Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 10, 378-390
2025
Publisher: Learning Gate
DOI: 10.55214/2576-8484.v9i10.10438

Optimal OCR setting and protection coordination on priority customer feeder at PT. PLN ULP Gondang Wetan using modified firefly algorithm

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Abstract: Reliability and continuity of electricity supply are vital for priority customers such as hospitals and other critical facilities. Overcurrent relays (OCR) play a key role in detecting overcurrent and preventing further system damage; however, proper coordination between main and backup relays is crucial to maintain protection efficiency. This study aims to optimize the Time Dial Setting (TDS) and OCR protection coordination using the Modified Firefly Algorithm (MFA) in the distribution system of PT. PLN ULP Gondang Wetan. MFA was implemented in MATLAB to determine optimal relay parameters, while ETAP software was used to verify Time-Current Characteristic (TCC) curves. Several IEEE characteristic curves, such as Normal Inverse, Very Inverse, Long-Time Inverse, and Extremely Inverse, were evaluated. Results show that MFA generates optimal TDS settings, improves relay coordination, reduces operating time, and produces Coordination Time Interval (CTI) values that fulfill the required criteria for protection selectivity. This method offers a systematic framework for optimizing OCR settings in Indonesian industrial power systems, reducing service interruptions and enhancing supply continuity for critical customers.

Keywords: *Coordination time interval, Modified firefly algorithm, Optimization protection coordination, Overcurrent relay, Time dial setting.*

1. Introduction

Reliability and continuity of electricity supply are important aspects of electric power systems, especially for priority customers such as hospitals, industry, and other critical facilities. Interruptions in supply to these users must be minimized or ideally eliminated to maintain service reliability and operational continuity.

Electrical faults, whether due to overloads or short circuits, must be detected and cleared swiftly, isolating only the affected section without disturbing the healthy portions of the network. To achieve this selective isolation, protection systems are employed. Protective relays, integral components of these systems, monitor system parameters and issue trip commands to circuit breakers when abnormal conditions occur [1]. Rather than preventing faults, protection systems shorten fault durations, mitigate their impacts, and reduce associated risks. An effective protection scheme thus must satisfy the five key criteria of reliability, selectivity, speed, simplicity, and economy [2].

Protection devices in priority customers, especially industrial systems, are required to quickly isolate parts of the system that fail so as not to affect the continuity of service in other parts of the system. For this reason, protection devices must be properly coordinated to prevent operational failures that could cause damage and loss of service continuity. This condition is contrary to the function of the protective device itself. To improve the performance of protection devices in safeguarding the system from all forms of interference, protection coordination is carried out to obtain the correct settings of the protection devices. Among protective devices, the overcurrent relay (OCR) operates when the monitored current exceeds a set pickup threshold. Using inputs from current transformers (CTs), the

History: Received: 11 August 2025; Revised: 15 September 2025; Accepted: 19 September 2025; Published: 9 October 2025
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OCR issues either instantaneous or time-delayed trip signals depending on its design and the nature of the fault. Instantaneous OCRs act without intentional delay for very high-magnitude faults, whereas inverse-time OCRs adjust their operating time according to the fault current magnitude, following predefined time–current characteristic (TCC) curves. However, coordinating protection is complex. A case study at PT. PLN ULP Gondang Wetan demonstrated very fast protection coordination, which resulted in the feeder side of priority customers not having enough time to coordinate their protection independently. If this situation persists, it will negatively impact the performance of SAIDI and SAIFI.

To overcome this problem, it is necessary to optimize the settings and coordination of overcurrent protection relays on priority customer feeders. One approach that can be used to achieve this optimization is through the Modified Firefly Algorithm, which is an optimization algorithm inspired by firefly behavior [3] and is effective in solving a variety of complex optimization problems. The optimization process is carried out using the MATLAB program, and the results will be tested using the ETAP simulation program. It is hoped that through this study, the relay time setting and protection coordination can be improved so that the protection response becomes more efficient and disruption to priority customers no longer affects the main distribution system of PT. PLN.

Over the past decade, a considerable number of research studies have been conducted on OCR protection systems. In research, Khurshaid et al. [4] focus on using an adaptive version of the firefly algorithm to optimize the coordination of overcurrent relays. The research demonstrates the algorithm's efficiency in improving relay coordination in electrical systems, similar to your work on optimizing relay settings for overcurrent protection. In research, Fitri et al. [5] explore enhancements to the firefly algorithm for optimizing directional overcurrent relays, focusing on improving relay coordination by reducing complexity and enhancing the precision of the firefly algorithm in industrial systems. This aligns with research aimed at optimizing relay coordination in the context of PT. PLN ULP Gondang Wetan. There are also research Tjahjono et al. [6] and Seng et al. [7] focusing on relay coordination, taking into account the impacts of inrush currents and motor-starting transients to reflect actual system behavior and maintain selectivity, and by Mahindhara and Pujiantara [8] focusing on modern industrial distribution networks with large induction motors and intricate interconnections.

The novelty of this study lies in the application of the Modified Firefly Algorithm (MFA) for the optimization of overcurrent relay (OCR) protection settings and coordination in electricity distribution systems serving priority customers such as hospitals and other critical facilities. Although the use of the firefly algorithm has been applied in various optimization contexts, this study modifies the algorithm to address the specific challenge in electrical protection systems, namely ensuring the selectivity and efficiency of relay coordination in distribution systems with fast uptime, while maintaining the continuity of power supply.

One of the key contributions of this study is the application of MFA in the optimization of protection coordination in priority customer feeders, an area that has not been extensively discussed in previous research. Electricity distribution systems that serve priority customers require highly selective protection arrangements to avoid disruption to vital services. This study introduces an algorithm that can optimize the Time Dial Setting (TDS) and Coordination Time Interval (CTI) on the relay to ensure that the operating time is efficient and effective, while ensuring that the protection operates correctly without sacrificing the speed of interference isolation.

In addition, the study utilized two software programs to support the simulation and validation of results. MATLAB was employed for MFA implementation, and ETAP was used for Time Current Characteristic (TCC) curve verification. This approach offers a more practical and applicable method within the electrical industry. It also enhances the study's results by comparing various IEEE TCC curves, such as the Normal Inverse (NINV), Very Inverse (VINV), and Extremely Inverse (EINV) curves, which have not been extensively examined in previous studies for similar cases. Each curve was tested to assess its impact on relay operation time and coordination between relays, providing new insights into the most efficient protection settings.

Thus, this study not only introduces innovations in the use of the Modified Firefly Algorithm (MFA) but also provides a new solution for the coordination of overcurrent relay (OCR) protection in distribution systems serving priority customers, to improve efficiency, selectivity, and reliability in overcoming power outages. This research contributes to the development of more sophisticated electrical protection systems that are adaptive to industrial needs, especially for priority customers who require a sustainable and reliable supply of electricity.

This research aims to develop and improve the protection system at PT. PLN ULP Gondang Wetan, especially in terms of regulating and coordinating OCR protection relays. First, this study aims to determine the optimal parameters of OCR protection relay settings and coordination, which are crucial in ensuring that the protection system functions properly and efficiently. Using more advanced methods, such as the firefly algorithm, this study aims to implement and evaluate these methods in the regulation and coordination of OCR protection relays. This implementation is expected to produce a more optimal solution compared to previously used methods. Furthermore, this research also aims to improve the setting and coordination of protection in PT. PLN ULP Gondang Wetan to enhance efficiency in protecting the electricity distribution system. Finally, this study will provide recommendations and implementation guidelines for the optimization of relay settings, which are expected to be applied to improve the performance and safety of the protection system at PT. PLN ULP Gondang Wetan. The remainder of this paper is organized as follows. Section 2 reviews fundamental principles and settings of overcurrent relays. Section 3 details the problem formulation and the MFA implementation in MATLAB. Section 4 presents the ETAP simulation results and performance analysis. Finally, Section 5 summarizes the key findings and outlines directions for future research.

2. Method

2.1. Overcurrent Relay Coordination Protection

An overcurrent relay is a protection device that activates when the monitored current exceeds a predefined pickup value, as occurs during system overloads or short-circuit faults. Using secondary inputs from current transformers (CTs), the relay continuously measures line current and compares it against its pickup setting. If the instantaneous current surpasses this threshold, the OCR initiates a trip sequence; otherwise, it remains inactive. Depending on its design and the nature of the disturbance, the relay may operate instantaneously or introduce a deliberate time delay to coordinate with downstream devices.

The fundamental operating principle of the OCR hinges on the comparison between the fault current If and the pickup current Ip. When $If > Ip$, the relay issues a trip command to the associated circuit breaker, isolating only the faulted section and thus preventing further damage to the network. Conversely, if $If \leq Ip$, the relay remains in a restrained state and takes no action, ensuring selectivity in normal and minor-fault conditions.

2.2. Selection Pickup Current Ip

When the current exceeds the predetermined threshold value, it reaches the pickup current (Ip). The pickup current is defined as the minimum current that must flow for the relay to start responding to a disturbance. In other words, the operating principle of an overcurrent relay is to detect abnormal current conditions and respond when the current value exceeds the specified threshold. The pickup current limit for a relay used as overload protection is defined in Mahindhara and Pujiantara [8] as follows:

$$1.05 \text{ FLA} < \text{Ip} < 1.4 \text{ FLA} \quad (1)$$

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 10: 378-390, 2025
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Meanwhile, the determination of pickup current limits for a relay functioning as short-circuit protection utilizes the minimum short-circuit current generated by a two-phase fault at the power source.

$$1.6 \text{ FLA} < \text{Ip} < 0.8 \text{ Isc Min} \quad (2)$$

FLA represents Full Load Ampere while Ipickup is the pickup current.

2.3. TDS Calculation

TDS is used to adjust how quickly an inverse time overcurrent relay operates after the current exceeds the pickup value (Ipickup). A higher TDS value results in a slower operating time. The calculation of TDS is generally based on IEEE standards. The formula is as follows [9]:

$$TOP = TDS\, x \left(\frac{A}{\left(\frac{If}{Ip}\right)^{p} - 1} + B \right) \quad (3)$$

Where TOP represents the relay's operating time in seconds, and TDS is a scaling factor that adjusts the overall delay of the relay response. The variables A, B, and P are characteristic constants that define the shape of the time-current curve. These constants vary depending on the selected relay curve type such as standard inverse, very inverse, or extremely inverse [9] and are typically provided by manufacturers or defined in the IEEE C37.112 standard [10] (refer to Table 3 for specific values). The Ip is pickup current and If is the fault current, and the ratio between If and Ip reflects the severity of the fault in relation to the relay's pickup threshold, as the ratio increases, the relay is expected to operate more quickly.

Table 1.
Coefficient Constraints for IEEE TCC Curves.

TCC Curve	A	B	p
IEEE Extremely Inverse	28.20	0.1217	2
IEEE Very Inverse	19.61	0.491	2
IEEE Moderately Inverse	0.0515	0.114	0.02
IEEE Normal Inverse	0.0226	0.01	0.02

2.4. Modified Firefly Algorithm Implementation

2.4.1. Firefly Algorithm

Firefly Algorithm (FA) is a metaheuristic optimization method inspired by natural phenomena, specifically the bioluminescent communication of fireflies. First proposed by Xin-She Yang, FA leverages the collective intelligence of living organisms in the search for optimal solutions. By modeling pairwise interactions among fireflies based on relative brightness and mutual distance, the algorithm balances global exploration and local exploitation within a complex search space. The interactions among fireflies follow three principles. All fireflies are mutually attractive, regardless of sex. Each individual moves towards any other brighter firefly. The brightness is determined by the value of the objective function under consideration [11].

Based on these three principles of firefly interactions, the movements of the firefly from its initial position toward i a brighter firefly at a position j can be described by the following equation:

$$x_i = x_i + \beta_0 e^{-\gamma r_{ij}^2}\left(x_j - x_i\right) + \alpha \epsilon_i \quad (4)$$

Where β_0 represents the attractiveness of fireflies at when distance r is zero. r represents the space separating two fireflies, γ is the absorption coefficient, α is the randomization factor with a range between 0 to 1, and lastly ϵ_i is a random value of the Gaussian distribution.

ISSN: 2576-8484
Vol. 9, No. 10: 378-390, 2025
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2.4.2. Modified Firefly Algorithm

In the Firefly Algorithm, the randomization parameter α, typically chosen in the interval between 0 and 1 controls the scale of stochastic movements. A large α enhances global exploration but risks overshooting optimal regions, whereas a small α improves convergence precision at the expense of search diversity. To balance these objectives, the Modified Firefly Algorithm employs an exponential damping schedule for α. At each iteration k, α is decreased by a small amount, thus gradually shifting the balance from exploration toward exploitation. α is updated according to:

$$\alpha^{k+1} = \alpha^{k}\, x \left(\frac{1}{2}\, x\, k_{max}\right)^{\frac{1}{k_{max+1}}} \tag{5}$$

where k_{max} is the total number of iterations. This adaptive decay maintains high randomness during early iterations, facilitating exploration and progressively concentrates the search around promising areas in later stages.

To contextualize this update within the full optimization workflow, Fig. 1 presents a detailed flowchart of the Modified Firefly Algorithm as applied to overcurrent relay coordination. Starting from the initialization of firefly positions and the objective function, the process iteratively evaluates brightness, computes mutual attractions, moves each firefly according to both deterministic and stochastic components, and updates α until convergence or the maximum iteration count is reached.

3. Results and Discussion

This study investigates the electrical distribution network of a priority customer industrial facility under PLN Gondang Wetan, hereafter referred to as Plant 1, with a total installed capacity of 23 MVA and a dedicated feeder serving its critical loads. The Plant 1 distribution system employs a radial, one-way configuration: energy is supplied from PLN's 20 kV medium-voltage network into the Medium Voltage Main Distribution Board (MVMDB 1), then routed through three transformers (Trafo IV-1, IV-2, and IV-3) to separate Low Voltage Main Distribution Boards (LVMDBs). Each feeder operates without a tie switch, ensuring strictly unidirectional power flow from the upstream source to the downstream load.

Table 2.
The Data of Transformer.

ID Transformer	MVA	Kv	%Z	X/R	Connection
Trafo 3 GI GDW	60	150/20	12.5	34.1	*delta*/wye
Trafo IV-1	4.5	20/0.4	8	12.14	*delta*/wye
Trafo IV-2	4.5	20/0.4	8	12.14	*delta*/wye
Trafo IV-3	2.5	20/0.4	8	10.67	*delta*/wye

Table 3.
The Current Transformer Ratio.

No	ID CT	CT Ratio (A)
1	CT 1	500/5
2	CT 2	2500/5
3	CT 3	160/5
4	CT 4	160/5
5	CT 5	160/5

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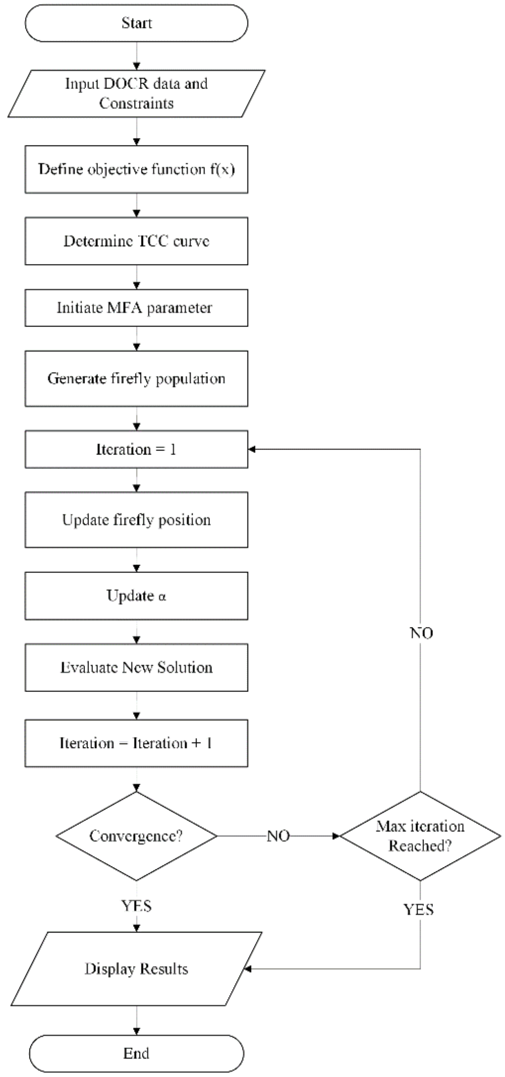

Figure 1.
Flowchart of MFA Implementation for OCR Coordination.

To simplify the process of protection coordination analysis, a typical representation is used as a model that can reflect the characteristics of the electrical system configuration in the plant. In Fig. 3, the configuration of the representative electrical system used as the basis of the analysis in this study is shown. The line analyzed is the distribution flow from Bus21 (20 kV), which is the supply entry point from PLN, to the secondary side of Transformer IV-2 (4500 kVA) on Bus89 (0.4 kV), and then distributed to the load. The selection of this single path aims to simplify the scope of the study without compromising the main characteristics of the system. This approach is sufficient to represent the pattern of power flow and protection coordination prevailing in the customer's system.

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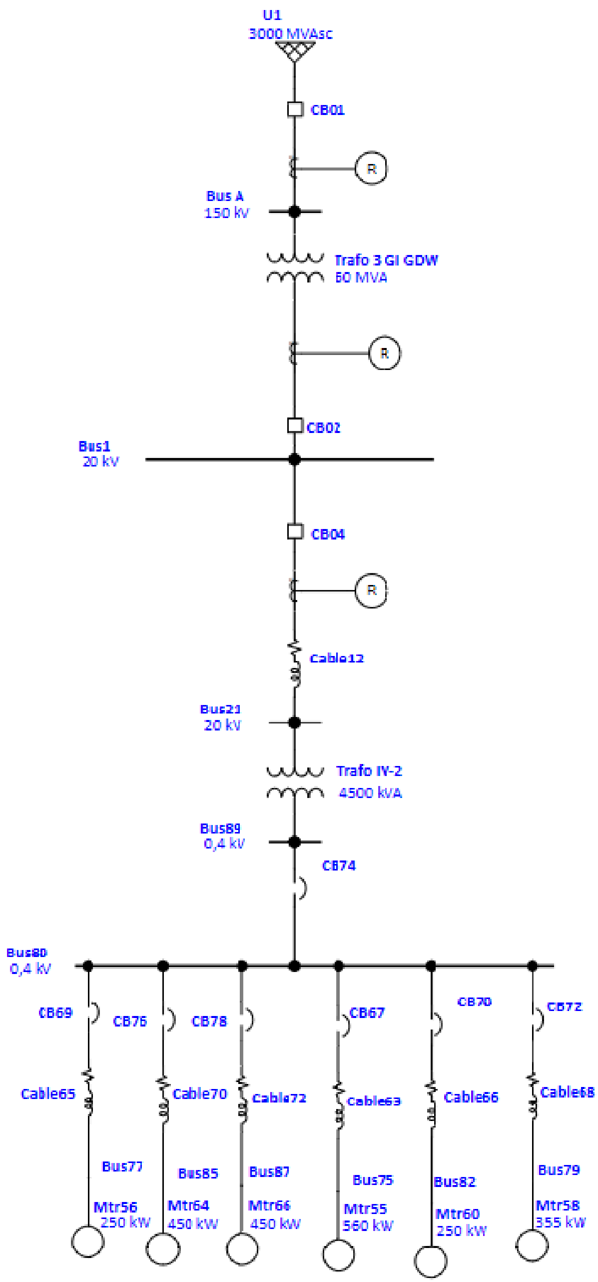

Figure 2.
Typical SLD Representation of the Electrical Distribution System for the Priority Customer Facility.

Short circuit occurs at two main fault points, namely at Bus21 (20 kV) and Bus89 (0.4 kV). The interference on Bus21 indicates a point of coordination of protection between the customer's system and the supply system of PLN, while the interference on Bus89 reflects the interference conditions on the low-voltage side that are directly related to the load. The maximum short circuit current data flowing to each protection relay for the two fault conditions are presented separately in Table 4 for the fault scenario on Bus21, and Table 5 for the fault scenario on Bus89.

Table 4.
Maximum Short-Circuit Currents Detected by Each Relay Under a Typical Fault at Bus21 (20 kV).

No.	CB ID	Voltage Level (kV)	Iscmax Primer (kA)	Iscmax Backup (kA)
1.	CB04	20	11.126	-
2.	CB02	20	3.760	11.126
3.	CB01	150	1.467	3.760

Table 5.
Maximum Short-Circuit Currents Detected by Each Relay Under a Typical Fault at Bus89 (20 kV).

No.	Call ID	Voltage Level (kV)	Iscmax Primer (kA)	Iscmax Backup (kA)
1.	CB74	0.4	77.824	-
2.	CB04	20	6.999	77.824
3.	CB02	20	3.760	6.999
4.	CB01	150	1.467	3.760

The algorithm randomly generates the initial population of TDS within the range of TDS constraints. Each population represents a candidate TDS setting for the entire relay and serves as a starting point for exploring optimal solutions. Fig. 4 shows the initial population distribution of CB04 TDS values under fault conditions at Bus 21 using the Normal Inverse curve (NINV) characteristic, while Fig. 4 also shows the initial population distribution of CB02 TDS values under fault conditions at Bus 21. Each point represents one individual population out of the first 25 fireflies raised by the MFA.

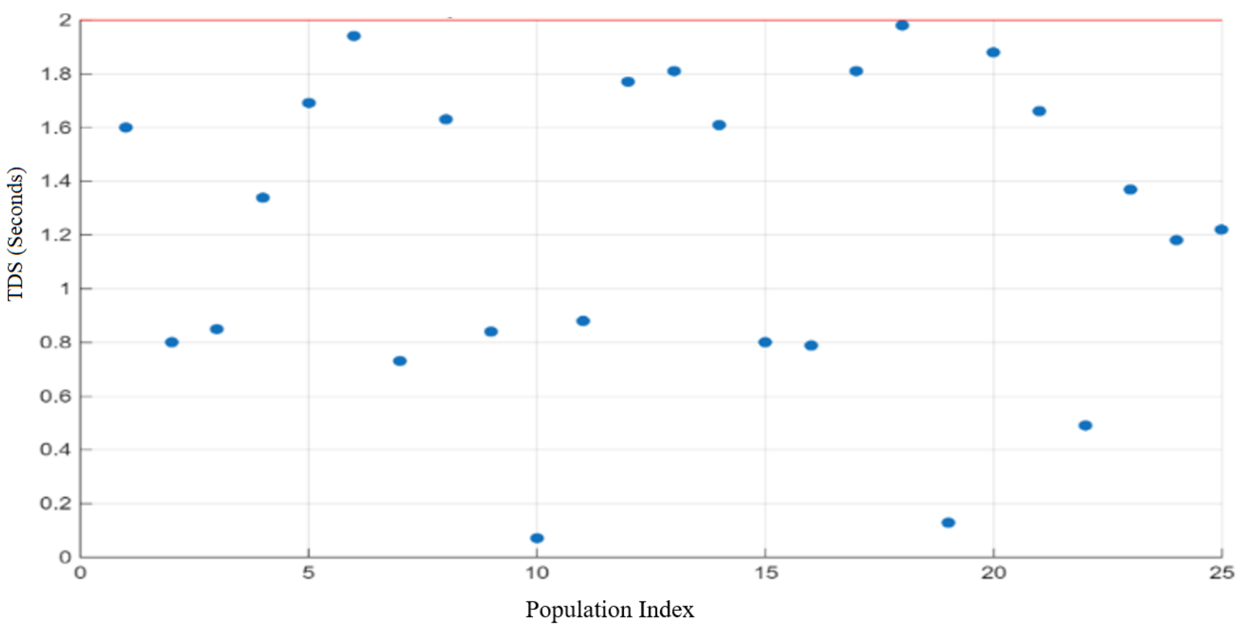

Figure 3.
Initial Population Distribution of CB04 TDS Values Under Fault Condition at Bus21.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 10: 378-390, 2025
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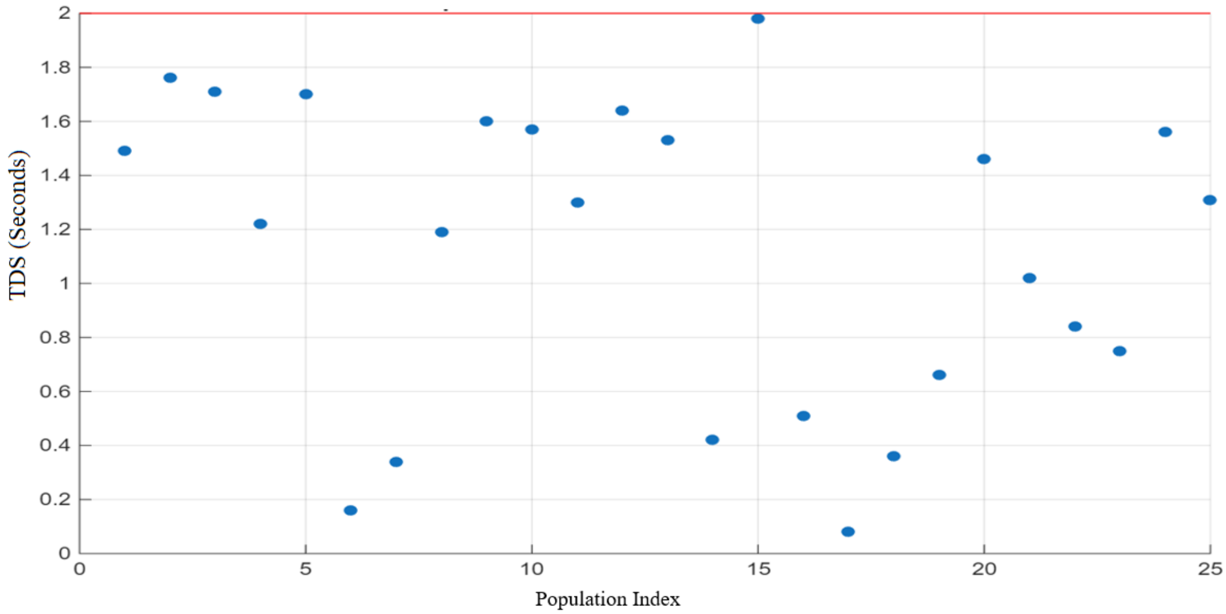

Figure 4.
Initial Population Distribution of CB02 TDS Values Under Fault Condition at Bus21.

Simulations were conducted using the Modified Firefly Algorithm (MFA) to optimize protection coordination based on various IEEE inverse time-current characteristics, including NINV, VINV, LTINV, and EINV. The optimization results are displayed in the form of a table, which includes FLA values, TAP settings, TDS values, and primary and backup relay uptime.

Table 6.
Optimized OCR Coordination with IEEE NINV Characteristics.

IEEE Normal Inverse Curve (NINV)							
Main Relays				**Backup Relays**			
Relay ID	**TAP**	**TDS**	**TOP (s)**	**Relay ID**	**TAP**	**TDS (s)**	**TOP (s)**
Relay 3	0.50	0.07	0.200	Relay 2	0.50	0.13	0.405
Relay 2	0.50	0.05	0.215	Relay 1	0.50	0.10	0.415

Table 7.
Optimized OCR Coordination with IEEE VINV Characteristics.

IEEE Very Inverse Curve (VINV)							
Main Relays				**Backup Relays**			
Relay ID	**TAP**	**TDS**	**TOP (s)**	**Relay ID**	**TAP**	**TDS (s)**	**TOP (s)**
Relay 3	0.50	0.09	0.155	Relay 2	0.50	0.14	0.385
Relay 2	0.50	0.07	0.180	Relay 1	0.50	0.11	0.370

Table 8.
Optimized OCR Coordination with IEEE LTINV Characteristics.

IEEE Long Time Inverse Curve (LTINV)							
Main Relays				**Backup Relays**			
Relay ID	**TAP**	**TDS**	**TOP (s)**	**Relay ID**	**TAP**	**TDS (s)**	**TOP (s)**
Relay 3	0.50	0.20	0.235	Relay 2	0.50	0.35	0.510
Relay 2	0.50	0.15	0.220	Relay 1	0.50	0.28	0.415

Table 9.
Optimized OCR Coordination with IEEE EINV Characteristics.

IEEE Extremely Inverse Curve (NINV)							
Main Relays				**Backup Relays**			
Relay ID	**TAP**	**TDS**	**TOP (s)**	**Relay ID**	**TAP**	**TDS (s)**	**TOP (s)**
Relay 3	0.50	0.06	0.140	Relay 2	0.50	0.09	0.300
Relay 2	0.50	0.05	0.165	Relay 1	0.50	0.08	0.265

Based on those results, the NINV Characteristic Curve results in the most stable coordination, while the VINV and EINV curves provide faster uptime but with a narrow CTI margin. A narrow CTI margin tends to increase the risk of protection miscoordination, which may compromise system reliability and safety. Thus, the results of these TDS and TOP settings can be used as a basis for recommendations for actual protection settings, especially for customer radial distribution systems with dominant load characteristics, as in this case study.

While the MFA optimization in MATLAB yields effective relay settings, ETAP-based validation is necessary to assess their performance under realistic network conditions. Fig. 7 presents ETAP simulations to verify the results under actual fault scenarios at Bus 21 (20 kV).

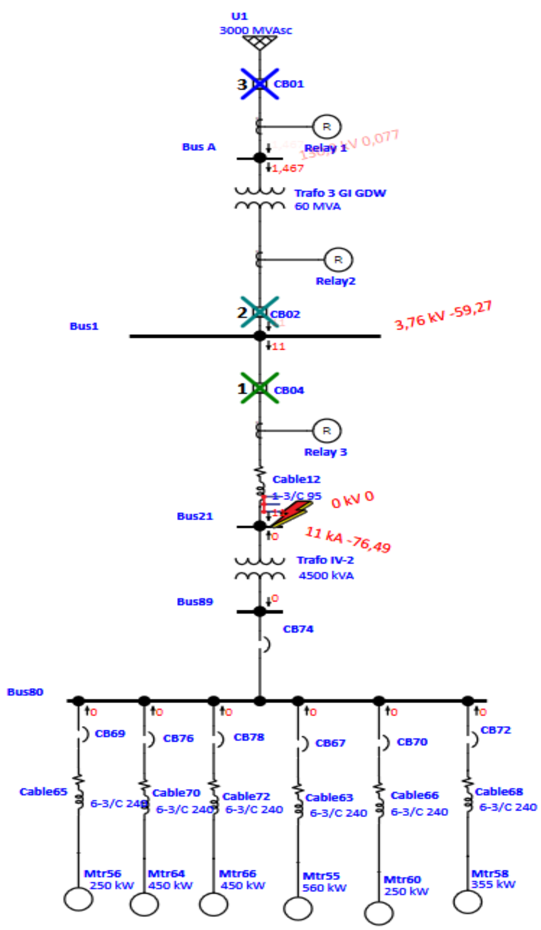

Figure 5.
Tripping Sequence During Fault at Bus21.

Relay 3, functioning as the primary protection device, is the first to respond under fault conditions. In the event that Relay 3 fails to operate, Relay 2 will act as the first-level backup to isolate the fault at

Edelweiss Applied Science and Technology
ISSN: 2576-8484
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Bus21. Should Relay 2 also fail to operate, Relay 1 will serve as the secondary backup relay, providing the final layer of protection to ensure system reliability.

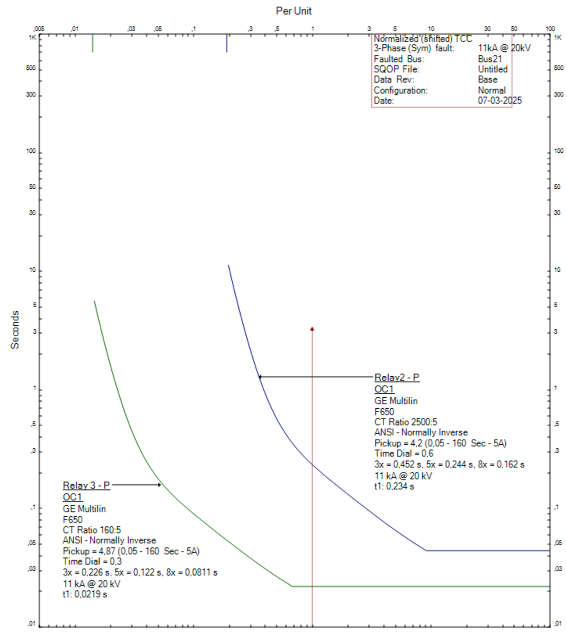

Figure 6.
TCC Curve of Relay 3 and Relay 2 Under Fault Conditions at Bus 21.

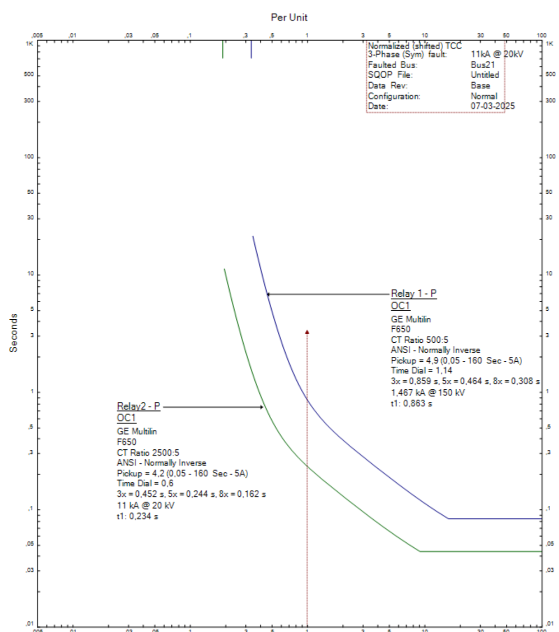

Figure 7.
TCC Curve of Relay 2 and Relay 1 for Interference Conditions on Bus 21.

The testing carried out in the ETAP software in Fig. 7 and Fig. 8 confirmed that the optimal coordination of protection relays can successfully isolate three-phase short-circuit currents with

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 10: 378-390, 2025
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minimal operating time, while maintaining good coordination and CTI that meet the minimum requirements for selective coordination in accordance with established protection standards.

4. Conclusion

Based on the objectives, results, and analysis carried out in this study, it can be concluded that the use of the Multifunctional Algorithm (MFA) method provides significant advantages compared to manual methods in the protection coordination process. The MFA method has proven to be more efficient because it can systematically determine various protection parameters such as TCC curve type, pickup value, TDS value, and CTI value, without relying on trial-and-error approaches or the use of standard values that are general. Furthermore, the optimization results show that the TDS and TOP values applied to each pair of primary and reserve relays result in a qualified CTI value, which is greater than or equal to 0.20 seconds. Thus, the main relay will operate first, and the backup relay will only operate when needed. For example, in the main and reserve relay pairs, such as Relay 3 and Relay 2, the CTI value obtained is 0.201 seconds, while in the Relay 2 and Relay 1 pairs, the CTI value is recorded at 0.223 seconds.

The application of MFA algorithms using MATLAB and TCC curve verification in ETAP also demonstrates that this method is not only theoretically superior but can also be applied in industrial simulations with consistent and reliable results. This shows that MFA has the potential to be applied in a wider industrial environment. Finally, with optimal protection settings, interference that occurs on the customer's feeder side can be isolated quickly, ensuring that the PLN (incoming side) system continues to operate uninterrupted, thus avoiding trips to the main system.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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DOI: 10.55214/2576-8484.v9i10.10438