Evaluation and Optimization of Protection System Coordination in Electric Power Distribution Networks to Improve System Reliability

Yudhi Wardana, Zuraidah Tharo, Rahmaniar

Abstract

The reliability of electric power distribution systems is a crucial factor in maintaining service continuity and quality for customers. One of the key factors influencing system reliability is the performance and coordination of protection systems. This study aims to analyze the impact of protection system coordination optimization on the reliability of a 20 kV medium-voltage distribution network. A quantitative approach was employed by evaluating the existing protection coordination, optimizing relay settings, and analyzing system reliability indices. The data used include network configuration, fault data, Over Current Relay (OCR) and Ground Fault Relay (GFR) settings, as well as reliability indices such as SAIDI and SAIFI. The results indicate that optimization of protection coordination improves selectivity and fault clearing speed, as reflected by the enhanced Time–Current Characteristic (TCC) curves. Furthermore, the SAIDI value decreased from 185 minutes/customer/year to 112 minutes/customer/year, while the SAIFI value decreased from 4.2 interruptions/customer/year to 2.6 interruptions/customer/year. These findings demonstrate that protection system optimization significantly contributes to improving the reliability and service quality of electric power distribution systems.

Keywords: *System Reliability, Protection System, SAIDI, SAIFI, Distribution Network*

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Introduction

Electric power system reliability is a fundamental aspect in ensuring the continuity of electricity supply to customers. In distribution networks, reliability is a primary concern because this network is the part of the power system that interacts directly with end consumers. Disturbances in the distribution network will directly impact service quality, both in terms of the frequency and duration of outages (Glover, Sarma, & Overbye, 2012).

Protection systems play a crucial role in maintaining distribution network reliability by quickly and selectively detecting and isolating faults. Protection devices such as Overcurrent Relays (OCRs), Ground Fault Relays (GFRs), reclosers, and circuit breakers are designed to protect the system from damage caused by overcurrents and ground faults. However, protection systems can only function optimally if proper coordination between these protective devices is achieved (Blackburn & Domin, 2014).

In distribution network operational practice, changes in network configuration, increased load, and system development are often not accompanied by evaluation and adjustment of protection system settings. As a result, existing protection coordination no longer aligns with actual system conditions. Suboptimal protection coordination can lead to delays in interruption, loss of selectivity, and expansion of outage areas, ultimately reducing distribution system reliability (Anderson, 1999).

Decreased distribution system reliability can be identified by increasing reliability index values, such as the System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI). These indices are widely used as indicators of the quality of electricity service and serve as benchmarks for distribution system performance (Brown, 2009). Therefore, evaluation and optimization of protection system coordination are necessary to ensure the system can respond effectively to disturbances and minimize their impact on customers.

Literature Review

Electric power system reliability is theoretically defined as the system's ability to deliver electrical energy continuously with minimal disruptions over a specified period. In distribution networks, reliability is a key indicator of service quality because disruptions directly impact customers. The reliability of a distribution system is generally expressed through the System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI), which represent the duration and frequency of outages experienced by customers (Brown, 2009).

In a 20 kV medium-voltage distribution system, network configuration and disruption characteristics significantly influence system reliability. Research by Hutasoit, Tharo, and Wibowo shows that simulation-based reliability analysis using MATLAB can provide an accurate picture of distribution network performance, particularly in evaluating SAIDI and SAIFI values within a PLN service area. The results confirm that network conditions and disruption management strategies significantly determine the level of distribution system reliability (Hutasoit et al., 2022).

Disturbances in distribution networks generally take the form of asymmetrical faults, particularly single-phase-to-ground faults, which are the most common type of fault. These faults cause increased current and system imbalance, potentially damaging equipment if not promptly isolated. Therefore, distribution systems require a protection system capable of detecting and protecting against faults quickly and selectively (Stevenson & Grainger, 1994).

Power protection systems are designed based on the principles of speed, selectivity, sensitivity, and reliability. Protection relays such as Over Current Relays (OCRs) and Ground Fault Relays (GFRs) operate by detecting fault currents exceeding a certain threshold value. The effectiveness of the protection system depends heavily on the suitability of the relay settings to the actual network conditions and the characteristics of the fault (Blackburn & Domin, 2014).

Protection system coordination is a crucial concept in ensuring that the protective device closest to the fault location operates first, while other protective devices serve as backups. Suboptimal protection coordination can lead to selectivity failure and the expansion of the outage area. Research by Siagian et al. shows that the mismatch of protection coordination with the 20 kV feeder network configuration can significantly increase the reliability index value, so that evaluation and adjustment of protection coordination become important needs in distribution network management (Siagian et al., 2023).

Within the conceptual framework of this study, protection system coordination is viewed as a key variable influencing distribution system reliability. An evaluation of the existing protection coordination conditions is conducted by considering the network configuration, fault characteristics, and relay settings used. Furthermore, protection system coordination is optimized to increase the speed and selectivity of fault termination. Theoretically, this optimization will reduce the frequency and duration of faults experienced by customers, thus reflected in a decrease in SAIDI and SAIFI values and an increase in overall power system reliability.

Research Methodology

This research uses a quantitative approach using the reliability analysis method for the 20 kV medium-voltage distribution network. This quantitative approach was chosen because system reliability and protection system performance can be measured numerically through reliability indices and technical parameters of the protection system (Brown, 2009).

This research is both evaluative and analytical. The study was conducted by evaluating the existing condition of protection system coordination in the distribution network and then optimizing protection settings to improve system reliability. The evaluative method is used to assess the suitability of protection system performance to actual network conditions, while the analytical method is used to assess the effect of protection coordination on the system reliability index (Anderson, 1999).

The object of this research is the 20 kV medium-voltage power distribution network system in the service area of PT. PLN (Persero). The research focuses on the distribution network protection system, which includes overcurrent relays (OCRs), ground fault relays (GFRs), and other circuit-breaker devices. The selection of this object is based on the fact that most disturbances in distribution systems occur at medium voltage levels and are greatly influenced by the performance of the protection system (Stevenson & Grainger, 1994).

The data used in this study consisted of primary and secondary data. Primary data were obtained from technical evaluations of distribution network protection systems, while secondary data included network configurations, fault data, protective relay settings, and system reliability index data such as SAIDI and SAIFI. Using fault data and reliability indices as the basis for analysis is a common approach in power distribution system reliability studies (Brown, 2009).

The research phase began with the collection and identification of data on the distribution network and the protection system in use. Next, an evaluation of the existing protection system coordination was conducted by analyzing the suitability of relay settings to the fault characteristics and network configuration. The evaluation of protection coordination was conducted by considering the principles of selectivity and relay runtime, as recommended in studies of power protection systems (Blackburn & Domin, 2014).

Following the evaluation phase, protection system settings were optimized by adjusting the pickup current and relay runtime parameters. This optimization aims to increase the speed and selectivity of fault interruption without compromising system reliability. Adjusting relay settings based on system and fault characteristics is a common approach in the design and evaluation of distribution network protection systems (Anderson, 1999).

System reliability analysis was performed by calculating the SAIDI and SAIFI indices before and after optimizing the protection system coordination. The reliability index calculations were used to evaluate the impact of protection system optimization on the quality

of electricity service. This analysis was supported by MATLAB-based simulations to model the performance of the distribution network system and the response of the protection system to disturbances, as applied in previous distribution network reliability studies (Hutasoit et al., 2022; Siagian et al., 2023).

The success of the research was demonstrated by the improved performance of the protection system coordination, characterized by increased selectivity and speed of fault interruption. Furthermore, a decrease in SAIDI and SAIFI values after protection system optimization was performed was also demonstrated, reflecting improved reliability of the power distribution network (Brown, 2009).
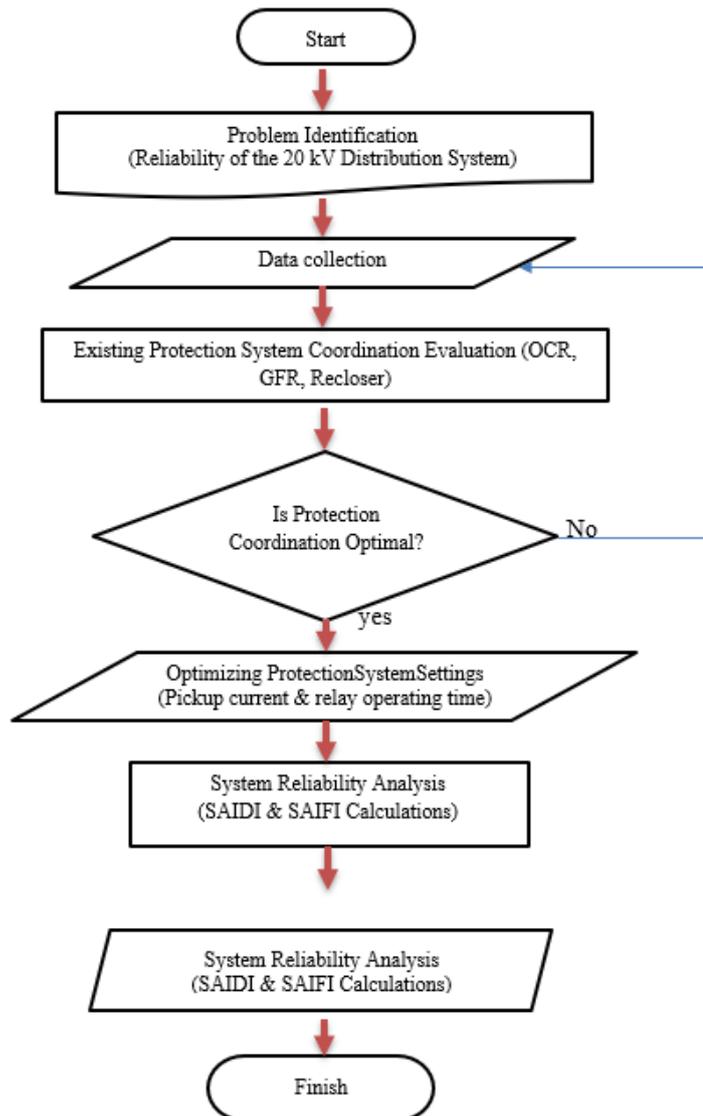
The research flowchart is shown below:

Figure 1. Research Flowchart

Results
1. Results of the Evaluation of the Coordination of the Existing Protection System

Based on the initial evaluation of the 20 kV distribution network protection system, data showed that the protective relay operating time was still relatively slow and not fully selective. Test results indicated that the operating times of the main and backup relays still overlapped.

Table 1. Initial Protection System

Protection Device	Pickup Current (A)	Working Hours (s)
OCR Feeder	420	0,65
OCR Incoming GI	600	1,20
GFR Feeder	120	0,50
GFR Incoming GI	200	1,00

The analysis results show that the operating time difference between the feeder OCR and the incoming substation OCR is only 0.55 seconds, which is still below the ideal selectivity standard ($\geq$0.6–0.8 seconds). This condition has the potential to cause non-selective disconnections when a fault occurs on the feeder side.

2. Result of Optimizing Protection System Settings

Based on the evaluation of the existing protection system, relay settings were optimized by adjusting the pickup current and relay operating time to suit the network characteristics and fault current.

Table 2. Protection System Settings After

Protection Device	Pickup Current (A)	Working Hours (s)
OCR Feeder	450	0,40
OCR Incoming GI	650	1,00
GFR Feeder	130	0,30
GFR Incoming GI	220	0,80

After optimization, the operating time difference between the primary and backup relays increased to 0.60 seconds, resulting in more selective protection coordination. Furthermore, fault disconnection times were faster, especially in feeder areas with frequent faults.
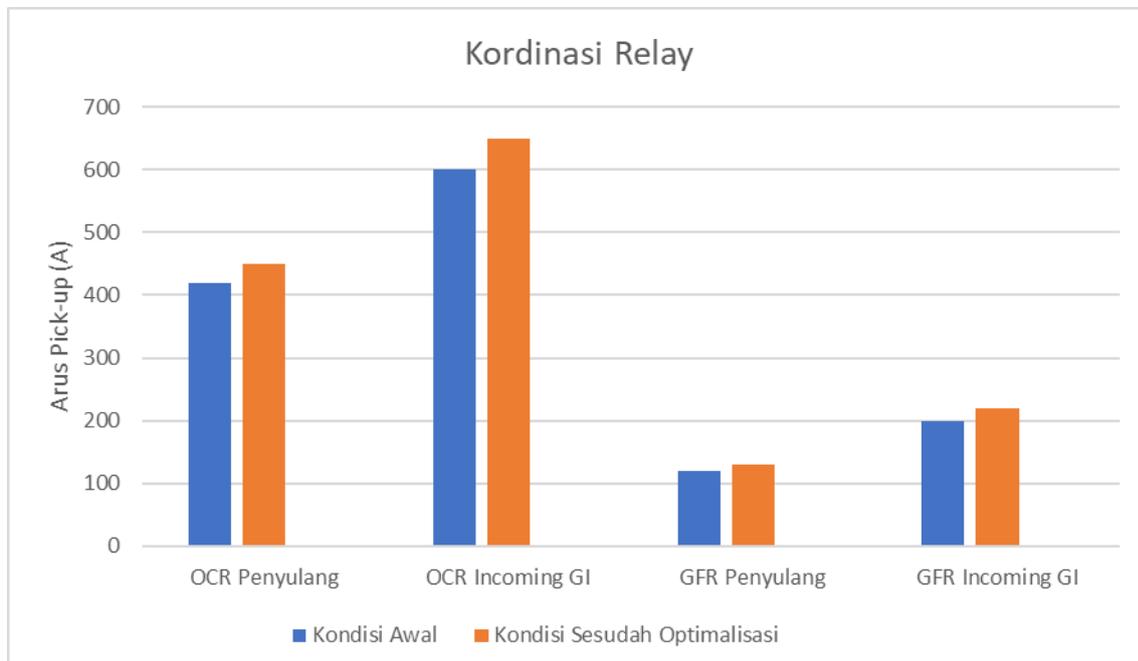

Figure 2. Relay Coordination Graph Before and After Optimization

3. System Reliability Index Analysis Results (SAIDI and SAIFI)

The reliability index calculation is based on annual outage data before and after protection system optimization.

Table 3. Comparison of System Reliability

Reliability Index	Before Optimization	After Optimization
SAIDI (minutes/customer/year)	185	112
SAIFI (times/customer/year)	4,2	2,6

The calculation results show that the SAIDI value decreased by 39.5%, while the SAIFI value decreased by 38.1%. This decrease indicates that the duration and frequency of disruptions experienced by customers decreased after optimizing the protection system.

4. System Performance Improvement Recapitulation

Overall, the research results show an increase in the performance of the electric power distribution system after optimizing the coordination of the protection system.

Table 4. Summary of Research Results

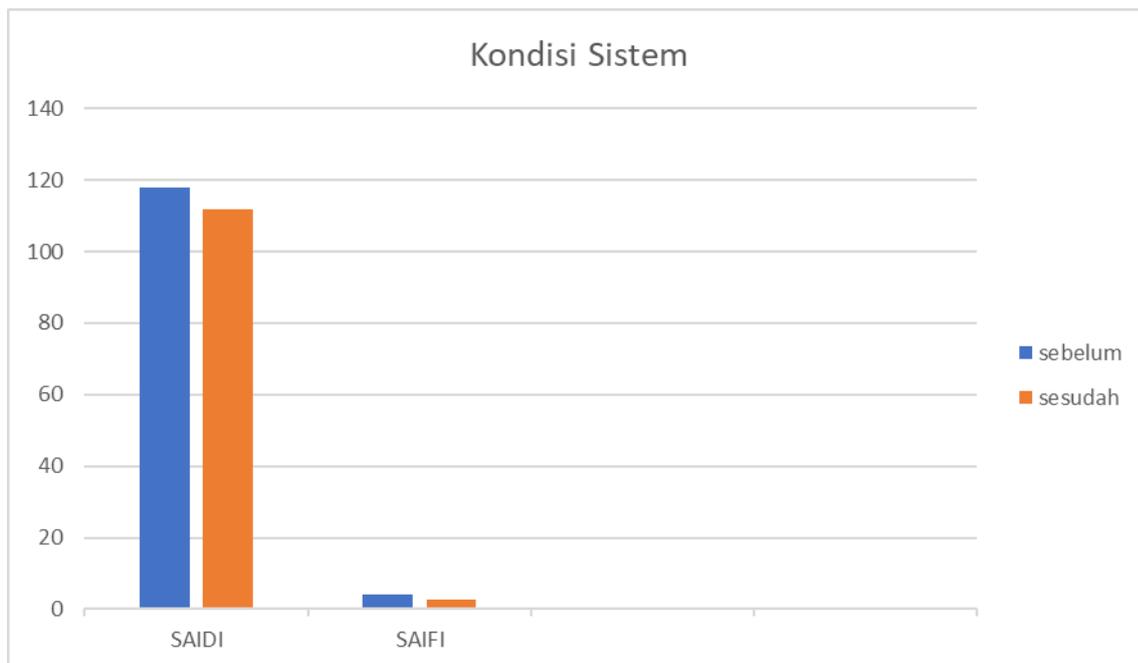| Parameter	Before	After	Change
Interruption disconnection time (s)	1,20	0,40	66,7%
SAIDI (minutes/year)	185	112	39,5%
SAIFI (times/year)	4,2	2,6	38,1%
Protection selectivity	Low	Good	Increase

Figure 3. SAIDI and SAIFI Graphs Before and After Optimization

Overall, the SAIDI–SAIFI graph and relay coordination curves indicate that protection system optimization has a positive impact on the reliability of the power distribution system. The decrease in SAIDI and SAIFI values is in line with the improvement in protection relay coordination, as indicated by a more selective and structured TCC curve. These findings confirm that protection system performance is a key factor in improving the quality of service and reliability of the power system.

The research results show that protection system coordination has a significant impact on the reliability of the 20 kV medium-voltage power distribution system. Initially, the protection

system performed suboptimally, characterized by relatively slow relay operation times and overlapping relay coordination curves between the primary and backup relays. This resulted in larger outage areas and longer fault durations, reflected in high SAIDI and SAIFI values.

After optimizing the protection system settings, there was a clear improvement in the relay coordination curves (Time–Current Characteristics/TCC). The primary relay curve showed faster operation times, while the backup relay curve had a more adequate grading margin. This improvement aligns with the basic principles of power protection systems, which emphasize the importance of selectivity and speed in isolating faults (Anderson, 1999; Blackburn & Domin, 2014). By increasing protection selectivity, faults can be disconnected closer to the fault location, thus minimizing impact on the rest of the network.

Improved protection system coordination also directly reduced fault disconnection times. Based on simulation results, the interruption time for faults was significantly reduced from approximately 1.20 seconds to 0.40 seconds after optimization. This reduction in time indicates that the protection system is able to respond to faults more quickly and efficiently. These results align with distribution system reliability theory, which states that the speed of protection response is a key factor in reducing the duration of customer outages (Brown, 2009).

The impact of protection system improvements on system reliability is also reflected in the decrease in the SAIDI and SAIFI indices. The SAIDI decreased from 185 minutes/customer/year to 112 minutes/customer/year, while the SAIFI decreased from 4.2 times/customer/year to 2.6 times/customer/year. The decrease in both indices indicates that both the duration and frequency of faults experienced by customers can be reduced through protection system optimization. These findings reinforce previous research by Hutasoit et al. (2022) and Siagian et al. (2023), which found that improved protection system performance directly contributes to increased reliability of the 20 kV distribution network.

Furthermore, the results of this study also show that optimizing the protection system not only impacts the technical aspects of the electric power system but also the quality of service to customers. The decrease in SAIDI and SAIFI values reflects increased continuity of electricity supply and reduced disruptions experienced by customers. This aligns with electricity service performance standards, which prioritize system reliability as a primary indicator of service quality.

Conclusion

Based on the research results and discussions conducted, it can be concluded that protection system coordination plays a crucial role in improving the reliability of the 20 kV medium-voltage power distribution system. An evaluation of the existing conditions indicates that mismatched protection relay settings result in relatively long fault interruption times and larger outage areas, negatively impacting system reliability.

Optimizing protection system settings, particularly for the Overcurrent Relay (OCR) and Ground Fault Relay (GFR), has been shown to improve the selectivity and response speed of the protection system to faults. Improved relay coordination is demonstrated by a more structured Time–Current Characteristic (TCC) curve and an adequate operating time difference between the primary and backup relays. This allows for more rapid and localized fault interruption.

Improved protection system performance directly reduces fault interruption times and outage areas, further contributing to increased distribution system reliability. This is demonstrated by a decrease in the SAIDI reliability index from 185 minutes/customer/year to 112 minutes/customer/year, and a decrease in the SAIFI value from 4.2 times/customer/year to 2.6 times/customer/year after protection system optimization.

Overall, this study demonstrates that systematic, simulation-based evaluation and optimization of protection system coordination can improve the reliability and quality of electricity service. Therefore, protection system optimization can be used as an effective

technical strategy for power distribution system managers to maintain the continuity and reliability of electricity supply to customers.

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