instantaneous, requiring no timing delay ($t1 = 0$).

Zone 2 tuning is based on several important considerations: (a) Zone-2 should cover the area up to the next busbar (bus B), (b) Zone-2 coverage should serve as back-up protection for the distance relay in front of it, (c) The Zone-2 impedance setting shall not exceed (over-reach) the Z2B setting of the relay on the next side, (d) The Zone-2 setting value must be less than 50% of the transformer impedance at the front substation, and (e) The setting must consider possible measurement errors from CT, PT, and other protection relay devices (Jamaah, 2014). Relay working time t2 ranges from 0.4 to 0.8 seconds.

Zone 3 settings follow similar principles with working time t3 ranging from 1.2 to 1.6 seconds. Additionally, zone-3 reverse settings are used when implementing teleprotection systems with blocking patterns (Jamaah, 2014).

To ensure that distance relays work selectively and instantaneously within their protection area, the system is equipped with a teleprotection device. Teleprotection is a series of devices that function to send and receive signals between substations, both upstream and downstream, to provide quick trip commands. The teleprotection scheme used in this study is the Permissive Under-Reach Transfer Trip Scheme (PUTT). In this scheme, the teleprotection device sends a signal (carrier send) to the adjacent substation if the distance relay detects a fault in zone 1. The substation that receives the signal (carrier receive), if its distance relay detects a fault in zone 2 and receives a signal from the TP, will issue a trip command with working time equivalent to zone 1 (Fariris and Sumpena, 2022).

Disturbances in power systems are abnormal conditions that deviate from the normal state and can trigger automatic operation of relays and power breakers, thus interrupting power flow. Disturbances can cause serious damage to the system, including current surges, voltage imbalances, disruption of power flow, and decreased system stability. Generally, disturbances are caused by external factors (weather, animals, plants, or humans) or internal factors (equipment malfunction). Based on their nature, disturbances are classified into two types: temporary disturbances, which resolve themselves after temporary disconnection, and permanent disturbances, which require immediate repair. To handle such disturbances effectively, the system needs reliable relay protection appropriate for its working zone.

The location of disturbances on the transmission system can be determined by the equation: Disturbance Distance (km) = (Zrelay × PT/CT × L1) / ZL1, where Zrelay is the impedance read by relay (ohms), PT is the voltage measuring transformer ratio, CT is the current measuring transformer ratio, L1 is the length of transmission line (km), and ZL1 is the impedance of transmission line (ohms).

One of the events that motivated this research was the occurrence of a disturbance on the 150 kV transmission line of the Baubau MHP - Raha GI section, which caused an outage with a total load outage of 8.7 MW for 2 hours 23 minutes. The disturbance triggered a comprehensive re-analysis of the coordination and working function of the distance relay, specifically to verify whether the relay operated according to its designated protection zone and whether the teleprotection system transmitted trip signals quickly and accurately to the connected substations.

Therefore, this study aims to analyze the coordination of distance relay settings and the performance of the teleprotection system in handling disturbances on the Baubau MHP GI - Baubau GI - Raha GI transmission line, and calculate the estimated power loss due to disturbances. Despite previous research on distance relay coordination in Indonesian transmission networks, limited studies have specifically examined the effectiveness of PUTT teleprotection schemes in accelerating fault isolation in multi-substation configurations. This research fills this gap by providing empirical evidence of PUTT system performance under actual fault conditions and demonstrating how proper relay-teleprotection integration can minimize both technical and economic impacts of transmission system disturbances.

The novelty of this study lies in its comprehensive analysis combining actual fault event data, multi-zone relay coordination verification, and economic impact assessment within a single framework. Unlike previous studies that primarily focused on relay setting calculations and theoretical validations, this research validates the actual performance of an implemented protection system under real fault conditions, providing practical insights for power system operators. It is expected that the results of this analysis can be an important input to improve the effectiveness and reliability of protection systems in similar transmission configurations, while minimizing the impact of disturbances on the continuity of electrical power distribution in the future.

RESEARCH METHOD

This research methodology begins with primary data collection from PT PLN (Persero) Baubau Transmission Service Unit and GI, as well as secondary data from journals, books, and research related to distance relays. Furthermore, the stages and procedures of the research were arranged, followed by data analysis and conclusion drawing to support the research objectives. The object of this research is the distance relay located at Baubau Substation, Raha Substation, and Baubau MHP Substation.

This research was conducted by selecting three substations in Southeast Sulawesi Province as the main object, namely Baubau Substation, Raha Substation, and Baubau MHP Substation. The three substations became the focus of study in the analysis of the protection system studied.

The data required in this study are the actual setting data of the distance relay, transmission line data, and transmission fault data. The distance relay that will be discussed in this final project is the distance relay located at the Baubau substation, Raha Substation, and Baubau MHP Substation.

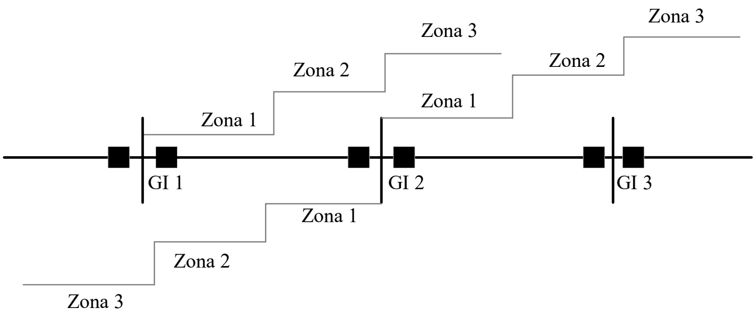

Fig. 1. ULTG Baubau Network Configuration

1. GI PLTMG Baubau - GI Baubau

Line Length	: 10.966 km
Conductor Type	: ACSR 2x250 mm
CCC	: 1200A
ZL1	: 0.656 + j3.174 Ω
ZL0	: 3.875 + j9.443 Ω

2. Baubau MHP GI - Raha GI

Line Length	: 96.77 km
Conductor Type	: ACSR 2x250 mm
CCC	: 1200A
ZL1	: 5,650 + j27,301 Ω
ZL0	: 24.21 + j87.785 Ω

3. Transformer GI MHP

Voltage : 150/20 kV
Power : 30 MVA
XT11 : 12,19% (91,425 Ω)

Table 1. Distance Relay Actual Setting Data

No.	GI Location	Bay Direction	Brand	Tipe	Z1	Z2	Z3	T_{Z1}	T_{Z2}	T_{Z3}
1.	GI Baubau	PLTMG Baubau	Toshiba	GRL 200	2,075	3,734	30,624	0	0,4	1,2
2.	GI PLTMG Baubau	Baubau	Toshiba	GRL 200	2,075	3,734	18,009	0	0,4	1,2
3.	GI Raha	PLTMG Baubau	MICOM	P545	17,843	24,534	53,529	0	0,4	1,2
4.	GI PLTMG Baubau	GI Raha	MICOM	P545	17,843	32,118	40,750	0	0,4	1,2

RESULT AND DISCUSSION

Disturbance Impedance Determination Scenario (Zf)

In this study, a fault simulation was conducted on a transmission line with a fault distance varying from 10% to 90% of the total line length, to evaluate the coordination performance of the distance relay setting. For example, at a 10% fault distance or 10.7736 km from Baubau GI to Baubau MHP GI, the relay at Baubau GI recorded a fault impedance of 2.545 Ω. Meanwhile, the relay at Baubau MHP GI, which saw the fault from the opposite direction as far as 0.1924 km, recorded an impedance of 0.0454 Ω. Meanwhile, the relay at Raha GI also detected the fault at that point with a distance of 96.9624 km and recorded an impedance of 22.33 Ω.

ZL = Line Length (Km) x Impedance (Ω / Km)
ZL1 = 10,966 x (0,0598 + j0,2894)
= 0,6557 + j3,1727
= 3,24 < 78,03
Z = (Interference Distance x ZL1)/(P/(C) x L1)
Z = (10,7736 x 3,24)/(1500/1200 x 10,966)
Z = 2,545 Ω

Table 2. Impedance seen by the distance relay at GI Baubau Bay GI PLTMG Baubau

Ratio		Line Length		Impedance (Ω)	
CT	PT	Scenario (%)	(Km)	ZL	Zrelay
1200	1500	10	10,7736	3,24	2,545
1200	1500	20	21,5472	31,84	5,0944
1200	1500	30	32,3208	31,84	7,6416
1200	1500	40	43,0944	31,84	10,1888
1200	1500	50	53,868	31,84	12,736
1200	1500	60	64,6416	31,84	15,2832
1200	1500	70	75,4152	31,84	17,8304
1200	1500	80	86,1888	31,84	20,3776
1200	1500	90	96,9624	31,84	22,9248

Analysis of Disturbance Scenarios with Actual Relay Settings

Simulation of disturbances on transmission lines with a distance variation of 10% to 90% of the total line length to assess the performance of distance relays. In the 10% scenario, the relay at GI Baubau detected a fault impedance of 2.545 Ω (zone 2, time delay 0.4 s), the relay at gi pltmg baubau detected 0.0454 Ω (zone 1, instant work), and the relay at GI Raha detected 22.33 Ω (zone 2). Due to the teleprotection scheme, gi pltmg sends a trip signal to pmt instantly and gi baubau is also tripping through the receive signal. In the 20% scenario, Baubau GI reads an impedance of 5.0944 Ω (zone 3, time delay 1.2 s), PLTMG GI reads 2.440 Ω towards Raha GI (zone 1), and Raha GI reads 19.8528 Ω (zone 2). So, the relay at the MHP GI will trip instantly, the relay at the Baubau GI does not work immediately, and the Raha GI relay also gives an instant trip command because it receives a teleprotection signal from the MHP GI.

Disturbance Analysis of ULTG Baubau Transmission System

Disturbance simulations were conducted on transmission lines with distance variations of 10% to 90% to evaluate the performance of distance relays. In the 10% scenario, the fault is detected by relays at Baubau GI (zone 2, 0.4 s delay), MHP GI (zone 1, instant working), and Raha GI (zone 2). Due to the teleprotection scheme, GI PLTMG is instant tripping and sends a signal to GI Baubau to trip synchronously. If the fault is close to GI Raha, the relay at GI Raha detects it in zone 1 and immediately trips and sends a PUTT signal to GI PLTMG. This signal accelerates the work of the relay at the MHP GI even though the fault is in zone 2. Teleprotection systems are important for coordination and quick disconnection to prevent damage and maintain system stability. If this system fails, the disconnection at the MHP GI will be delayed by zone 2 time, which could jeopardise equipment and system stability. In the 20% scenario, Baubau GI detects the fault in zone 3 (1.2 s delay), the MHP GI in zone 1 (instant work), and Raha GI in zone 2. However, due to the teleprotection signal from the MHP GI, the Raha GI relay also immediately orders a trip. This shows that the coordination and relay settings are appropriate and effective.

Transmission Line Disturbances

Disturbances in power systems are abnormal conditions that disrupt the continuity and reliability of electricity supply (Martinez et al., 2022; Sciences et al., 2017; Ward, 2013). To design an effective protection system, it is necessary to accurately calculate the fault current and voltage based on the type of fault and the impedance of the current path, including from the source, transmission line, and fault point. This calculation is an important basis for assessing the performance and selectivity of the protection system, especially in setting the distance relay and its coordination with other protection equipment. Disturbances to the transmission system not only disrupt continuity of service, but also cause energy losses. In this case, the disturbance caused an outage for 2.383 hours with an affected load of 8.7 MW. This resulted in 20,732.1 kWh of undelivered energy. If multiplied by the average electrical energy tariff of Rp1,444/kWh, the value of economic losses due to the disruption reached around Rp29,939,622.40. This shows that disruptions to the transmission system not only have a technical impact, but also cause significant financial losses, so strengthening the protection system is very important to minimise similar risks in the future.

CONCLUSION

This paper discusses the importance of setting and coordinating distance relays in the 150 kV transmission line protection system between Baubau MHP GI, Baubau GI, and Raha GI. Based on the results of the analysis, it can be concluded that the distance relay settings applied to the three substations have worked according to the predetermined protection zone, especially zone 1 which allows fast and selective fault termination. The distance relay at GI Raha is proven to be able to detect faults within zone 1 and send teleprotection signals to GI MHP Baubau to disconnect the system simultaneously, thus accelerating the fault isolation process.

Simulation and impedance testing proved that the protection system works reliably and coordinated. The application of the PUTT teleprotection scheme also proved effective in supporting the speed of protection response and preventing the widespread impact of the disturbance. In addition, the calculation of the estimated power loss due to the fault showed a total of 20,732.1 kWh of undelivered energy, with an economic loss of Rp29,939,622.4. This reinforces the importance of an appropriate protection system to reduce the technical and financial impacts of transmission system disturbances.

Therefore, the coordination of distance relay settings and the utilisation of teleprotection systems are crucial components in ensuring the reliability and continuity of electrical power delivery to consumers. Periodic evaluation of protection performance as well as simulation based on real conditions is highly recommended to ensure that protection works optimally in the face of various types of disturbances.

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