Analysis of Protection System Optimization in Electric Power Distribution Networks to Reduce Customer Disturbances

Kania Isfahani, Zuraidah Tharo, Solly Ariza Lubis

Abstract

The protection system is a vital element in maintaining the reliability of 20 kV power distribution. The main problem that often arises is widespread outages due to non-selective relay coordination (overlapping). This study analyzes optimization measures through resetting the Overcurrent Relay (OCR) and Ground Fault Relay (GFR) and strategic recloser placement. Using technical data from various feeders and ETAP software simulations, it was found that proper relay timing synchronization can reduce the extent of outages and improve the SAIDI and SAIFI reliability indices.

Keywords: Protection System, 20 kV Distribution Network, Relay Coordination, OCR, GFR, Recloser, ETAP, Reliability (SAIDI/SAIFI).

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Introduction

In an electric power system, the distribution network is the most vulnerable to disruptions due to its extensive reach and direct exposure to the external environment. According to operational data from PT. PLN, most disruptions in the 20 kV distribution network are temporary. However, if the protection system does not operate optimally, these disruptions can turn into permanent outages, which can harm customers economically and in terms of comfort [1].

Optimizing protection involves more than just installing equipment; it involves coordinating equipment to ensure selective operation. "Miscoordination" often occurs when relays in the substation (upstream) operate faster than relays or protection devices (such as reclosers or fuses) downstream. As a result, a small disruption at the feeder end can cause a power outage throughout the entire area supplied by that feeder. Therefore, in-depth analysis of short-circuit current calculations and Time Multiplier Setting (TMS) adjustments is necessary to ensure an intelligent and efficient protection system[2].

The 20 kV distribution network has high environmental exposure, which poses a risk of both phase-phase and phase-ground faults. The direct link between optimizing the protection system and reducing customer interruptions lies in the system's ability to localize the affected area. Without optimal coordination, a small downstream disturbance can trigger a tripping of the Circuit Breaker (PMT) at the substation, resulting in a total blackout across the entire feeder.

By implementing optimizations—such as synchronizing the Time Current Curve (TCC) and properly placing reclosers—the system can distinguish between temporary and permanent interruptions. This significantly reduces the outage duration (SAIDI) and outage frequency (SAIFI) experienced by customers, thereby maintaining energy supply continuity and minimizing economic losses due to customer outages.

Literature Review

2.1 Distribution Protection System Components

- Over Current Relay (OCR): Works on the principle of overcurrent. This relay must be able to distinguish between normal peak load current and short circuit fault current.
- Ground Fault Relay (GFR): Designed to detect residual currents due to ground faults. Since most distribution systems use neutral grounding through resistance (NGR), GFR has higher sensitivity than OCR.
- Auto Recloser: A highly effective automatic recloser for temporary disturbances (80% of total distribution disturbances). Strategic recloser placement can divide the feeder into multiple protection zones.

2.2 Principles of Selectivity and Grading Time

Selectivity is the ability of a protection system to isolate the smallest affected area. This is achieved by adjusting the grading time between devices[3]. The IEEE and SPLN standards recommend a grading time of 0.2 to 0.4 seconds to ensure that downstream devices operate before upstream devices [4].

2.3 Protection Philosophy

A protection system is a set of safety devices that detect abnormal conditions in a network. Its main components include current transformers (CTs), protective relays, and circuit breakers (CBs). The primary function of protection is to minimize equipment damage and maintain human safety. A protection system must meet five main criteria: selectivity (switching off only the affected area), stability, speed, sensitivity (the ability to detect even the smallest disturbances), and reliability.

2.4 Short Circuit Current Theory

A short circuit occurs when there is a failure of insulation between conductors or between conductors and ground. To calculate this, the sequence impedance method is used.

General Formula for 3-Phase Short Circuit Current:

$$I_{hs3\emptyset} = \frac{VL-L}{\sqrt{3}\ x\ Ztotal}$$

Where:
$I_{hs3\emptyset}$ = short circuit current 3 phase [A]
$V_{L\text{-}L}$ = voltage line [V]
Z_{total} = source impedances + transformer impedance + lateral impedance [Ohm].
Single-Phase to Ground Short Circuit Current Formula:

$$I_{hs1\emptyset} = \frac{3x\ VL-N}{Z1+Z2+Z0+3Zn}$$

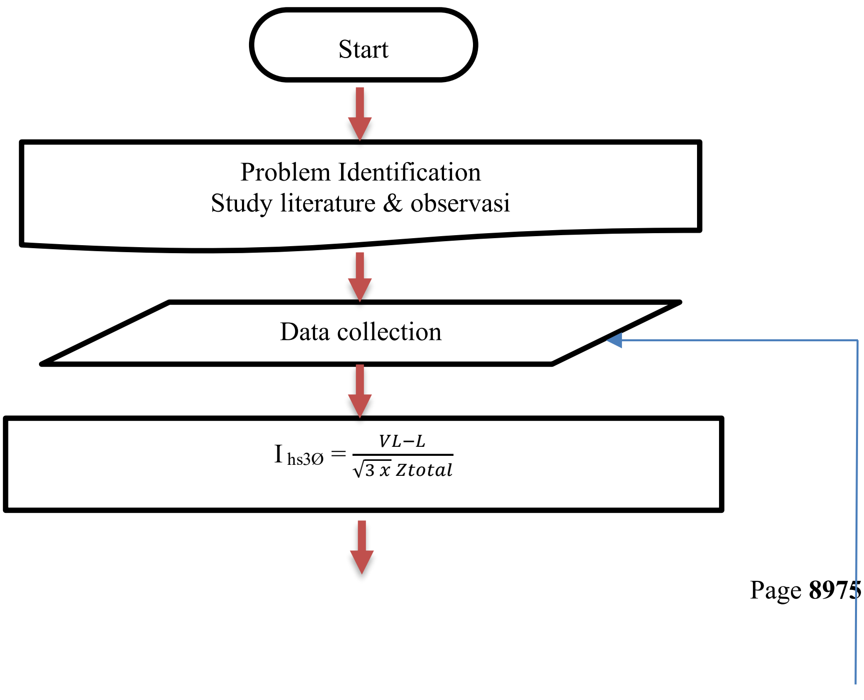
Where Z1, Z2, Z0 are the positive, negative, and zero sequence impedances, and Zn is the neutral grounding impedance (NGR).

Research Methodology

This research uses a quantitative approach with the following stages:

1. Technical Data Collection: Taking data on power transformer specifications, feeder length, conductor type, and peak load data from daily operation reports [5].
2. Short Circuit Current Calculation: Using the sequence impedance formula to calculate 3-phase, 2-phase, and 1-phase fault currents to ground at points 0%, 25%, 50%, 75%, and 100% of the network length [6].
3. Existing Setting Analysis: Evaluate the Time Multiplier Setting (TMS) value and current pick-up current to see whether they are still in accordance with the latest fault current profile [7].
4. Coordination Simulation: Modeling the network into ETAP software to see the time-current characteristic curve (TCC) [7].
5. Field Observation: Taking existing setting data on OCR/GFR at the Main Substation and Recloser.
6. Single Line Diagram (SLD) Modeling: Building a distribution network model using ETAP software.
7. Manual Calculation: Calculate short circuit current at various points (0%, 25%, 50%, 75%, 100%) as simulation comparison data.
8. Coordination Evaluation: Analyze the grading time (time difference) between relays. If < 0.3 seconds, then reset the TMS.
9. Validation: Run Fault Insertion simulation on ETAP to ensure downstream relays work first.

The research flowchart is shown below:



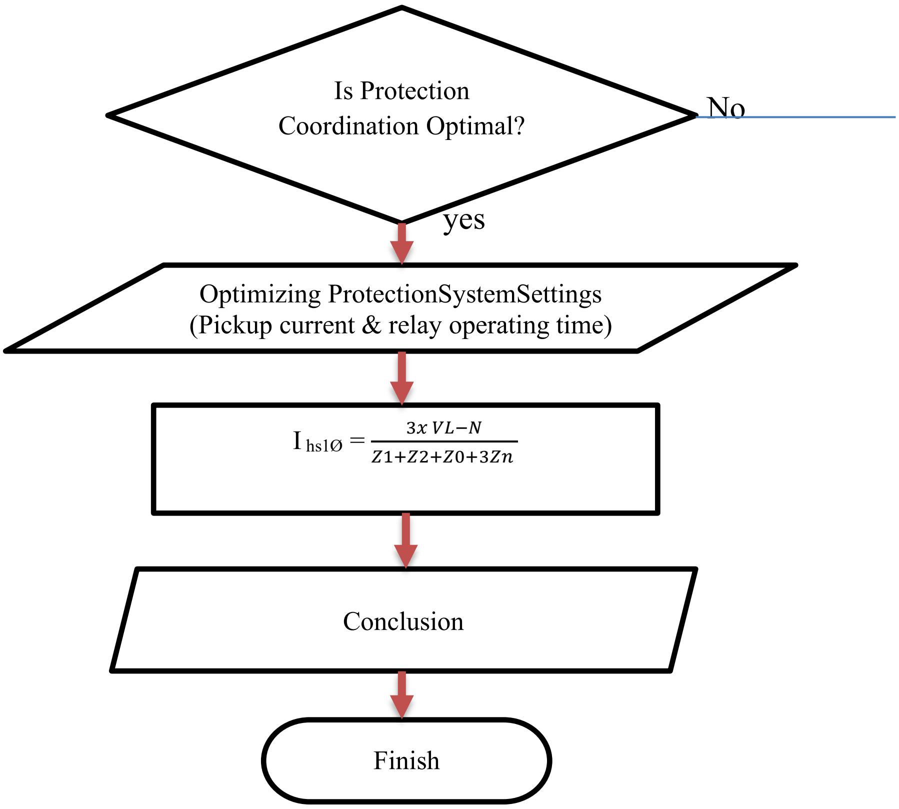


Figure 1. Research Flowchart

Results

4.1 Short Circuit Current Analysis

Based on data analysis on the Nginden and Brenggolo Feeders, a pattern of exponentially decreasing fault current with distance was found [8]. For example, the 3-phase fault current at the base of the feeder (10% distance) was 17,021 A, while at the end of the feeder (100% distance) it decreased to 5,137 A [9]. This decrease indicates that the relay must remain sensitive to detect faults at the end even though the current is relatively small compared to faults near the busbar [10]. The following is the data for calculating the short circuit current on the Feeder.

Table 1. The Short Circuit Current

Interference Distance (%)	**Distance(km)**	**3-phase current (A)**	**2-phase current (A)**	**Single-Phase Current to Ground (A (A)**
1% (Busbar)	0.1	17.021	14.740	985
25%	3.5	12.450	10.780	920
50%	7.0	9.120	7.897	845
75%	10.5	6.840	5.923	780
100%	14.0	5.137	4.448	710

4.2 Optimal Setting Calculation (Resetting)

For example, the calculation of phase-phase current (Ihs2phi) at the point of 50% of the network length (7 km): Given VL-L = 20 kV, and the total impedance at that point Ztotal = 1.46 Ω

$$I_{hs2Ø} = \frac{\sqrt{3}}{2} \times I_{hs3Ø} = \frac{\sqrt{3}}{2} \times \frac{20000}{\sqrt{3}x1.46}$$

$$I_{hs2Ø} = \frac{20000}{2x\ 1.46} = 6.849 \text{ A}$$

These results are then used to determine the pick-up current on the OCR so that there is no overlap with the peak feeder load.

4.3 Recloser Placement Optimization

The addition of a recloser at the 50% point of the feeder length has proven effective. If a permanent fault occurs at the end of the feeder, only the load after the recloser is cut off, while customers between the substation and the recloser remain supplied with electricity. This reduces the average outage duration (SAIDI) by up to 40% [11].

4.4 TCC Curve Synchronization

Simulation results show that many protection failures are caused by the intersection of the OCR curve between the incoming and outgoing sides [12]. Optimization is carried out by changing the relay characteristics to Standard Inverse with TMS adjustments[13].

Resetting Results: The outgoing relay is set at a TMS of 0.05, while the downstream recloser is set at a TMS of 0.03. With this coordination, simultaneous trips no longer occur, thus improving the stability of the electricity supply to customers [14].

Conclusion

Based on the analysis and discussion, it can be concluded that optimizing the protection system in the electricity distribution network must be done by recalculating the short-circuit current according to the current load conditions and network configuration. This step is crucial to ensure that coordination between the Over Current Relay (OCR), Ground Fault Relay (GFR), and Recloser operates selectively. By setting a minimum grading time of 0.3 seconds, the system can effectively localize faults, thus avoiding widespread blackouts. Furthermore, the use of simulation software such as ETAP has proven crucial in validating the accuracy of relay settings before field implementation, ensuring the reliability of the protection system in the face of various fault scenarios.

To maintain optimal protection system performance, distribution operators are advised to perform regular routine maintenance, particularly on the battery components as a backup power source and the Circuit Breaker (PMT) mechanics, so that the relays can operate precisely according to the planned disconnection times. Furthermore, as renewable energy technology advances, further studies are needed to assess the impact of distributed generation integration, such as solar power plants (PLTS), on bidirectional fault currents. This study is essential to ensure future protection systems remain adaptive and maintain the safe continuity of electricity supply to customers.

References

[1] Z. Tharo, M. Ridho, P. Siagian, U. Pembangunan, and P. Budi, "Terhadap Kinerja Sistem Proteksi Gardu Induk 150 KV," vol. 12, no. 3, 2024.

[2] P. Wibowo, S. Anisah, and R. B. Pratama, "Analisis Pengaruh Penggantian Konduktor pada Saluran Udara Tegangan Menengah 20kV terhadap Drop Tegangan di PT . PLN (Persero) UP3 Bangkinang," vol. 5, no. 2, pp. 803–812, 2025.

[3] S. Anisah, Z. Tharo, and F. Prayogi, "Sistem Monitoring Daya dan Arus Listrik Pada Pembakit Power and Electric Current Monitoring System in Wind Power Plants Based on Thingspeak," vol. 8, no. 1, pp. 189–194, 2024, doi: 10.31289/jesce.v6i2.12617.

[4] Y. K. Jajang Wijaya1, Sukahir 2 , Asep Muh. Soleh3 , Direstu Amalia 4, "Bagaimana sistem proteksi dapat mempengaruhi keandalan jaringan listrik," no. 1, 2024.

[5] S. Khodijah and N. Syifa, "Evaluasi Efisiensi Sistem Proteksi pada Jaringan Distribusi Tegangan Menengah," vol. 1, no. 2, pp. 48–55, 2025.

[6] H. D. Paminto and A. Kiswantono, "Rancang Simulasi Sistem Over Current Relay Pada Jaringan Distribusi 20KV Mengggunakan ETAP," vol. 3, no. 1, pp. 45–49.

[7] D. R. Supendi and Y. P. Hikmat, "Evaluasi Jaringan Distribusi Listrik Tegangan Rendah

Untuk Penyediaan Energi Pada Laboratorium Teknik Di Politeknik Negeri Bandung," pp. 511–520, 2023.
[8] E. Idriana, R. Putri, S. Meliala, and D. Fariadi, "Analisa Setting Koordinasi Proteksi Over Current Relay Pada Jaringan Distribusi Di PT . PLN (Persero) ULP Pangkalan Brandan," vol. 10, pp. 22–29, 2021.
[9] I. W. Jondra, I. K. Suryawan, I. P. Agus, and S. Wibawa, "Fuse Memproteksi Inverter dan Baterai BESS dalam Sistem Distribusi Listrik," vol. 14, no. 2, pp. 318–328, 2025.
[10] S. Luthfi, H. Rangga, N. Hermawan, and P. Surya, "Evaluasi Kinerja Sistem Proteksi Penyulang Trawas PT . PLN (PERSERO) ULP Pandaan," vol. 11, no. 2, 2024.
[11] S. Meliala, "Memaksimalkan Kinerja Sistem Tenaga Listrik Di Jaringan Distribusi 20 Kv Pada PT . PLN (Persero) Unit Pelaksana Pelayanan Pelanggan (UP3) Sigli," vol. 10, pp. 30–34, 2021.
[12] I. C. T. Siahaan, A. A. Nasution, A. Yanie, and I. Roza, "Analisis Keandalan Sistem Tenaga Listrik," vol. 2, no. 3, pp. 45–52, 2024, doi: 10.61240/jmri.v2i3.83.
[13] P. Hariyanto, M. Idris, and M. Isnen, "Perancangan Alat Proteksi Tegangan Listrik Berlebih dan Menurun pada Jaringan Distribusi Tegangan Rendah," vol. 2, pp. 46–52, 2020.
[14] I. Daffa, F. Al, A. H. Andriawan, and R. S. Widagdo, "Studi Kinerja Sistem Proteksi Arus Lebih pada Sistem Distribusi Tegangan Menengah 20 kV Penyulang Nginden PT . PLN UP3 Surabaya Selatan," pp. 411–422, 1945.