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

Achmad Jawahir Januarestu
Department of Electrical Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
achmadjawahirjanuarestu@gmail.com

Margo Pujiantara
Department of Electrical Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
margo@ee.its.ac.id

Ardyono Priyadi
Department of Electrical Engineering
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
priyadi@ee.its.ac.id

Riko Satrya Fajar Jaelani Putra
Marine Electrical Engineering Department
Shipbuilding Institute of Polytechnic Surabaya
Surabaya, Indonesia
riko.satrya@ppns.ac.id

***Abstract*— Overcurrent Relay (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 (Ip) and Time Dial Setting (TDS). To achieve optimum relay coordination by setting the time dial, several optimization methods have been used such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Fire Fly Algorithm (FA) and Grasshopper Optimization Algorithm (GOA). The TDS setting was determined through the Grey Wolf Optimization (GWO) method in this study. The GWO algorithm was capable of identifying the optimal TDS setting for each OCR process. This is confirmed by the results of tests carried out with the ETAP application. The primary and secondary relays are able to coordinate effectively to secure three-phase faults that occur on each bus. The 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*— grey wolf optimization (GWO), protection coordination overcurrent relay (OCR), short circuit maximum (IscMax), time dial setting (TDS),.

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 (Ip) and the second ones is time dial setting (TDS) [1]. The Ip setting for each relay can be determined by first finding the minimum short-circuit current (IscMin) 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 relays 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 optimization 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 optimization 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 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. Methods, III. results and discussion , and IV. conclusion

II. Methods

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].

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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, OCR 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 (Ip) for overload following by criteria:

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

To determine the limits of the pick up current (Ip) as protection during a short circuit, the following by criteria:

$$1.06\ FLA < Ip < 0.8IscMin \quad (2)$$

Based on the formulas from equation (1) and equation (2), it can be determined that the pick up current (Ip) 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 ampere (FLA) represents the maximum current of the load under normal conditions, and IscMin refers to the short circuit between phases (Isc for 2 phases) during the steady state duration (30 cycles) [13].

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

$$TAP = \frac{Ip}{Primary\ CT} \quad (3)$$

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

The OCR requires the TDS to add the I_P setting. Top is a total time operation relay and IscMax max is short circuit three phase. 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:

$$Top = \frac{k\ x\ TDS}{\left[(\frac{IscMax}{Ip})^{\alpha} - 1\right] x\ \beta} \quad (4)$$

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 mecanical	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. Control Variable and Constrain

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

1) Control variable : 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:

$$TopMin \leq Topi \leq TopMax \quad (5)$$

$$TDSMin \leq TDSi \leq TDSMax \quad (6)$$

$$IpMin \leq Ipi \leq IpMax \quad (7)$$

The aforementioned equations illustrate that $TopMin$, $Topi$, and $TopMax$ represent the minimum time operation, actual time operation of relay i, and maximum time operation relay, respectively. $TDSMin$, $TDSi$, and $TDSMax$ represent the time dial setting maximum, actual setting time dial relay i, and time dial setting minimum, respectively. Additionally, $IpMin$, Ipi, and $IpMax$, respectively representing as a pick up current minimum, pick up current of relay i, and pick up current maximum 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 :

$$Top_{backup} - Top_{Primary} \geq CTI \quad (8)$$

The aforementioned equations illustrate that Top_{backup}, $Top_{primary}$, and CTI representing as the time operation of backup relay, time operation of primary reley and time interval between backup relay and primary relay, respectively.

C. 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.

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

OF represents the objective function, while Topi represents time operation of the relay i until relay n , according to the formula above.

D. Grey Wolf Optimization

The wolf is a social animal that lives in groups comprising more than a dozen individuals. These groups have a rigid hierarchical structure as shown in figure 1. 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 wolf 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].

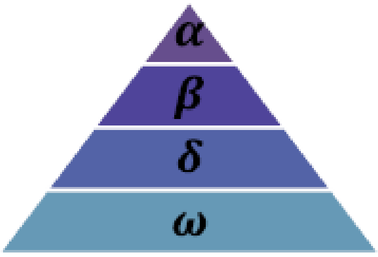


Fig. 1. Hierarchy grey wolf optimization

1) 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:

$$D = | C.Xp(t) – X(t) | \quad (10)$$

$$X (t+1) = Xp(t) – A.D \quad (11)$$

In this context, D represents the distance between the wolf and the target. In this model, where the variable t represents the current iteration, $Xp(t)$ 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 equation (12) and equation (13) respectively, are :

$$A = 2ar_1 – a \quad (12)$$

$$C = 2r_2 \quad (13)$$

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

The random vectors r_1 and r_2 are defined on the interval [0,1] and during the iteration process, demonstrate a linear iteration from from 2 to 0. The range of values for A is given by the interval [-2, 2]. The range for C is [0, 2].

2) Encircling the Prey

In accordance with the alpha wolf guidance, beta and delta wolf approaching prey. Initially, the distance between the wolfs is calculated using equation (15) to equation (20). Subsequently, equation (21) is employed to ascertain the manner in which the brown wolf.

$$D\alpha = | C1.X_\alpha (t) – X(t) | \quad (15)$$

$$D\beta = | C2.X_\beta(t) – X(t) | \quad (16)$$

$$D\delta = | C3.X_\delta(t) – X(t) | \quad (17)$$

$$X1 = X_\alpha – A1.D_\alpha \quad (18)$$

$$X2 = X_\beta – A2.D_\beta \quad (19)$$

$$X3 = X_\delta – A2.D_\delta \quad (20)$$

$$X (t+1) = (X1+X2+X3)/3 \quad (21)$$

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 wolf, respectively, and their values range between [0,2].

3) 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 wolf will move away from the target and perform a global search; if |A|<1, the grey wolfs will start attacking their prey like a scheme on the figure 2.

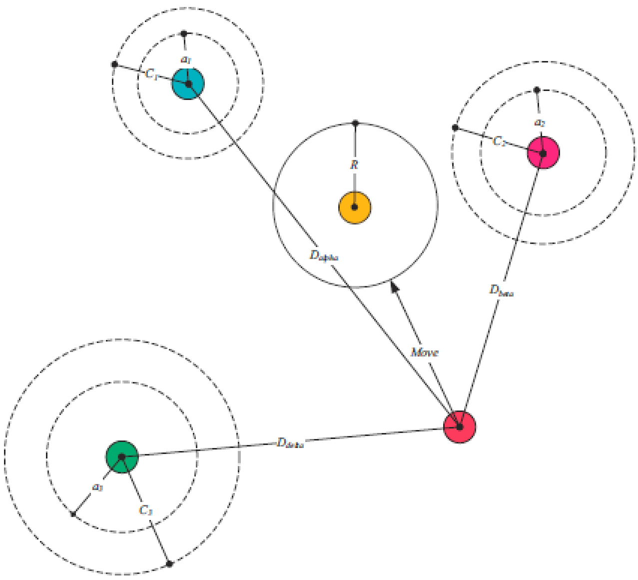


Fig. 2. Wolfs attack the prey

E. 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 grey wolf social hierarchy and behaviour. 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 as the sequence in figure 3, allowing for quick identification of optimal protection settings through a reliable coordination system.

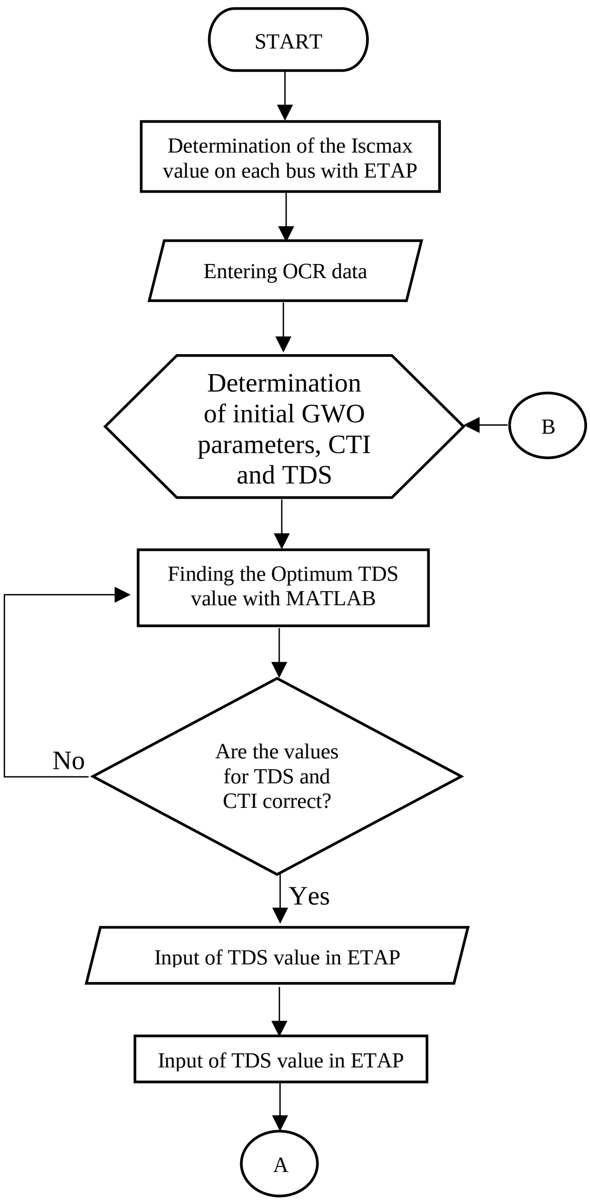
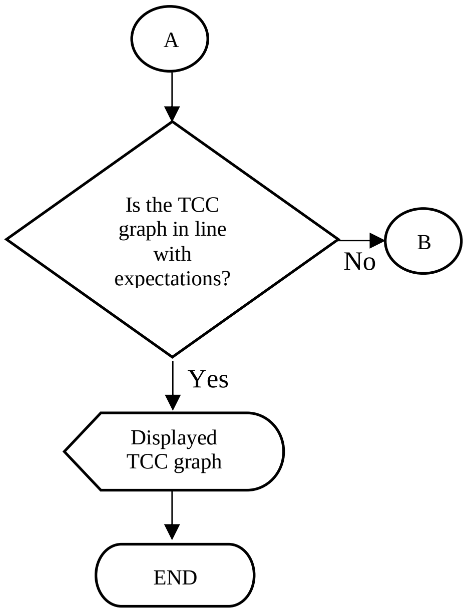


Fig. 3. Flowchart of GWO application for protection coordination



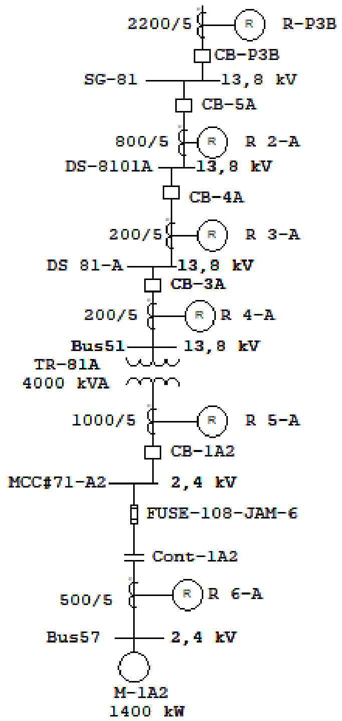


Fig. 4. *Single line diagram (SLD) of the electrical system*

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.

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.

III. Results And Discussion

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. 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.Furthermore, the number of agents and the number of algorithm iterations are identical.

Table III. Setting Data OCR

Rele ID	Voltage (kV)	Isc_{Max} Prim (A)	Isc_{Max} Sec (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

Voltage is the relay operating voltage is adapted to the location of the relay. Isc_{Max} Prim is the value of the three phase short circuit on the bus under the operating of primary relay and Isc_{Max} Sec is the value of the three-phase short circuit on the bus under the operating of backup relay, obtained from the ETAP simulation results. FLA is the total maximum current of all loads under relay and Ip is pickup current setting for the relay to operate.

A. *Simulation of GWO and GOA Algorithms*

The reliability of both algorithms can be seen from the convergence curves of the two algorithms. From figure 5 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.

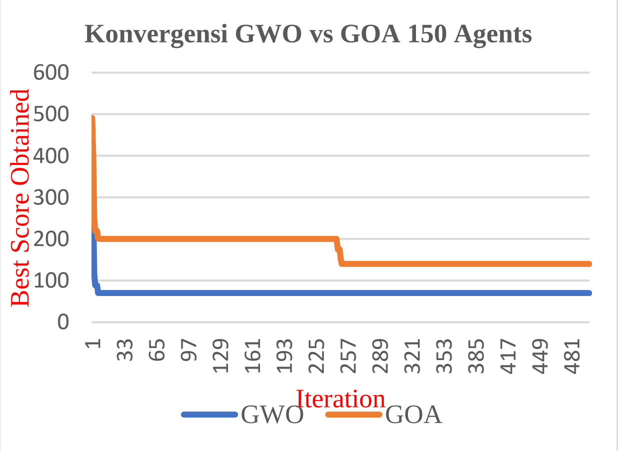


Fig. 5. Comparison of convergence curves with 150 agents

The GWO and GOA simulations were conducted with an identical number of agents, specifically 150 agents 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 optimization 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 demonstates that the objective function (OF) of GOA is greater than that of GWO. We can get it by MATLAB aplication. This demonstrates that the GWO algorithm is more effective than the GOA algorithm. In addition, the CTI values between the primary and secondary relays do not violate the limits as shown in Table V.

Table V. CTI optimization results of the GWO algorithm

Fault Location	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 optimization 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:

Base on figure 6 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 of securing undisturbed areas, with a CTI of 0.343s.

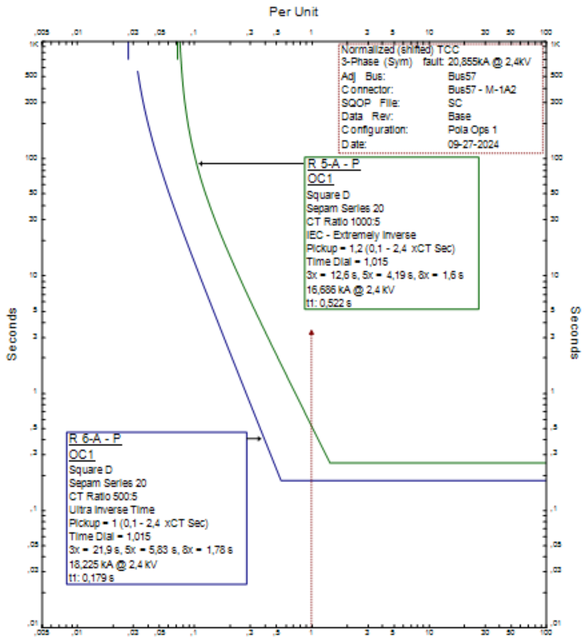


Fig. 6. Fault 3 phase short circuit is detected on bus 57

Base on figure 7 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.

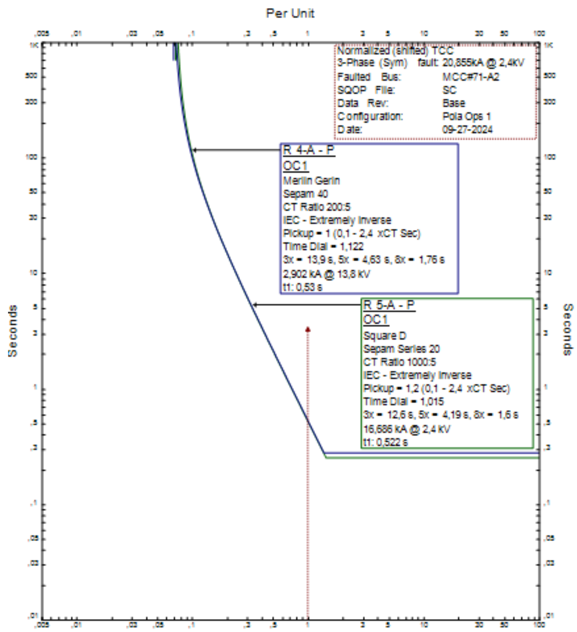


Fig. 7. Fault 3 phase short circuit is detected on MCC71

Base on figure 8 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 . 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 of securing unaffected areas.

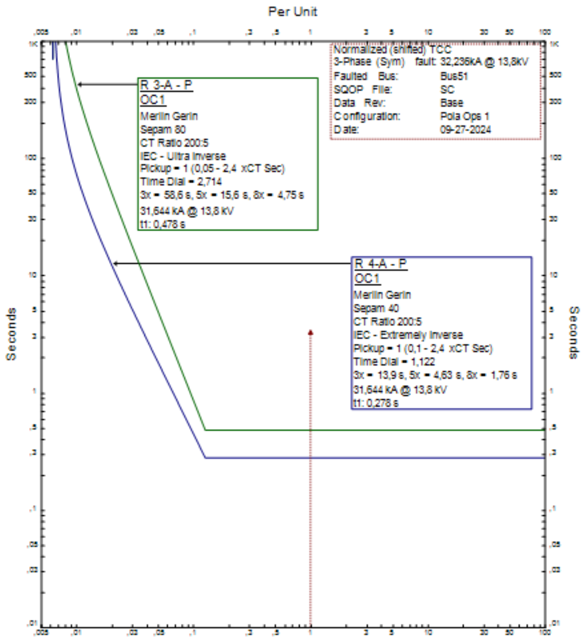


Fig. 8. Fault 3 phase short circuit is on Bus 51

Base on figure 9 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. With a CTI of 0.201s, the implementation of relay coordination has proven to be an effective and selective method of securing unaffected areas.

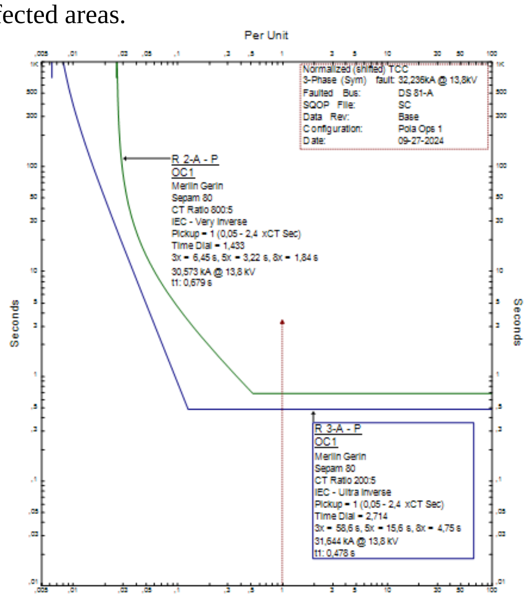


Fig. 9. Fault 3 phase short circuit is detected on Bus DS 81A

Base on figure 10 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 second with a CTI of 0.341s, the coordination of the above relay has proved to be an effective and selective method of securing interference free areas.

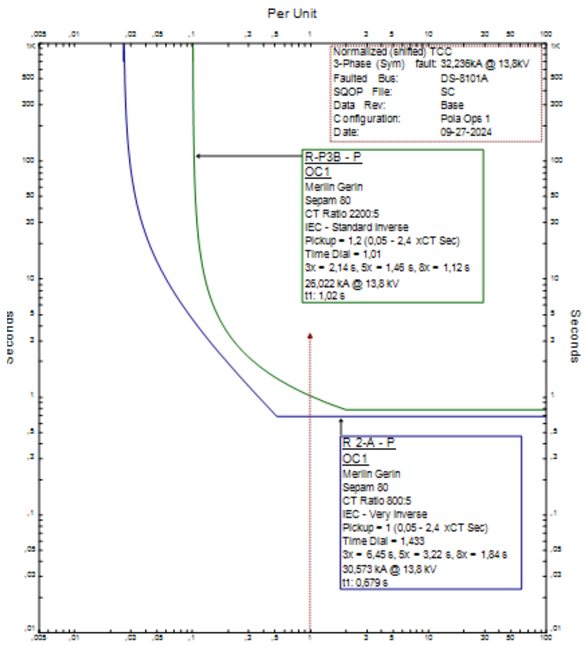


Fig. 10. Fault 3 phase short circuit is detected on DS 8101A

Base on figure 11 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.

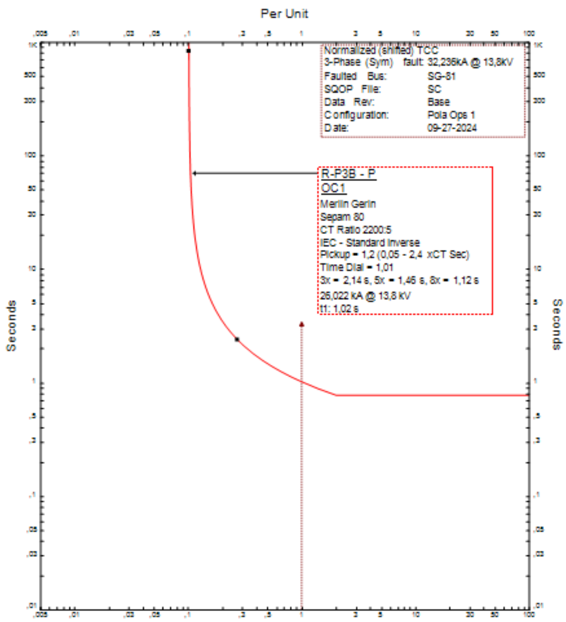


Fig. 11. Fault 3 phase short circuit is detected on Bus SG 81

IV. 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, GWO exhibits superior convergence properties in comparison to GOA. GWO was able to achieve a steady state at the 8th iteration, whereas GOA required 252 iteration to reach the same point. 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 value for GOA is 70.1283, while that for GWO is 70.0251. This demonstrates that GWO is more effective than GOA in identifying the optimal TDS setting value, as indicated by its smaller objective function value.

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