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Research Original Article

Enhancing Adaptive Overcurrent Protection in Multi-Loop Distribution Networks with Distributed Generation Using Genetic Algorithms

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Abstract

Electrical energy is something that everyone needs. The increase in the use of electrical energy will increase the transmission and distribution system of electrical energy, so the electrical energy distribution system must be more reliable. Adding Distributed Generation (DG) to the distribution system can improve reliability and power quality issues. To overcome the influence of DG, a new optimization setting is needed to account for the presence of Distributed Generation. This study aims to simulate a protection system with the right relay operation time to minimize the impact of interference and apply the Genetic Algorithm method in the relay coordination setting on a multi-loop distribution network with Distributed Generation. In this study, the development will be carried out using the IEEE 9-Bus multiloop plant distribution system with the application of Distributed Generation using a Genetic Algorithm. The method in this study begins with creating a single-line diagram on ETAP, followed by the placement and determination of forward and reverse relays. Furthermore, the steps include dividing and determining loops I, II, and III for the Isc generation value in each loop. The optimization process using the Genetic Algorithm can be carried out after the Isc value of each loop is obtained. After reaching the maximum iteration value, the TDS and Ipickup values result from optimization. The value is then converted into a time domain. The genetic algorithm results with a maximum iteration value of 1500 show that the protection system coordinates more optimally and efficiently, as reviewed from the cut-off sequence and time delay value in the event of a disturbance. The total time delay value in the Genetic Algorithm calculation is 3.6027 seconds. The minimum total time delay value is the more optimal the protection system coordinates.

Keywords: Optimization, Overcurrent, Multi-loop Distribution, Distributed Generation, Genetic Algorithm

Introduction

Currently, electricity is something that everyone very much needs. Almost always, all devices used to support human activities require energy [1]. Electrical resources, such as gas, coal, water, and more, are converted into electrical energy and then transmitted and distributed to consumers [2]. The government continues to strive to increase the amount of electricity people consume per capita. Overall, Indonesia's per capita electricity consumption has continued to grow since 2017, reaching 1,285 kilowatt-hours in 2023, up from 1,173 kilowatt-hours in 2022. With the increase in the use of electrical energy, transmission and distribution systems must be more reliable.

A distribution system is part of an electric power system that distributes electrical power from a significant power source (load power source) to an electric power subsystem directly related to the customer [3]. This is because the distribution network delivers electrical power directly to the load center, also called the customer [4]. The power distribution system requires good reliability to meet the electricity needs. This is done to ensure that electricity is appropriately distributed to consumers. The reliability of an electrical system is determined by the number of outages or interruptions that occur. In addition to the system, Distributed Generation can improve reliability and solve power quality problems [5], [6].

Distributed Generation (DG) is a power generation system that uses many small energy resources scattered throughout the region [7]. This differs from conventional power plants located in one prominent location, such as steam or hydro, because the plants are distributed using many renewable and non-renewable energy resources spread across various locations [8]. Protection systems can be installed in multiple power systems to reduce short-circuit currents due to the possibility of trip faults on the power grid [9], [10]. In a distribution system with DG, the protection system is used to identify short-circuit fault currents and loads from various causes in the field. A new optimization setup that considers the presence of DG is required to overcome the influence of DG [11], [12].

To ensure good coordination and minimal operating time, many studies have been conducted on overcurrent relays (OCR) and directional overcurrent relays (DOCR) in determining the optimal Dial Time (TDS) and Ipickup settings using heuristic techniques and conventional methods [13], (Example & Syamsir, 2022), [15]. In addition, the trial and error methods used on complex systems could be more efficient and take a long time. Therefore, optimization strategies replace conventional methods [16], [17].

Studies on optimization techniques as a substitute for conventional methods have been conducted. Rahmatullah and Dewantara's research in 2019 conducted a survey of DOCR optimization using the Modified Particle Swarm Optimation (MPSO) method. The values for scheme 1 are 5.92 seconds, scheme 2 is 3.654 seconds, scheme 3 is 4.884 seconds, and scheme 4 is 3.759 seconds, respectively [18], [19]. In addition, Winarno et al., 2022, conducted a DOCR coordination study using Artificial Neural Network Backpropagation Conjugate Gradient (ANN BPCG). The study found that the 27th neuron had a Mean Squared Error (MSE) value of 0.458.18. Under each generation condition, the average TDS difference from relay 1 to relay 15 is 0.0011 seconds, with an overall average percentage difference of 0.1081% [20], [21]. Even though many studies have been conducted on OCR or DOCR optimization methods, few studies have studied the Adaptive Overcurrent protection scheme on multi-loop distribution systems using Algorithmic Genetics (GA).

This research will use genetic algorithms to develop a multiloop IEEE 9-Bus plant distribution system. GA is an adaptive search algorithm that performs random searches using natural selection mechanisms and genetic principles [22]. Designing protection coordination for a radial system is not a difficult task. However, the researchers faced difficulties working with multi-loop systems, especially when the system was connected to DG. This is because the DOCR settings on multi-loop systems use only the lowest values, so the relay operation time depends on the amount of interference current. Variations in the current of disturbances can be caused by scattered generation in the system. Changing the protection settings took the researchers longer [18]. Some critical factors to consider to facilitate protection coordination in a multi-loop system are TDS (Time et al.) settings, CTI time coordination intervals, and operating time for each primary relay and backup relay. The goal is to get the best value and achieve the suitable adjustments. The researcher will study the problems described and how to optimize DOCR in a multi-loop distribution system with DG using the GA method.

Materials & Methods

A. Types and Variables of Research

The type of research is quantitative to evaluate the ideal TDS and Ipickup values on DOCR relays in a multi-loop distribution system with DG. Overcurrent in a multi-loop distribution system with DG is used as the research variable.

B. Data Collection Methods

This study uses observation and documentation to collect data. The data used comes from IEEE 9-Bus and ETAP 19.0.1 software, including:

1. Data Generator
2. Data Distributed Generation
3. Load and channel data
4. Primary relay pair data and Backup relay
5. Fault current and nominal current data

C. Data Analysis Methods

In the MATLAB R2018a environment, genetic algorithms will be used to process the data that has been collected. Several steps are taken to optimize the coordination of protection with genetic algorithms and increase the operating time on the main relay, considering the constraints set. The Coordination Time Interval (CTI) between the primary and backup relay operation times should be at least 0.2 seconds. In addition, the importance of regulating population size has been recognized. Populations that are too small have a lower number of chromosomes, which can reduce the likelihood of mutations, and populations that are too large can slow down the process of genetic algorithms. Also, pay attention to the mutation parameters ranging between 0 and 1. A mutation value of 0 indicates no mutations, and a mutation value of 1 indicates that each chromosome has a potential mutation. Determining the maximum number of iterations is also essential to stop the process of genetic algorithms [23].

The effectiveness of the genetic algorithm to be used depends mainly on determining these parameters. Parameter values can make genetic algorithms inefficient and time-consuming. However, if the value is too small, the resulting result will likely not be optimal. The use of genetic algorithms in multi-loop distribution networks is illustrated in the following diagram.

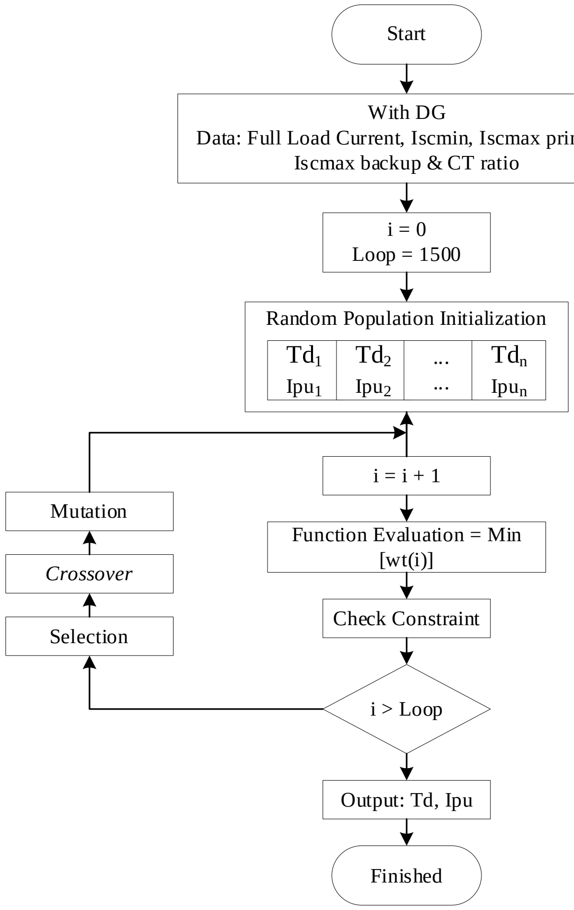

Figure 1. Flowchart Genetic Algorithm (GA) for Protection Coordination

D. Single Line Diagram Multi-loop System

In this study, two Distributed generators (DG) will be used, which will be described as DG1 and DG2, and one main generator will be used, which will be described as G1. This research uses DG because if the main generator is disrupted, the DG will be in charge of backing up the area around the main generator. Because the DG capacity is not more than 5 MW on a 20 KV distribution network, the DG capacity is 3.5 MW. The jagging diagram of the modified 9-Bus multiloop distribution used in this study is seen in Figure 2.

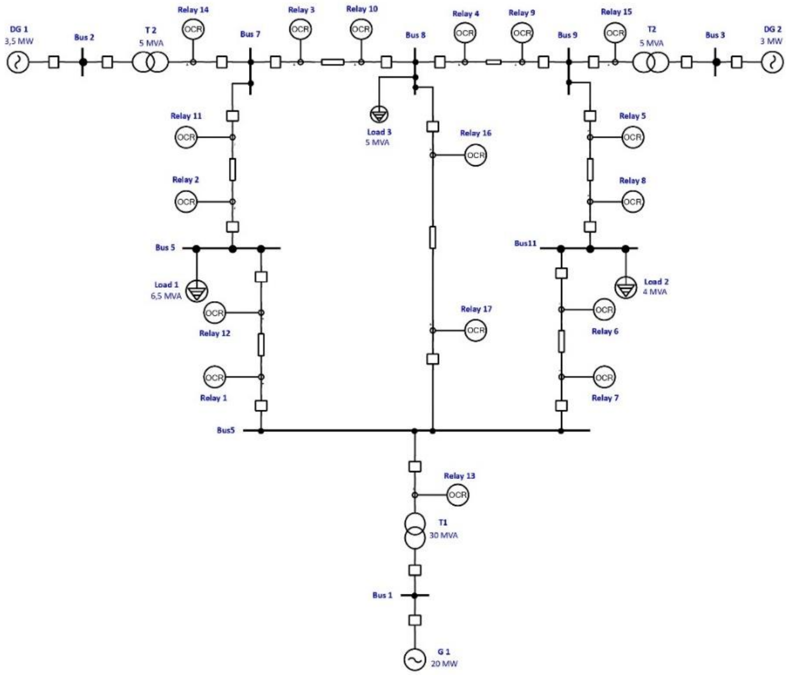

Figure 2. Single Line Diagram 9 Modified Multi-loop Bus

E. Single Line Data Diagram Multi-loop System

This study will simulate the protection coordination of this multi-loop system using ETAP software. Some things to note are the generator's and DG's specifications, as shown in Table 1 and Table 2, where the generator is used as the primary source and the DG as the auxiliary source.

Table 1. Data Generator

No	Kind	Power (MW)	Voltage (kV)	Power Factor (%)
1	Generator	20	14	85

Table 2. Data Distributed Generation

No	Kind	Power (MW)	Voltage (kV)	Power Factor (%)
1	DG 1	3.5	15	85
2	DG 2	3	13.5	85

Table 3 describes the installed load, known as the installed load. Self-installed loads are components of ETAP that represent the combined load between static loads and motor loads.

Table 3. Load Data

No	Load Type	Bus	Voltage (kV)	Power Factor (%)
1	1	5	20	85
2	2	6	20	85
3	3	8	20	85

Table 4 describes the channel data installed on this simulation. The cables used in this study will be divided into two parts, each limited by a minor or auxiliary bus. The focus is to evaluate the value of the Ifla that passes through the bus.

Table 4. Channel Data

Line	Bus	R/Km Ohm	X/Km Ohm	Distance (m)
1	4-5	0.348	0.121	1000
2	4-6	0.348	0.121	1000
3	5-7	0.348	0.121	1000
4	6-9	0.348	0.121	1000
5	8-9	0.348	0.121	1000
6	7-8	0.348	0.121	1000
7	8-4	0.348	0.121	2000

For relays, there are two conditions: clockwise and counterclockwise. In the event of a disruption to a particular bus, the relay will work according to the predetermined conditions. Table 5 describes the division of relay pairs.

Table 5. Primary Relay Pair Data and Backup Relay

Clock Wise		Counter Clock Wise	
Main Relay	Relay Backup	Main Relay	Relay Backup
[1]	[2]	[3]	[4]
R1	R16	R12	R11
	R13	R11	R14
	R6		R10
R2	R1	R10	R9
R3	R2		R17
R4	R3	R9	R8
	R16		R15
[1]	[2]	[3]	[4]
R5	R4	R8	R7
	R15	R17	R7
	R16		R13
R6	R5		R12
R16	R3		
	R4		

F. Ifla Channel Data Capture

The value of Iscmax, a parameter required to achieve optimal inverse curve settings, is calculated by collecting Ifla data from each channel. This Ifla value can be found at the maximum current value obtained from the simulation results.

Furthermore, TDS calculations will be carried out in each iteration until the best value is obtained.

Table 6. Maximum Data Current of 3 Core XLPE Cable

BS6622/BS7835 Single Core Armoured 22kV XLPE Stranded Copper Conductor			
Cross-sectional Area (mm2)	Current Ratings		
	Laid in Ground (Amps)	Drawn Into Ducts (Amps)	Laid in Air (Amps)
[1]	[2]	[3]	[4]
70	270	260	320
95	320	300	380
120	360	340	440
[1]	[2]	[3]	[4]
150	410	370	490
185	450	400	560
4240	510	450	650
300	570	490	730
400	640	530	830
500	700	570	940
630	760	610	1050
800	-	-	-
1000	-	-	-

In this study, a distribution system is used so that the cable is a 3-core XLPE cable with a diameter of 70 mm2, laid on the water's surface. The specifications of the cables used can be seen in Table 3.7. After selecting the cable for the distribution system, figure 3.4 shows how to set a three-core XLPE cable with a diameter of 70 mm2 by opening the library on ETAP and selecting a predetermined cable with a diameter of 70 mm2 after being selected and then automatically the Ifla value can be found by looking at the cable datasheet.

Table 7. Ifla Channel Data

Line	Bus	Diameter (mm^2)	Ampere
1	4-5	70	320
2	4-6	70	320
3	5-7	70	320
4	6-9	70	320
5	8-9	70	320
6	7-8	70	320

Used in a distribution system plan with a diameter of 70 mm2, which generates an electric current of 320 A on the main bus and auxiliary bus, table 7 describes the cables' data and the maximum current that can be charged on the line.

Results and Discussion

A. Calculation of Protection Coordination Manual

This manual calculation divides the multiloop distribution system into three loops (Loop I, Loop II, and Loop III). Each loop is made up of several parts. The purpose of this loop division is to improve the accuracy of calculations. This manual calculation is performed repeatedly or iteratively to find the TDS value with the fastest operating time.

Table 8. Iscmax Value on Loop I

Bus	Forward				Reverse			
	Main		Backup		Main		Backup	
	Relay	Current (I)	Relay	Current (I)	Relay	Current (I)	Relay	Current (I)
1	R16	2160	R3	748	R17	3450	R12	773
10	R1	3840	R16	486	R12	1710	R11	1010
11	R2	2990	R1	2300	R11	2450	R10	1970
12	R3	2020	R2	1540	R10	3450	R17	1690

Table 8 is the Iscmax value of each relay in the loop I. In loop I, Iscmax occurs on buses 1, 10, 11, and 12. In the forward state of bus 1, the working relay is relay 16 as the main relay, and relay three is the Backup relay. On bus 10, relay 1 is the main relay, and relay 16 is the Backup relay. Furthermore, on bus 11, the main relay is relay 2, and the Backup relay is relay 1. Moreover, on bus 12, relay 3 is the main relay, and relay 2 is the Backup relay. Meanwhile, in a reverse state on bus 1, relay 17 works as the main relay and relay 12 as a backup relay. On bus 10, relay 12 was the main relay, and relay 11 was the Backup relay. On bus 11, the main relay is the Backup relay relay 10. Moreover, on bus 12, the relay that works as the main relay is relay 10, and the Backup relay is relay 17.

Table 9. Iscmax Value in Loop II

Bus	Forward				Reverse			
	Main		Backup		Main		Backup	
	Relay	Current (I)	Relay	Current (I)	Relay	Current (I)	Relay	Current (I)
1	R17	3400	R6	681	R16	2160	R9	679
13	R4	3500	R17	1690	R9	1940	R8	1520
14	R5	2450	R4	2030	R8	2950	R7	2370
15	R6	1610	R5	1020	R7	3910	R16	486

Table 9 is the Iscmax number for each relay in loop II. In loop II, Iscmax occurs on buses 1, 13, 14, and 15. On bus 1, the forward relay that will work is relay 17 as the main relay and relay 6 as the backup relay. The reverse relay that works is relay relay 16 as the main relay and relay nine as the Backup relay. On bus 13, the forward relay that works is relay 4, the main relay, with backup relay 17. The reverse relay that works is relay nine, the central relay with backup relay 8. Then, on bus 14, the forward relay that works is relay five as the central relay with Backup relay 4. Meanwhile, the reverse relay that works is relay 8 with Backup relay 7. For bus 15, the forward relay that works is relay six as the main relay and relay five as the Backup relay. Relay seven is used instead of the main relay for a working reverse relay, and relay 16 is used as a backup relay.

Table 10. Iscmax Value on Loop III

Bus	Forward				Reverse			
	Main		Backup		Main		Backup	
	Relay	Current (I)	Relay	Current (I)	Relay	Current (I)	Relay	Current (I)
10	R1	3840	R6	681	R12	1710	R11	1010
11	R2	2990	R1	2300	R11	2450	R10	1970
12	R3	2020	R2	1540	R10	3450	R9	1030
13	R4	3500	R3	1090	R9	1940	R8	1520
14	R5	2450	R4	2030	R8	2950	R7	2370
15	R6	1610	R5	1020	R7	3910	R12	773

Table 10 is the Iscmax value in loop III. In loop III, Iscmax occurs on buses 10, 11, 12, 13, 14, and 15. On bus ten, the forward relay that works is relay 1, bus 10, 11, 12, 13, 14, and 15. On bus 10, the forward relay that works is relay one as the main relay, followed by backup relay 6. For reverse relays that work on reverse relays, relay 17 is the main relay, and relay 11 is the backup relay.

On bus 11, the forward relay that works as the main relay is relay 2 with the Backup relay 1. Meanwhile, in the reverse relay, the main relay that works is relay 11, with relay ten as the Backup relay. On bus 12, relay 3 is the main relay, and relay 2 is the backup relay in the forward state. Relay 10 is the main relay in a reverse state with Backup relay 9. Then, in bus 13, the forward relay is relay four as the main relay and relay three as the Backup relay. The reverse relay that works is relay nine as the main relay and relay eight as the Backup relay. On bus 14, the forward relay that works is relay five as the main relay and relay four as the Backup relay. For a reverse relay that works, relay 8 is the main relay, followed by backup relay 7. Moreover, on the 15 bus, the forward relay works with relay six as the main relay and relay five as the Backup relay. Meanwhile, in the reverse relay that works, relay 7 is the main relay, and relay 12 is the Backup relay.

If one of the relays has two or more different Iscmax values, the Iscmax value taken is the highest. For example, relay 12 as Backup in loop I has an Iscmax value of 422 A, while relay 12 as Backup in loop III has an Iscmax value of 773 A. So, the Iscmax value taken for relay 12 as backup is 773 A, the highest value. To calculate the TDS and Ipickup values, several other values such as Ifla, Iset, and CT values are needed as a type of relay, which will be described in Table 11.

Table 11. Nila Ifla, Iset, and CT Data for Manual Calculation

Relay	Ifla	Iset	CT	
(1)	(2)	(3)	Primary (4)	Skunder (5)
1	320	336	400	5
2	320	336	400	5
3	320	336	400	5
4	320	336	400	5
5	320	336	400	5
6	320	336	400	5
7	320	336	400	5
8	320	336	400	5
9	320	336	400	5
10	320	336	400	5
11	320	336	400	5
12	320	336	400	5
13	866	909,3	1000	5

14	144,3	151,515	200	5
15	144,3	151,515	200	5
16	320	336	400	5
17	320	336	400	5

Here is an explanation of an example manual calculation to find the Ipickup value and the TDS value in relay 16:
Iset = 1.05 x Ifla
Where in Table 11, Ifla is valued at 320A
Iset = 1.05 x 320
Iset = 336

$$\text{Ipickup} = \text{Iset x} \left[\frac{\text{CT Sekunder}}{\text{CT Primer}}\right]$$

Primary CT is worth 400, and secondary CT is worth 5.

$$\text{pickup} = 336 \text{ x } \left[\frac{5}{400}\right]$$

Ipickup = 4.2 Ampere

With this, the Ipickup value has been obtained at 4.2 A. This value will be input into the ETAP software, which will later be used as a current setting function on the protection relay. Next is to calculate the TDS value. From the previous data, it can be known that the values needed are as follows:

TD = 0.5391 Second
Iscmax Backup = 486A
Iset Backup = 336A
α = 0,02
k = 0.14

So that the TDS value can be calculated:

$$\text{TDS} = \text{TD x} \left[\frac{\left[\frac{\text{Iscmax backup}}{\text{Iset backup}}\right]^{\alpha} - 1}{\text{k}}\right]$$

$$\text{TDS} = 0.5391 \text{ x } \left[\frac{\left[\frac{486}{336}\right]^{0,02} - 1}{0,14}\right]$$

TDS = 0.5391 x 0.0529232857
TDS = 0.02853

From this calculation, the TDS value obtained is 0.02853 seconds. So, it can be known that the parameters used to optimize the coordination of the Directional Over Current Relay (DOCR) relay are the TDS and Ipickup values as described in the example of manual calculation on relay 16. In addition, the calculation can be used in the following relay calculation.

This study uses the Delay Time (TDS) value to determine the slope of the inverse curve between the main relay and the backup relay. The TDS value is also significant because it is used in algorithmic genetic calculations and manual calculations. The Ipickup value is as essential as the current setting on the main and the Backup relay. A recap of TDS and Ipickup values is available in Table 12.

Table 12. Ipickup and TDS Values on Manual Calculation

Relay (1)	Ipickup (2)	TDS (3)	TD (4)
1	4,2	0,12093	0,37399
2	4,2	0,13493	0,23168
3	4,2	0,10099	0,411
4	4,2	0,14359	0,39368
5	4,2	0,13338	0,34881
6	4,2	0,05834	0,63147
7	4,2	0,16783	0,46705
8	4,2	0,1236197	0,38972
9	4,2	0,09297	0,36468
10	4,2	0,12753	0,37444
11	4,2	0,08566	0,29586
12	4,2	0,08006	0,33885
16	4,2	0,02853	0,10535
17	4,2	0,08631	0,36647
	Total		5,09305

Table 12 shows the manual calculation results, including the values of the wait time, TDS, and Ipickup. The total waiting time value for this manual calculation from relay 1 to relay 17 is 5.09305 seconds, which will be compared to the calculation performed using the genetic algorithm.

B. Optimization of Protection Coordination Using Genetic Algorithm

Previously, manual calculations had been used to explain the coordination of the protection relay, resulting in a total delay time value of 5.093052 seconds. This chapter will use genetic algorithms to describe the coordination of protection relays. The convergence curve will result from this calculation. This curve includes several parameters to limit the data running process to obtain the ideal TDS value. The TDS value or delay time obtained from the constraints of this parameter is more suitable than a manually calculated value.

Table 13. Main Relay Iscmax Data and Backup Relay

Relay (1)	Ifla (2)	Iscmax		CT (5)
		Primer (3)	Backup (4)	
1	320	3840	2300	80
2	320	2990	1540	80
3	320	2020	748	80
4	320	3500	2030	80
5	320	2450	1020	80
6	320	1610	681	80
7	320	3910	2370	80
8	320	2950	1520	80
9	320	1940	1030	80
10	320	3450	1970	80
11	320	2450	1010	80
12	320	1710	773	80
16	320	2160	486	80
17	320	3400	1690	80

Some of the parameters required for calculations using the Genetic Algorithm are presented in Tables 4.6 and 4.7. Table 4.6 displays data on Ifla, Primary Iscmax, Iscmax Backup, and CT value ratios, while Table 4.7 displays primary relay and Backup relay pairs. The genetic algorithm simulation program also requires parameters to be entered based on a trial error by looking at the convergence curve and output results. This parameter should also be included in the MATLAB program. Parameter values include:

1. Maximum Iteration: 1500
2. Population Size: 100
3. Mutation Rating: 0,02
4. Selection: 0.5 or 50% of the population

This parameter sets the desired value on the genetic algorithm, such as the maximum iteration, where the resulting value and the number of iterations used are better. However, in this study, the maximum value of iterations is 1,500 because it is considered sufficient. Evaluated based on a more optimal time delay value compared to manual calculations. This study used a population of 100 and a mutation of 0.02 because, based on trial and error, this value may take a shorter time to reach the optimal iteration. to produce an ideal convergence curve. However, a choice score of 0.5 indicates the goal of choosing the best candidate.

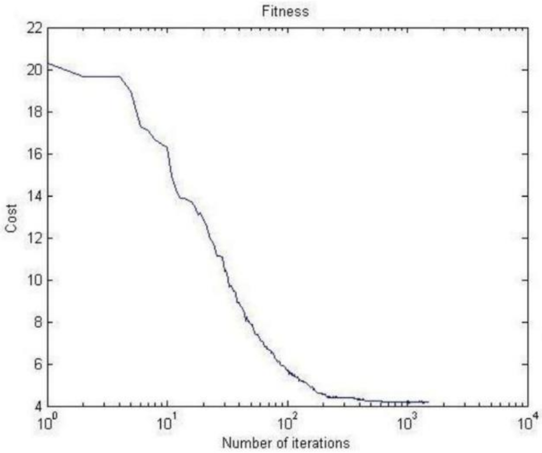

Figure 3. Convergence Curve Using Genetic Algorithm

The convection curve of the genetic algorithm is shown in Figure 3, where this optimization is carried out from 1 to

1500, with a fitness convergence value of 4,161 in the 1392nd iteration.

Table 14. Time Delay Genetic Algorithm Value

Relay	Genetic Algorithm		
	Ipickup	TDS	TD
1	4,91	0,13	0,39
2	4,85	0,09	0,3022
3	4,28	0,07	0,2712
4	4,48	0,07	0,2101
5	4,28	0,06	0,2092
6	4,25	0,06	0,266
7	4,7	0,1	0,2919
8	4,71	0,06	0,1999
9	5,06	0,06	0,2639
10	4,91	0,06	0,1892
11	4,84	0,06	0,2235
12	5,04	0,06	0,2864
16	4,22	0,06	0,2222
17	4,6	0,09	0,277
Total Time Delay (Second)			3,6027

From the results of running the Genetic Algorithm, the total time delay produced is 3.6027 seconds, as shown in Table 4.8. Each running value obtained will be different, so it can be seen from Table 4.5 and Table 4.8 that the total time delay value will be more optimal if using the Genetic Algorithm with a maximum iteration of 1500. The total time delay value generated in the calculation using the Genetic Algorithm is minimal and faster by 5.09305 seconds. The coordination system will be optimal if the total time delay value is minimal.

C. Comparison of Coordination Results of Manual Calculation Protection and Genetic Algorithm (GA)

The total time delay value from the manual calculation is 5.093005 seconds, and the total time delay value from the calculation using GA is 3.6027. Where the difference between the total time delay from the manual and GA calculations is 1.49035 seconds, it can be concluded that the time delay value is a reference value for relay optimization.

Table 15. Comparison of Total Time Delay Values of Manual Calculation and Genetic Algorithm

Relay (1)	Manual Calculation			Genetic Algorithm		
	Ipickup (2)	TDS (3)	TD (4)	Ipickup (5)	TDS (6)	TD (7)
1	4,2	0,12093	0,37399	4,91	0,13	0,39
2	4,2	0,13493	0,23168	4,85	0,09	0,3022
3	4,2	0,10099	0,411	4,28	0,07	0,2712
4	4,2	0,14359	0,39368	4,48	0,07	0,2101
5	4,2	0,13338	0,34881	4,28	0,06	0,2092
6	4,2	0,05834	0,63147	4,25	0,06	0,266
7	4,2	0,16783	0,46705	4,7	0,1	0,2919
8	4,2	0,12361	0,38972	4,71	0,06	0,1999
9	4,2	0,09297	0,36468	5,06	0,06	0,2639
10	4,2	0,12753	0,37444	4,91	0,06	0,1892
11	4,2	0,08566	0,29586	4,84	0,06	0,2235
12	4,2	0,08006	0,33885	5,04	0,06	0,2864
16	4,2	0,02853	0,10535	4,22	0,06	0,2222
17	4, 2	0,08631	0,36647	4,6	0,09	0,277
	Total Time Delay (Second)		5,09305	Total Time Delay (Second)		3,6027

From the time delay value of the main relay and the Backup relay, the CTI value obtained is 0.998 seconds.

Table 16. Comparison of CTI Values from Manual and GA Calculations

Relay		TD		CTI Manual (5)	CTI GA (6)
Main (1)	Backup (2)	Main (3)	Backup (4)		
1	6	0,37399	0,57399	0,2	0,2107
	16	0,37399	0,576192	0,202202	0,7601
2	1	0,23168	0,43168	0,2	0,2034
3	2	0,411	0,611	0,2	0,2794
4	3	0,39368	0,54881	0,15513	0,2081
	17	0,39368	0,467982	0,074302	0,2966

5	4	0,34881	0,54881	0,2	0,2684
6	5	0,63147	0,83147	0,2	0,2146
7	12	0,46705	0,66705	0,2	0,3486
	16	0,46705	0,576192	0,109142	0,8581
8	7	0,38972	0,58972	0,2	0,2733
9	8	0,36468	0,56468	0,2	0,2329
10	9	0,37444	0,57444	0,2	0,2567
	16	0,37444	0,576192	0,201752	0,2176
11	10	0,29586	0,49586	0,2	0,2328
12	11	0,33885	0,53885	0,2	0,2476
16	3	0,112595	0,59368	0,481085	0,396
	9	0,112595	0,57444	0,461845	0,2236
17	6	0,366467	0,57399	0,20752323	0,3237
	12	0,366467	0,66705	0,300583	0,3635

From running GA on MATLAB software, the primary time delay relay value, Backup time delay relay, and CTI value are obtained as described in Table 16. It can be seen that the CTI value of the application on the main relay and the Backup relay has worked according to the CTI constraint ≥ 0.2 seconds, where no relay pairs work below the value of 0.2 seconds. However, some CTI values exceed 0.2 seconds. This can be corrected by changing the characteristic curve. So, it can be concluded that the GA results in this study are better coordinated by the protection system than manual calculations, judging from the cut-off sequence and time delay value in case of interference. The total time delay value in the GA calculation is 3.6027 seconds because the total time delay value of the GA calculation is minimal and faster than the manual calculation, with a total time delay of 5.09305 seconds. The minimum total time delay value is the more optimal the protection system coordinates.

Conclusions

Based on the results of simulation and optimization analysis of directional over current relay coordination in the network of multi-loop distribution system with DG using Genetic Algorithm, several conclusions can be drawn as follows:

1. The relay operation time with manual calculation resulted in a total time delay value of 5.09305 seconds while using the Genetic Algorithm method produced a total time delay value of 3.6027 seconds. Based on the total time delay value, a difference of 1.49035 seconds was obtained. This difference shows that optimization using the Genetic Algorithm with a maximum iteration value of 1500 can efficiently coordinate 29.28% more optimally.
2. The CTI (Coordination et al.) value of the application on the main relay and the Backup relay has worked according to the CTI constraint ≥ 0.2 seconds. No relay pairs work below the value of 0.2 seconds; however, some CTI values exceed 0.2 seconds. This can be corrected by changing the characteristic curve so that the results of the Genetic Algorithm with a maximum iteration value of 1500 protection systems coordinate efficiently and optimally.

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