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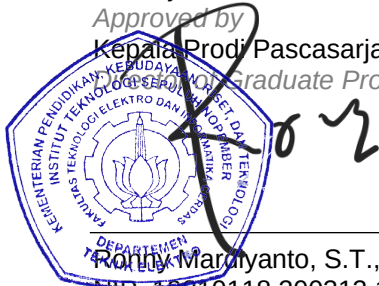
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Optimization Protection Coordination by Optimizing Time Dial Settings at PT. Pupuk Sriwidjaja Palembang Using Grey Wolf Method

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Overcurrent Rele (OCR) is an important component in the electric power protection system. One of the parameters that must be set on the OCR is the Pickup Current (I_p) and Time Dial Setting (TDS). To achieve optimum relay coordination by setting the time dial, several optimisation methods have been used such as Genetic Algorithm (GA), Particle Swarm Optimisation (PSO), Fire Fly Algorithm (FA) and Grasshopper Optimisation Algorithm (GOA).

In this study, the TDS setting was determined through Using the Grey Wolf Optimisation (GWO) method. The GWO algorithm was able to determine the optimum value of the TDS setting for each OCR process. This is validated by the results of tests conducted using the ETAP application. The primary and secondary relays are able to coordinate effectively to secure three-phase faults that occur on each bus.

Furthermore, GWO demonstrated a superior convergence rate in compared to GOA, therefore enhancing its capacity to identify a more optimal TDS setting value. Furthermore, the objective function of GWO is more effective than that of GOA, thereby enhancing its ability to function in a more optimal manner. The results of this test demonstrate that the GWO algorithm is a reliable method for directly identifying the optimal TDS setting value for determining relay coordination settings.

Keywords—Protection Coordination Overcurrent Rele (OCR), Short Circuit Maximum (I_{scMax}), Time Dial Setting (TDS), Grey Wolf Optimization (GWO).

I. INTRODUCTION

The one of the essential components in an electrical system is OCR. OCR is designed as a protection device that responds as quickly as possible to open the circuit breaker when an abnormal current occurs. In programming the coordination of an OCR, there are two types of parameters setting: the first one is Pickup Current (I_p) and the second ones is Time Dial Setting (TDS) [1]. The I_p setting for each relay can be determined by first finding the minimum short-circuit current (I_{scMin}) and full load amps (FLA) [2]. In order to ascertain the TDS value, it is first necessary to identify the IP value and the type of relay used, as the inverse curve characteristics of different types of relay from different manufacturers vary considerably. [3].

The characteristics of the OCR can be observed on the Time Current Curve (TCC). This Inverse Time-Current graph

is used to represent the relay's operational graph. To avoid malfunctions in the primary relay, It is recommended that a secondary relay be provided as a backup to maintain System safety. This can be achieved by adjustment of the time delay of the primary relay and the time delay of the secondary relay. in accordance with the regulations in force [4]. The time delay, the Current Time Interval (CTI) may be set between 0.2 and 0.4 seconds for ensuring the selectivity of the relay coordination [5].

The optimisation of the co-ordination of relays is becoming an increasingly popular method for obtaining the most optimal TDS settings. The application of this optimization method is expected to improve the performance of relays during faults. In previous studies, A number of optimisation algorithms have been implemented, for example the Particle Swarm Optimization (PSO), Genetic Algorithm (GA) and the Firefly Algorithm (FA) [6], Particle Swarm Optimization (PSO) [7], Fire Fly algorithm (FA) [8] and Grasshopper Optimization Algorithm (GOA) [9].

In this study, the process of finding the TDS value is conducted using the Grey Wolf Optimization (GWO) method. GWO's starting point will be an initial population, commonly referred to as agents, that will be applied to each case study [10]. GWO is implemented to obtain the most optimal relay parameter settings and serves as a solution for finding relay coordination settings using MATLAB.

This journal is divided into several sections: I. Introduction, II. Power System Protection, specifically Relay Coordination, III. Grey Wolf Optimization Algorithm, IV. Analysis of Research Results, and V. Conclusion

II. ELECTRICAL POWER SYSTEM PROTECTION

Electrical faults can occur anywhere, at any time. These failures must be anticipated with a reliable protection system. Power system protection is designed to minimise damage to electrical components in the event of faults [11]. Coordinated relay protection is expected For improvement the reliability, selectivity and reliability of the protection system [12].

A. Overcurrent Relay

The one of the essential components in a protection system is OCR. The OCR can detect anomalies in the flow of electricity through the electrical system. Based on its curve

type, OCRs are categorized into three types: Instantaneous , Inverse and Definite Time.

1) Setting Parameters OCR Inverse Time Current

The inverse time, current overcurrent relay operates in a similar way, where an increase in the amount of current flowing through the relay leads to reduced relay operating time. This type of inverse time current OCR includes several curve types: Very Inverse, Long Time Inverse , Ultra Inverse, Standard Inverse and Extremely Inverse [11].

In order to set the inverse time current OCR, it is necessary to enter a number of parameters, including the pickup current and the time dial setting.

According to British Standard 142, the determination of the Pick Up Current (I_p) for overload following by criteria:

$$1.05FLA < I_p < 1.4FLA \quad (1)$$

To determine the limits of the Pick Up Current (I_p) as protection during a short circuit, the following by criteria:

$$1.06 FLA < I_p < 0.8I_{SC \text{ MIN}} \quad (2)$$

Based on the formulas from equations 1 and 2, it can be determined that the Pick Up Current (I_p) serves as the set point for the current at which the circuit breaker must trip if the flowing current exceeds this set point. Full Load Amperage (FLA) represents the maximum current of the load under normal conditions, and ISC MIN refers to the short circuit between phases (I_{sc} for 2 phases) during the steady state duration (30 cycles) [13].

In addition to the I_p setting, the OCR also requires a TAP setting so that it can operate when the I_p setting is exceeded. The following formula is used to calculate TAP:

$$TAP = \frac{I_p}{\text{Primer CT}} \quad (3)$$

TAP is the tapping value from the transformer, while the Primary CT refers to the ratio value of the primary side of the transformer.

The OCR requires the TDS to add the I_p setting. Calculation of TDS, The following formula can be used by The values of all coefficients are being entered k , α and β in accordance with the inverse curve being used:

$$Top = \frac{k \times TDS}{\left[\left(\frac{I}{I_p}\right)^{\alpha} - 1\right] \times \beta} \quad (4)$$

TABLE I INVERSE CURVE COEFFICIENT

Curve Type	Coefficient		
	k	α	β
Ultra Inverse	315.2	2.5	1
Long Time Inverse	120	1	13.33
Extremely Inverse	80	2	0.808
Very Inverse	13.5	1	1.5
Standard Inverse	0.14	0.02	2.97

2) Coordination Time Interval (CTI)

Time difference operation between primary and secondary relay is CTI. According to the recommendations from IEEE Std 242-2001, the CTI settings can be seen in table:

TABLE II COORDINATION TIME INTERVAL (CTI)

Component	Time (s)	
	Electro mechanical	Static
Relay overtravel	0.1	0
Circuit breaker for opening time	0.08	0.08
Tolerance of relay and setting errors	0.12	0.12
Total of CTI	0.3	0.2

B. Problem Statement

Several issues in relay protection coordination reles are divided into three parts: control variables, constraints, and objective functions.

1) Control Variables

In this research, the control variable is TDS value. The method of the GWO algorithm is used to obtain the most optimal TDS value. The TDS configuration is carried out to achieve the most optimal and reliable relay settings.

2) Constrain

In application, all relay setting values must meet the following predetermined constraints:

$$Top_{Min} \leq Top_i \leq Top_{Max} \quad (5)$$

$$TDS_{Min} \leq TDS_i \leq TDS_{Max} \quad (6)$$

$$Ip_{Min} \leq Ip_i \leq Ip_{Max} \quad (7)$$

The aforementioned equations illustrate that Top_{Max} , Top_i , and Top_{Min} represent the maximum, actual, and minimum operational time relay, respectively. TDS_{Max} , TDS_i , and TDS_{Min} represent the maximum, actual, and minimum time dial setting relay, respectively. Additionally, the minimum, actual, and maximum pickup current of the relay, represented by Ip_{Min} , Ip_i , and Ip_{Max} , respectively, are also of interest.

To ensure continued reliability of the protection system, it is essential that the timing between primary and backup relay satisfies following constraint :

$$Top_{bacukup} - Top_{Primer} \geq CTI \quad (8)$$

3) Objective Function

The objective function (OF) represents the total operating time of the relays installed in the system. The objective is to minimise the duration of relay operation in order to safeguard areas that are not impacted by the fault. This allows them to continue their normal operations.

$$OF = \sum_{i=1}^n Top_i \quad (9)$$

OF represents the objective function, while T_{op} represents the relay operating time, according to the formula above.

III. GREY WOLF OPTIMIZATION (GWO)

The wolf is a social animal that lives in groups comprising more than a dozen individuals. These groups have a rigid hierarchical structure. Grey Wolf Optimization algorithm is composed of four distinct levels of wolves, designated as alpha (α), beta (β), delta (δ), and omega (ω), respectively. The alpha wolf is the primary decision-maker within the group, responsible for guiding the collective's actions. The Beta and Delta wolves support the Alpha, while the omega wolf serves as a representative for the remaining wolves. Influenced by the three previous wolves, the fourth wolf, called the Omega Wolf, obeys their commands. It is this hierarchical structure that the grey wolf uses for hunting and foraging. The alpha, beta, and delta wolves are the most proximate to the prey, while the omega wolf follows them in order to search for, track, and encircle their target. Once the circle has reached a sufficiently small size, the omega wolf initiates an attack and proceeds to consume the prey [14].

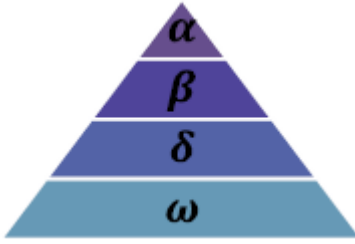


Fig. 1. Hierarki Grey Wolf Optimization

A. Searching for Prey

The hunt for the grey wolf begins with the search for prey., and their behaviour can be described through the application of a mathematical formula:

$$D = |C \cdot X_p(t) - X(t)| \quad (10)$$

$$X(t+1) = X_p(t) - A \cdot D \quad (11)$$

In this context, D represents the distance between the wolves and the target. In this model, where the variable t represents the current iteration, $X_p(t)$ denotes the position of the prey, the position vector of the wolf is denoted by $X(t)$, and the updated vector of the next generation of wolves is denoted by $X(t+1)$. Coefficients A and C , defined in Eqs. 12 and 13 respectively, are :

$$A = 2ar1 - a \quad (12)$$

$$C = 2r2 \quad (13)$$

$$a = 2(1-t/T) \quad (14)$$

The random vectors $r1$ and $r2$ are defined on the interval $[0,1]$ and during the iteration process, demonstrate a linear decrease from 2 to 0. The range of values for A is given by the interval $[-2, 2]$. The range for C is $[0, 2]$.

B. Encircling the Prey

In accordance with the alpha wolf's guidance, Beta and Delta wolves approaching prey. Initially, the distance between the wolves is calculated using equations (15) to (20). Subsequently, equation (21) is employed to ascertain the manner in which the brown wolves hu.

$$D\alpha = |C1 \cdot X_\alpha(t) - X(t)| \quad (15)$$

$$D\beta = |C2 \cdot X_\beta(t) - X(t)| \quad (16)$$

$$D\delta = |C3 \cdot X_\delta(t) - X(t)| \quad (17)$$

$$X1 = X_\alpha - A1 \cdot D_\alpha \quad (18)$$

$$X2 = X_\beta - A2 \cdot D_\beta \quad (19)$$

$$X3 = X_\delta - A2 \cdot D_\delta \quad (20)$$

$$X(t+1) = (X + X2 + X3)/3 \quad (21)$$

In accordance with the aforementioned equations, the variable X_α represents the location of the alpha wolf, X_β signifies the position of the beta wolf, and X_δ denotes the location of the delta wolf. The random vectors $C1$, $C2$, and $C3$ are derived from the alpha, beta, and delta wolves, respectively, and their values range between $[0,2]$.

C. Attacking the Prey

Once the prey has stopped moving, the target will be attacked by a group of grey wolves. By reducing the value of a from 2 to 0 during the iteration process, this process can be simulated. If $|A| > 1$, the grey wolves will move away from the target and perform a global search; if $|A| < 1$, the grey wolves will start attacking their prey.

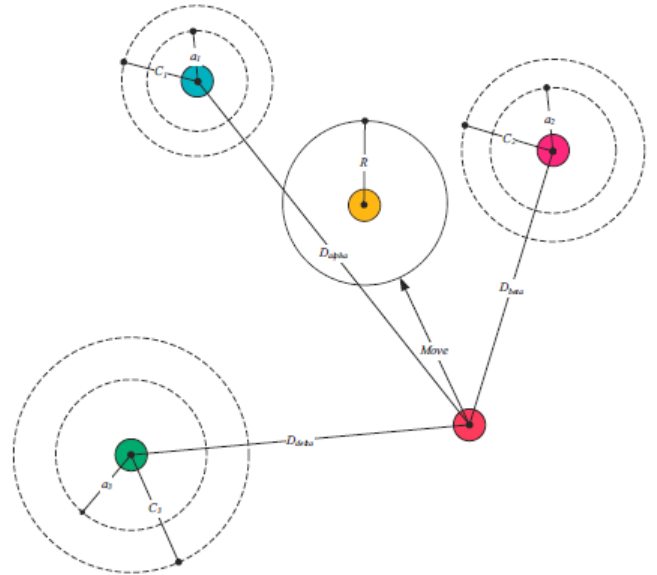


Fig. 2. Wolves Attack the Prey

D. Application of GWO

One of the popular new algorithms is GWO. GWO was the brainchild of Seyedali Mirjalili, whose inspiration was the grey wolf. The proposed method will mimic the social hierarchy and behaviour of the grey wolf. GWO has demonstrated highly competitive results compared to other metaheuristic algorithms such as Particle Swarm Optimization (PSO), Differential Evolution (DE), Gravitational Search Algorithm (GSA) Evolutionary Programming (EP), and Evolution Strategy (ES). The results show that GWO has superior exploitation capabilities, can perform exploration, avoids local optima, and achieves convergence. Thus, GWO proves its capability of high performance [15].

In application, this algorithm has been used for optimal reactive power dispatch problems, with results showing that GWO can effectively and efficiently solve the issue with minimal deviation [16]. GWO has also been used to solve both single-objective and multi-objective optimal power flow problems, demonstrating high performance [17]. Additionally, GWO has been used to find the gain of a PID controller for a quadruped robot, showing that GWO is faster and more efficient than PSO and GA algorithms in finding global and local optimization [18]. Based on GWO's optimization capabilities from previous research, this study will use the GWO algorithm to find the optimal TDS value to be applied in protection systems, allowing for quick identification of optimal protection settings through a reliable coordination system.

E. GWO Flowchart for Protection System

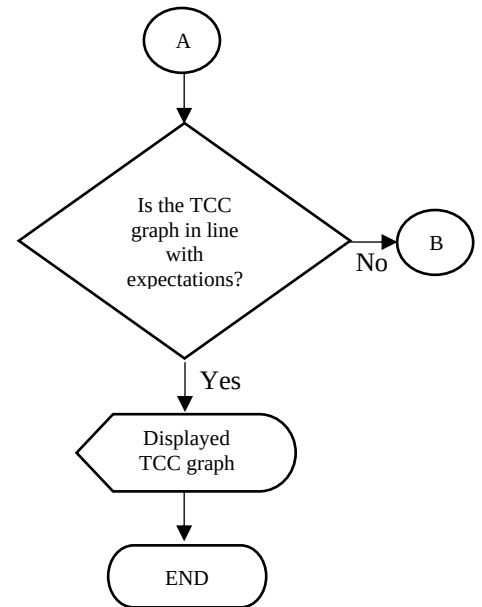
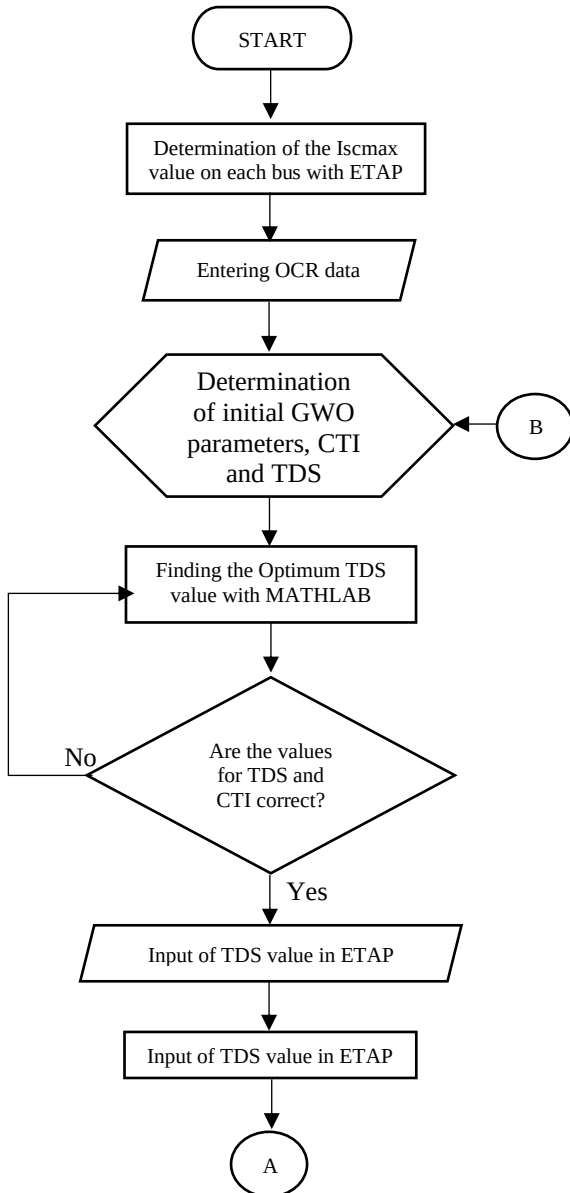


Fig. 3. Flowchart of GWO Application for Protection coordination

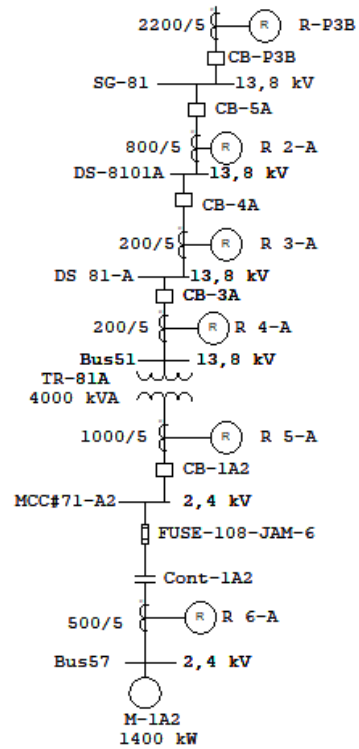


Fig. 4. Single Line Diagram (SLD) of the Electrical System

The application of GWO in protection systems is very helpful in finding the optimal coordination settings for relay protection. To determine the TDS value, all initial parameters of GWO need to be included.

The search for TDS is performed using the GWO algorithm in MATLAB. The TDS values generated by the GWO algorithm are then applied to the OCR in the Single Line Diagram (SLD) of the system using the ETAP application. To validate the accuracy of the applied OCR settings, it is necessary to check the TCC curve using the ETAP application.

IV. SIMULATION RESULTS AND DISCUSSION

The TDS values generated by GWO are simulated on a radial type SLD in an industrial plant as shown in Figure 4. The Single Line Diagram consists of 6 buses and 6 OCRs. The OCR setting parameters are adjusted according to Table III. Using these setting parameters, GWO will determine the Time Dial Setting for each OCR using MATLAB programming.

This simulation evaluates the performance of the GWO algorithm compared to the GOA algorithm, both of which are subjected to the same type of disturbance. The two methods are compared with the same OCR and load parameter settings. Furthermore, the number of agents and the number of algorithm iterations are identical.

Table III. OCR Setting Data

Rele ID	kV	I _{scmax} Prim (A)	I _{scmax} Sek (A)	FLA (A)	Ip (A)
R P3B	13.8	26022	0	2108.6	2640
R 2-A	13.8	30573	26022	669.3	800
R 3-A	13.8	31644	30573	167.3	200
R 4-A	13.8	31644	3164	167.3	200
R 5-A	2.4	16686	2902	962.3	1200
R 6-A	2.4	18225	16686	387.2	500

A. Simulation of GWO and GOA Algorithms

The reliability of these two algorithms can be seen from the convergence curves of the two algorithms. From Figure 6 we can see that GWO has a better convergence than GOA in finding the optimum Time Dial relay setting. GWO can reach the steady state at the 8th iteration while GOA reaches the steady state at the 252th iteration.

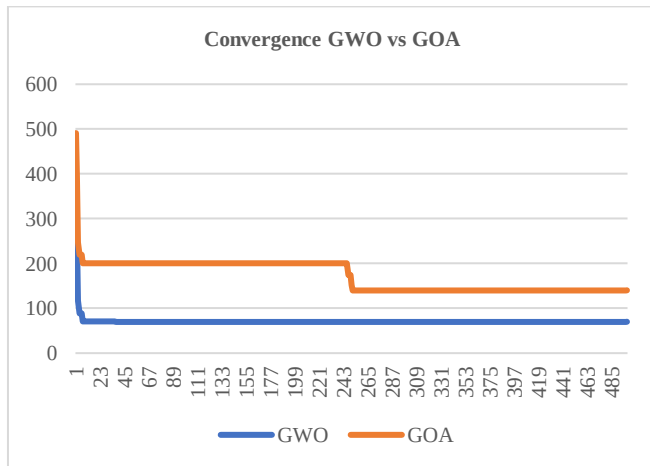


Fig 5. Comparison of convergence curves with 150 agents

The GWO and GOA simulations were conducted with an identical number of agents, specifically 150 and 500 iterations, respectively. The optimal TDS value generated by GWO is then applied to ETAP for the purpose of validating the reliability and effectiveness of the GWO algorithm in

identifying the optimal TDS setting value on OCR. An examination of the inverse time-current curve (TCC) enables the determination of whether the OCR is performing in accordance with expectations.

Table IV. GWO vs GOA Optimisation Results

ID Relay	Curve type	GWO		GOA	
		TDS	OF	TDS	OF
R 6A	UI	1,0150	70,0251	1,0100	70,1283
R 5A	VI	1,0150		1,0100	
R 4A	EI	1,1223		1,1382	
R 3A	UI	2,7144		3,0000	
R 2A	SI	1,4330		1,5388	
R P3B	UI	1,0100		1,0100	

Table IV demonstrates that the objective function (OF) of GOA is greater than that of GWO. This demonstrates that the GWO algorithm is more effective than the GOA algorithm.

Table V. CTI Optimisation Results of the GWO Algorithm

Location Fault	Protection		Top (S)		CTI (S)
	Prim.	Sec.	Prim.	Sec.	
BUS57	R 6A	R 5A	0,179	0,522	0,3430
MCC71	R 5A	R 4A	0,522	0,53	0,0080
BUS51	R 4A	R 3A	0,278	0,478	0,2000
DS 81-A	R 3A	R 2A	0,478	0,679	0,2010
DS-8101A	R 2A	R P3B	0,679	1,02	0,3410
SG-81	R P3B		1,02		0,0000

In order to ascertain the reliability of the TDS optimisation settings generated by the GWO algorithm, it is possible to observe the TCC curve through ETAP by triggering a three-phase short circuit fault on each bus. The following section will examine the efficacy of the primary and backup relays in maintaining the reliability of the electrical system. The following failures were tested and found to exist:

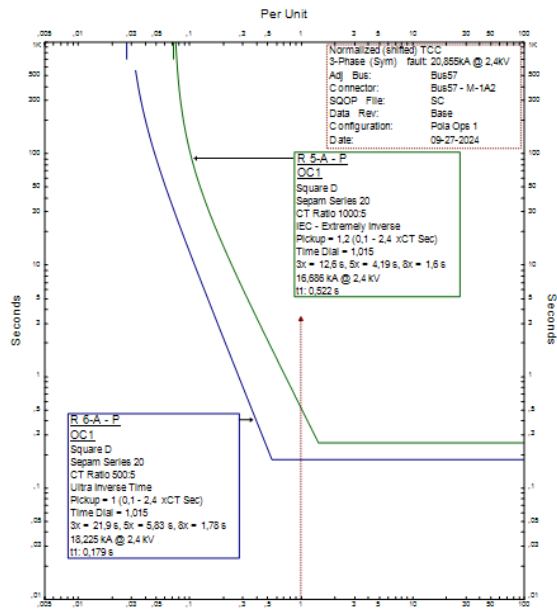


Fig 6. Three-phase short-circuit fault detected on bus 57

The TDS settings generated by the GWO algorithm from Table IV have been successfully implemented in relay 6A, which serves as the primary relay, and relay 5A, which serves as the secondary relay. The implementation of this configuration is intended to ensure the continued reliability of the protection system in the event of a maximum short circuit occurring on bus 57. Relay 6A works for 0.179s while relay 5A as a backup relay works for 0.522s. The implementation of relay coordination has proven to be an effective and selective method for securing areas that are not affected by interference, with a CTI of 0.343s..

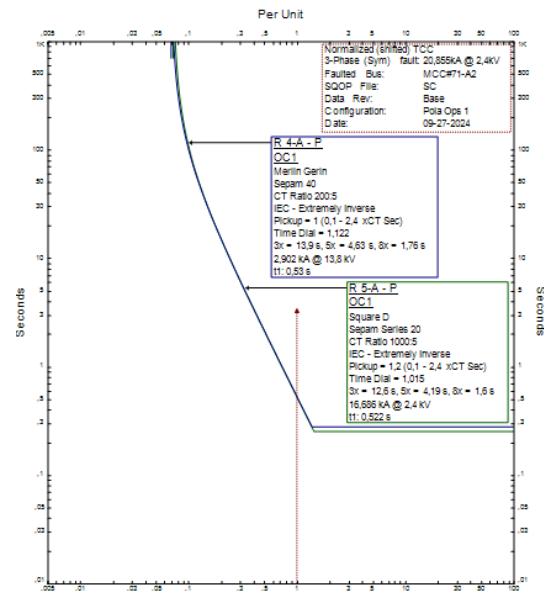


Fig 7. Three-phase short-circuit fault detected on MCC71

The TDS settings generated by the GWO algorithm from Table IV have been successfully applied to maintain the reliability of the protection system when a maximum short circuit occurs at MCC71. The settings have been implemented for relay 5A, which is the primary relay, and relay 4A, which is the secondary relay. Relay 5A works for 0.522s while relay 4A as a backup relay works for 0.530s.

This relay coordination has worked effectively and selectively. This is because the two relays work at different voltage levels.

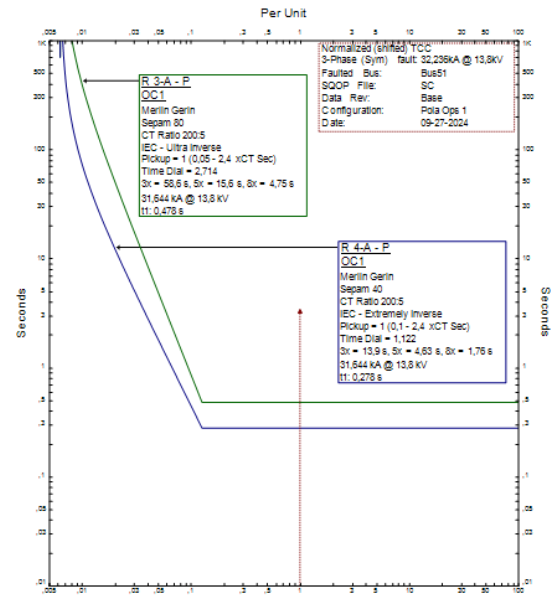


Fig 8. Three-phase short-circuit fault detected on Bus 51

The TDS settings generated by the GWO algorithm from Table IV have been successfully implemented in relay 4A, which has been designated as the primary relay, and relay 3A, which has been designated as the secondary relay. This configuration ensures the reliability of protection system in case of maximum short-circuit on bus 51. Relay 4A is operational for a duration of 0.278 seconds, while relay 3A which serves as a backup relay is operational for a duration of 0.478 seconds. The aforementioned relay coordination, with a CTI of 0.2 seconds, has been demonstrated to be an efficacious and selective method of securing unaffected areas.

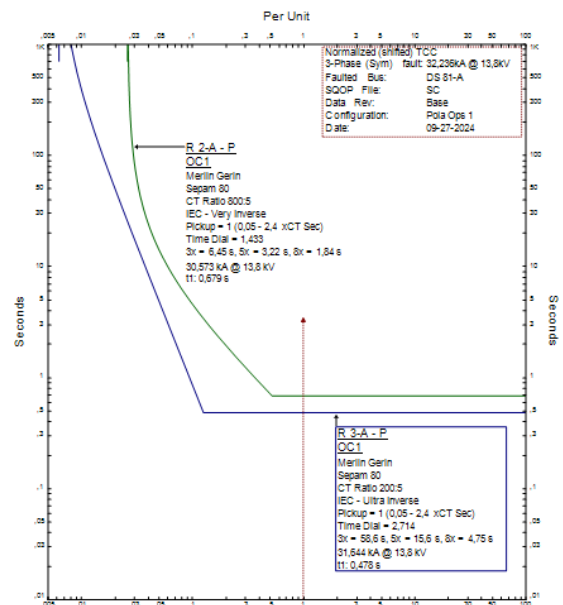


Fig 9. Three-phase short-circuit fault detected on Bus DS 81A

The TDS settings generated by the GWO algorithm from Table IV were successfully applied to maintain the reliability of the protection system when a maximum short circuit

occurred at bus 51. Relay 3A was designated as the primary relay, while relay 2A was designated as the secondary relay. Relay 3A works for 0.478s while relay 2A as a backup relay works for 0.679s. The implementation of relay coordination has proven to be an effective and selective method for securing areas that are not affected by interference, with a CTI of 0.201s.

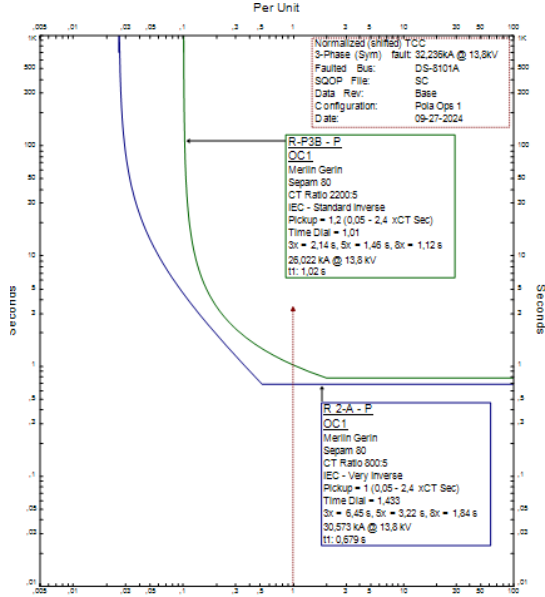


Fig. 10. Three-phase short-circuit fault detected on DS 8101A

The TDS settings generated by the GWO algorithm from Table IV have been successfully implemented in Relay 2A, which has been designated as the primary relay, and in Relay P3B, which has been designated as the secondary relay. This configuration ensures the reliability of the protection system in the event of a maximum short circuit on the DS8101A bus. Relay 2A is operational for 0.679 seconds, while relay P3B which serves as a backup relay is operational for 1.02 seconds. With a CTI of 0.341s, the coordination of the above relays has proved to be an effective and selective method of securing interference-free areas..

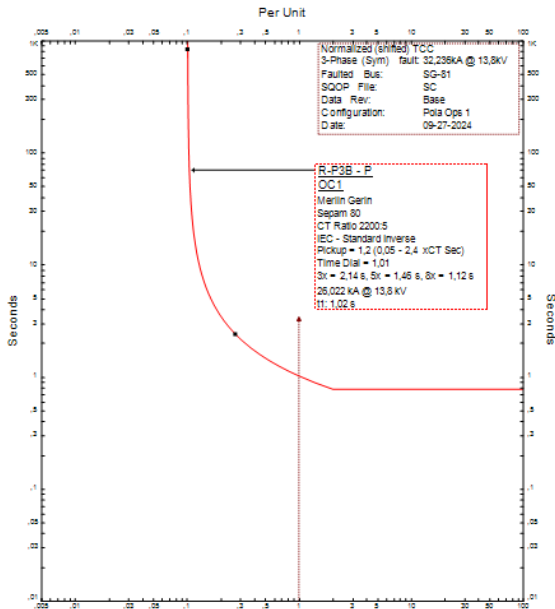


Fig. 11. Three-phase short-circuit fault detected on Bus SG 81

The TDS settings generated by the GWO algorithm from Table IV were used to determine that P3B is primary without backup. This is due to the occurrence of the disturbance on the bus in closest proximity to the source.

V. CONCLUSION

The GWO algorithm has been demonstrated to be effective in identifying the optimal Time Dial parameter setting value of OCR. The OCR has been shown to provide effective protection against three-phase short circuit faults on each bus tested using the ETAP application. The primary and secondary relays have been observed to operate in a selective and effective manner, ensuring the secure isolation of unaffected areas.

In addition, the GWO algorithm demonstrates superior convergence properties in comparison to GOA. This demonstrates that the GWO algorithm is more reliable and faster at identifying the optimal TDS value than the GOA algorithm.

Furthermore, the objective function of GOA is more extensive than the one observed in GWO. This demonstrates that GWO is more effective than GOA in identifying the optimal TDS setting value.

REFERENCES

- [1] F. Razavi, H. A. Abyaneh, M. Al-Dabbagh, R. Mohammadi, and H. Torkaman, "A new comprehensive genetic algorithm method for optimal overcurrent relays coordination," *Electr. Power Syst. Res.*, vol. 78, no. 4, pp. 713–720, 2008, doi: 10.1016/j.epsr.2007.05.013.
- [2] H. K. Karegar, H. A. Abyaneh, V. Ohis, and M. Meshkin, "Pre-processing of the optimal coordination of overcurrent relays," *Electr. Power Syst. Res.*, vol. 75, no. 2–3, pp. 134–141, 2005, doi: 10.1016/j.epsr.2005.02.005.
- [3] M. Pujiantara, D. C. Riawan, A. Indrasaputra, T. P. Sari, and V. Raki Mahindara, "The automation of time dial setting calculation and inverse type curve selection for over current relay based on numerical computation in real industrial electrical system," *4th IEEE Conf. Power Eng. Renew. Energy, ICPERE 2018 - Proc.*, pp. 1–6, 2018, doi: 10.1109/ICPERE.2018.8739673.
- [4] R. Krishan, "Optimal Coordination of Overcurrent Relays using Gravitational Search Algorithm with DG Penetration," 2014.
- [5] A. Darabi, M. Bagheri, G. B. Gharehpetian, and S. Member, "Highly Accurate Directional Overcurrent Coordination via Combination of Rosen 's Gradient Projection – Complex Method With GA-PSO Algorithm," *IEEE Syst. J.*, vol. PP, pp. 1–12, 2019, doi: 10.1109/JSYST.2019.2904383.
- [6] N. Rezaei, M. N. Uddin, I. K. Amin, M. L. Othman, and M. Marsadek, "Genetic Algorithm-Based Optimization of Overcurrent Relay Coordination for Improved Protection of DFIG Operated Wind Farms," *IEEE Trans. Ind. Appl.*, vol. 55, no. 6, pp. 5727–5736, 2019, doi: 10.1109/TIA.2019.2939244.
- [7] A. Tjahjono *et al.*, "Adaptive modified firefly algorithm for optimal coordination of overcurrent relays," *IET Gener. Transm. Distrib.*, vol. 11, no. 10, pp. 2575–2585, 2017, doi: 10.1049/iet-gtd.2016.1563.
- [8] S. N. Langazane and A. K. Saha, "Effects of Particle Swarm Optimization and Genetic Algorithm Control Parameters on

- Overcurrent Relay Selectivity and Speed,” *IEEE Access*, vol. 10, pp. 4550–4567, 2022, doi: 10.1109/ACCESS.2022.3140679.
- [9] R. S. F. J. Putra, M. Pujiantara, and V. Lystianingrum, “Overcurrent Relay Coordination Setting on Distribution Power System Using Grasshopper optimization Algorithm,” *2023 Int. Semin. Intell. Technol. Its Appl. Leveraging Intell. Syst. to Achieve Sustain. Dev. Goals, ISITIA 2023 - Proceeding*, pp. 804–809, 2023, doi: 10.1109/ISITIA59021.2023.10221124.
- [10] A. Korashy, S. Kamel, A. R. Youssef, and F. Jurado, “Solving Optimal Coordination of Direction Overcurrent Relays Problem Using Grey Wolf Optimization (GWO) Algorithm,” *2018 20th Int. Middle East Power Syst. Conf. MEPCON 2018 - Proc.*, pp. 621–625, 2018, doi: 10.1109/MEPCON.2018.8635234.
- [11] F. Abidin, M. Pujiantara, and D. F. U. Putra, “Optimasi Total Operating Time Rele Arus Lebih dengan Pertimbangan Konfigurasi Mesh, Open-mesh, dan Radial Menggunakan Firefly Algorithm,” *J. Tek. ITS*, vol. 9, no. 2, 2021, doi: 10.12962/j23373539.v9i2.53424.
- [12] C. S. Mardegan and R. Rifaat, “Considerations in Applying IEEE Recommended Practice for Protection Coordination in Industrial and Commercial Power Systems-Part i,” *IEEE Trans. Ind. Appl.*, vol. 52, no. 5, pp. 3705–3713, 2016, doi: 10.1109/TIA.2016.2563405.
- [13] V. R. Mahindhara and M. Pujiantara, “Optimasi Time Dial Setting (TDS) Relay Arus Lebih Menggunakan Adaptive Modified Firefly Algorithm Pada Sistem Kelistrikan PT. Pupuk Kalimantan Timur,” *J. Tek. ITS*, vol. 5, no. 2, 2016, doi: 10.12962/j23373539.v5i2.16019.
- [14] J. Liu, X. Wei, and H. Huang, “An Improved Grey Wolf Optimization Algorithm and Its Application in Path Planning,” *IEEE Access*, vol. 9, pp. 121944–121956, 2021, doi: 10.1109/ACCESS.2021.3108973.
- [15] S. Mirjalili, S. M. Mirjalili, and A. Lewis, “Grey Wolf Optimizer,” *Adv. Eng. Softw.*, vol. 69, pp. 46–61, 2014, doi: 10.1016/j.advengsoft.2013.12.007.
- [16] M. H. Sulaiman, Z. Mustaffa, M. R. Mohamed, and O. Aliman, “Using the gray wolf optimizer for solving optimal reactive power dispatch problem,” *Appl. Soft Comput. J.*, vol. 32, pp. 286–292, 2015, doi: 10.1016/j.asoc.2015.03.041.
- [17] A. A. El-Fergany and H. M. Hasanien, “Single and Multi-objective Optimal Power Flow Using Grey Wolf Optimizer and Differential Evolution Algorithms,” *Electr. Power Components Syst.*, vol. 43, no. 13, pp. 1548–1559, 2015, doi: 10.1080/15325008.2015.1041625.
- [18] M. A. Şen and M. Kalyoncu, “Optimal Tuning of PID Controller Using Grey Wolf Optimizer Algorithm for Quadraped Robot,” *Balk. J. Electr. Comput. Eng.*, vol. 6, no. 1, pp. 29–35, 2018, doi: 10.17694/bajece.401992.