OPTIMAL COORDINATION OF OVERCURRENT RELAY PROTECTION USING EVOLUTIONARY PROGRAMMING

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[OPTIMAL COORDINATION OF OVERCURRENT RELAY PROTECTION USING EVOLUTIONARY PROGRAMMING]

ABSTRACT

Protection of distribution system is one of the major significant elements in power systems. Overcurrent relay is one of most commonly used protective relays and commonly used for the protection of ring and radial sub transmission systems, and distribution systems. Directional overcurrent relay is mainly used for the primary protection of ring distribution systems as the same magnitude of fault current can flow in either direction. In the distribution system, the protection relay is one of the equipment in the system that can detect from any abnormal activity and protect the area under its observation. The time coordination between protection relay need to be at minimum of time interruption. Hence, the optimum setting for all coordination protection relay is necessary to protect the system from any electrical fault and disturbance. Some researches have been carried out on coordination of overcurrent relays. Due to the difficulty of existing techniques employing different types of algorithm, the usual optimal coordination of overcurrent relays is generally carried out by heuristic, meta-heuristic optimization methods. Therefore, this research employed a metaheuristic optimization for Evolutionary Programming (EP) to find the optimum time for optimization overcurrent protection relay in radial distribution system. The optimum time for each relay during the fault occurrence is the obtained from the optimization process. This meta-heuristic method is selected as it has less parameters to be adjusted and computationally simple to adopt with the coordination problem. The performance of the applied method is tested on 3-bus radial system with different load current. The obtained results are compared with the reference case study.

Keywords: Evolutionary programming, overcurrent protection relay, optimization.

[PENYELARASAN OPTIMAL PERLINDUNGAN GEGANTI PERLINDUNGAN MENGGUNAKAN PENGATURCARA EVOLUSI]

ABSTRAK

Dalam sistem kuasa, perlindungan adalah salah satu aspek yang penting. Geganti lebihan arus adalah salah satu alat pelindung yang sering digunakan secara meluas untuk perlindungan sistem penghantaran selari dan gegelung serta di dalam sistem pengagihan. Penggunaan utama geganti lebihan arus berarah digunakan untuk perlindungan utama sistem pengagihan gegelung jika terdapat kebocoran arus, magnitud kebocoran arus akan mengalir ke arah yang sama. Dalam sistem pengagihan, gegantin perlindungan adalah salah satu peralatan yang dapat mengesan sebarang aktiviti yang tidak normal dan akan melindungi kawasan di bawah pemerhatiannya. Penyelarasan masa di antara geganti perlindungan perlu berada dalam masa gangguan yang minimum. Oleh itu, tetapan optimum bagi semua koordinasi penyambungan geganti perlindungan diperlukan untuk melindungi sistem dari sebarang kerosakan dan gangguan elektrik. Beberapa penyelidikan telah dijalankan tentang penyelarasan koordinasi geganti perlindungan. Disebabkan kesukaran daripada teknik yang sedia ada, mereka memperkenalkan pelbagai jenis algoritma seperti koordinasi geganti optimum untuk lebihan arus dilakukan oleh kaedah pengoptimuman heuristik, meta-heuristik. Oleh itu, kajian ini menggunakan pengoptimuman metaheuristik Pengaturcaraan Evolusi (EP) untuk mencari masa optimum terbaik untuk pengoptimuman geganti perlindungan lebihan arus dalam sistem pengedaran selari. Masa yang optimum bagi setiap geganti semasa kebocoran berlaku diperolehi daripada proses pengoptimuman. Kaedah meta-heuristik ini dipilih kerana tidak memerlukan banyak parameter untuk diselaraskan dan pengiraan pengkomputeran yang sangat mudah untuk diadaptasi apabila terdapat masalah koordinasi. Prestasi kaedah yang diterapkan dan diuji pada sistem selari 3-bus dengan beban arus yang berbeza. Keputusan yang diperoleh akan dibandingkan dengan kajian kes rujukan.

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LIST OF SYMBOLS AND ABBREVIATIONS

I_L	:	Setting Current
I_O	:	Input Current
I_S	:	Setting Current
I_{pick}	:	Pickup Current
S_L	:	Line Apparent Power
t_{opj}	:	Relay Operating Time
t_{opjb}	:	Backup Relay Operating Time
A	:	Ampere
CB	:	Circuit Breaker
CT	:	Current Transformer
CTI	:	Coordination Time Interval
EA	:	Evolutionary Algorithm
EI	:	Extremely Inverse
EP	:	Evolutionary Programming
ES	:	Evolutionary Strategy
FT	:	Fitness Test
GA	:	Genetic Algorithm
IDMT	:	Inverse Definite Minimum Time
IEC	:	International Electrotechnical Commission
L	:	Load
LP	:	Linear Programming
OF	:	Objective Function
OM	:	Optimum Method
p.f	:	Power Factor

PS	:	Plug Setting
PSM	:	Plug Setting Multiplier
S	:	Apparent Power
SI	:	Standard Inverse
TDS	:	Time Dial Setting
TMS	:	Time Multiplier Setting
TS	:	Tap Setting
VI	:	Very Inverse

CHAPTER 1: INTRODUCTION

1.1 Background

In the power system engineering, the design of power system should be in safe condition and situation at all times. No matter how properly in details the power system has been designed, the possibility of fault happened cannot be prevented. The engineers must design the power system in worst case scenario or design near to the ideal case. The arc is highly destructive at the point when the fault happens. Even far away from the point of fault, huge fault current flowing from upstream conductors could cause damages if the current continues flowing for more than two seconds. These faults will present risks to human's life, animals, environment, assets and reputation for the power utility companies.

Power system protection among one of the necessary components for the electrical power system engineering. The purpose of engineer to designs the protection scheme which to ensure uninterruptedly electrical system, hence it will allow maximum power flow in the distribution system (Hernanda, Kartinisari, Asfani, & Fahmi, 2014). Usually, there are three basic components for the protection system: -

1. Relays
2. Circuit Breaker
3. Current Transformer

Since electrical power system growths within this modern century, the design of the electrical power system also become more complex. Because of that, the power system protection becomes so important in the distribution system. In electrical power system engineering, the relay is a complicated electromechanical equipment. Relay is a device that made to responds to a change in its electrical or mechanical input.

The output contacts for the relay are used for protection control and indication purposes. There are 3 types of relays: -

1. Tripping, control or auxiliary (instantaneous) relay
2. Time delay relay
3. Protection relay

This research is more focus on protection relay. Protection relay is an electrical device which can deliver a signal to provide direction for circuit breaker to cut off the faulty load area in that system (Hussain, Rahim, & Musirin, 2013). To maintain the coordination of protection devices, the equipment that have been affected in several fault potentials need to be selective to make sure the consistency of the system in safe operation (Jazaeri, Farzinfar, & Razavi, 2015). In with effectiveness of protection system, the load area has been affected with any faults must be removed within shortest possible time without disturbing the main power system (Alipour & Pacis, 2016). Also, to disconnect the smallest load section of the connected system that comprising cause of the fault.

For designing the electrical protection relay, the fault characteristics required to be recognize and understand by the design engineers. Related to this, the engineers must to be conversant and knowledgeable about tripping traits of various protection relays. The relays characteristics must be able to sense and detect abnormal of intolerable fault conditions. With the specified characteristics and without affecting other undesired areas, the relay will take action to trip the faulty line without affecting other undesired area. The engineer has to calculate the operating time and design the protection relay that will trip during any fault that have been recognized and identified.

There are principle and function for the protection relay: -

1. Must trip quickly during fault happen
2. The trip happens only when necessary or fault current detected
3. Not to operate wrongly or malfunction when fault happen
4. Must have discrimination or stability

The relay operating characteristics is depending on the energizing quantities that fed to the voltage, current and combination of voltage and current. From the characteristics of voltage and current, there are several types of relays have been developed and design by the engineers such as: -

1. Overcurrent relay – For current
2. Overvoltage / Undervoltage relay – For voltage
3. Directional relay – For phase angle between voltage and current
4. Distance relay – For impedance computation from voltage and current

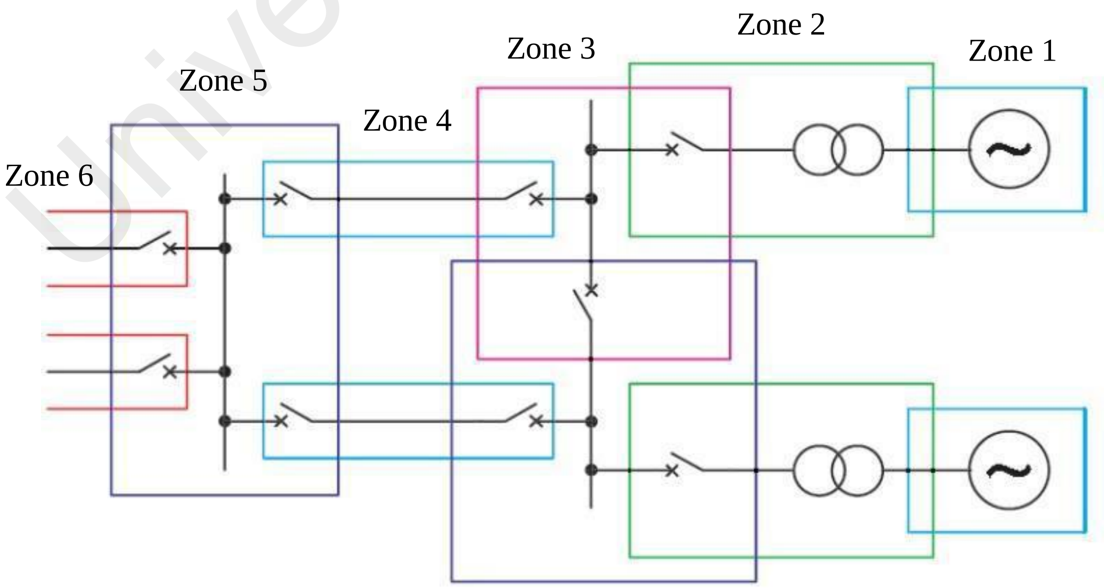

Figure 1.1: Overlapping of Protection Zone

Figure 1.1 show the overlapping zone of protection for electrical system. It is necessary to have more than one primary protection system operating. When the primary protection is fail to react or non-availability, some other means of fault isolation is required. This secondary layer is referred to as ‘backup protection’. When fault happen, both the primary and backup protection system will detect the fault simultaneously. Nevertheless, the backup protection operation should be delayed to make sure that the primary protection clears the fault first.

According to statistical studies, there are large numbers of protection relay was tripped due to mistake and wrong in calculation or poor settings instead of to actual faults (Paithankar & Bhide, 2011). The significance of designing a better protection system and considering various method are ascending frequently in power system is because of faults, under frequency, overload and overvoltage. All these circumstances can cause disruption to main electrical load supply and might be harm and loss of electrical or mechanical appliances linked and associated within the power system. Unexpected develop shunt fault current are the problem that will impact the electrical power system (Paithankar & Bhide, 2011).

1.2 Problem Statement

In electrical power system, there are large number of radial network are available, which is protected using time delay overcurrent protection relay. When the fault happens in the distribution system, the relay which is close to fault location must trip first. If the nearest protection relay fails to detect due to higher operating time than the backup protection relay will trip first to prevent the fault from propagating in the whole distribution system. This is the procedure to interrupt minimum load during faults occurrence. Else, protection relay which is nearby the electrical load power generator will additionally had a dangerous situation or large cut out time delay.

Then the optimization of coordination overcurrent protection relay will be use in this research to overcome the problem. Additionally, there are limits the maximum number of breaker for overcurrent relay coordination in radial system which is must less than five (Glover, Sarma, & Overbye, 2012). Else, protection relay which is nearby the electrical load power generator will additionally had a dangerous situation or large cut out time delay.

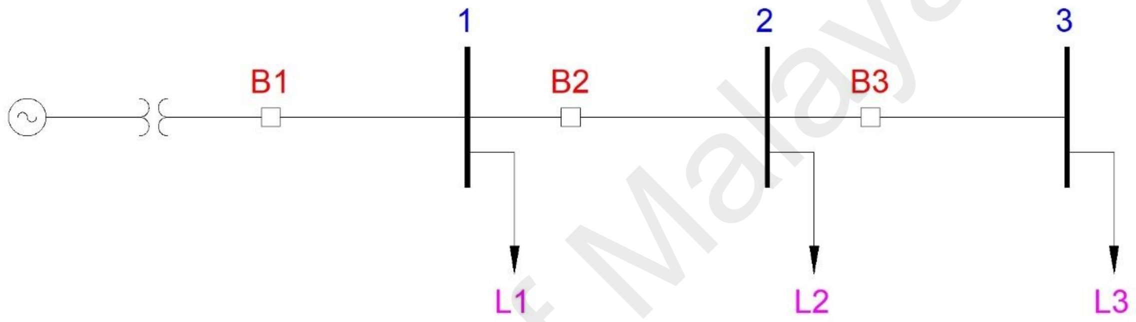

Figure 1.2: Electrical Radial Distribution System Example

For the protection relays, there are relay for primary protection and backup protection in the electrical distribution system. Refer to Figure 1.2, when the fault happens near B3, the B3 will be the primary protection and B2 will become backup protection. Between the relay, there have intermission time which can call as the Coordination Time Interval (CTI). That will explain difference between backup protection relay operating time and the time under primary protection relay when clear the fault. Specific determination of relay operating times is complicated through numerous elements such as frequency, Current Transformer (CT) ratio, Plug Setting (PS) or Tap Setting (TS) and the breaker operating time. Consequently, to justify all the factors in many efficient operation, the normal CTI between 0.2 to 0.5 seconds must be chosen (Glover et al., 2012).

To solve the coordination problems, a lot of method, technique and algorithm already been developed and generated. The Evolutionary Programming (EP) algorithm will be use in this research to solve the optimization time and coordination problems for overcurrent relay.

1.3 Objectives

The objectives of this project are:

1. To find the best optimization time coordination between overcurrent protection relay in electrical radial distribution system using Evolutionary Programming (EP) algorithm technique.
2. To obtain the minimum relay operating time by using optimization algorithm in radial distribution system.
3. To analyze the value of Tap Setting (TS) and the effect to the coordination time for overcurrent protection relay by using optimization algorithm.

1.4 Scope of Research

The scope of this research will be focusing in electrical protection system such as relays, fault current, time interval in relay and the time coordination between protection relay.

1.5 Research Project Outline

This report is divided into five (5) chapters as per following:

Chapter 1: Introduction – Within this chapter, the research background is discussed. The objectives and scope of the research are described.

Chapter 2: Literature Review - Within this chapter, related research materials and power system protection would be summarized and discussed.

Chapter 3 – Methodology - Within this chapter, from the initial data provide has been calculated by using equation for the International Electrotechnical Commission (IEC) Standard overcurrent relay. The Evolutionary Algorithms (EA) will be explain and the flow chart for Evolutionary Programming (EP) also provided. The programming software is by using MATLAB.

Chapter 4: Results & Discussions – Within this chapter, results that obtained from the MATLAB simulation for overcurrent relay protection coordination will be provided and will be discuss.

Chapter 5: Conclusion – Within this chapter, the overall research will be concluded.

CHAPTER 2: LITERATURE REVIEW

2.1 Overcurrent Protection

Overcurrent protection relay is one of a category of protection relay that will react though the limit of a setting value when the load current surpasses. The current setting multipliers for overcurrent relays commonly can be classified from 50 to 200% increase within in 25% that can be referred indicate as Tap Setting (TS) (Korde & Bedekar, 2016). TS for every relay can be measured through two specifications. First is the maximum load current and second is minimum fault current (Mohammadi, Abyaneh, Razavi, Al-Dabbagh, & Sadeghi, 2010; Razavi, Abyaneh, Al-Dabbagh, Mohammadi, & Torkaman, 2008). For every potential fault location, relay coordination is needed to figure out the arrangement and continuity of relay operations. In this case with enough limits and beyond extra time delays, the faulted load area for the system can be cut off (Thangaraj, Pant, & Deep, 2010). Only the TMS based on predetermined pickup current settings can be optimized.

Between the various potential arrangements used to reach the optimum level of relay coordination with utilizing the time grading or current grading, or both time and current grading combination. The initial guess settings must have biased. The explanation for overcurrent protection coordination is a very constrained domain and it is subject to the user preference such as time-grading, current-grading and minimum operating time grading (So, Li, Lai, & Fung, 1997). In the overcurrent relays coordination problem, to find the PSM and TMS of each relay is the main objective. Furthermore, to reduce and minimize properly the overall operation time for primary relay will be an objective.

However, to assure consistency coordination of the protection system, backup relay would not perform first unless the primary relay misses to perform or did not take the action to cut out when the fault happens. The backup protection relay characteristic is like a defender to operate as the second level defend for line protection on condition if slightly failure happen at the primary relay. For the best coordination among primary relay and backup relay, the entire constraints below the shortest operation time should be satisfy all the parameters. These parameters are PSM, TMS, Objective Function (OF) and Optimum Method (OM). For an optimal coordination for the type of electrical system for radial system or ring system, non-linear relay characteristic proportionate to TS, PSM and TMS are important features (So et al., 1997). Figure 2.1 below show that the different current setting graph for different relay.

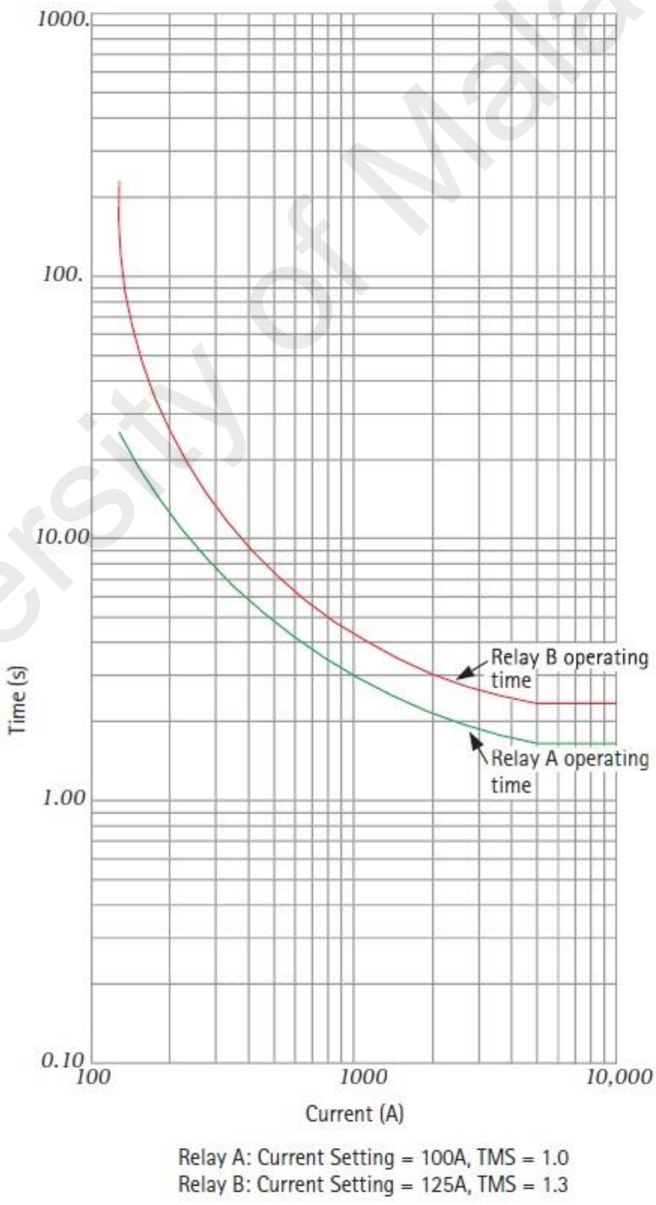

Figure 2.1: Relay Characteristics for Different Current Setting

Protection relays which combine the time grading and current grading tripping parameters is called IDMT. In the electrical distribution system, the IDMT relay occasion is to be diverse accordingly to the parameters and tripping time needed of the protection relay.

For the current grading or time grading tripping characteristics of IDMT relays requirement must be different accordingly to the characteristics of another protection relay and the tripping time needed that have been set in the electrical distribution system (Glover et al., 2012). For these purposes, the standard characteristics of Inverse IDMT relay as according to IEC 60255 standard as shown in Figure 2.1. There are four types of characteristic of relay as shown in table below: -

Table 2.1: Relay Characteristics According IEC 60255 Standard

Relay Characteristic	Equation (IEC 60255)
Standard Inverse (SI)	$t = TMS \times \frac{0.14}{I_r^{0.02} - 1}$
Very Inverse (VI)	$t = TMS \times \frac{13.5}{I_r - 1}$
Extremely Inverse (EI)	$t = TMS \times \frac{80}{I_r^2 - 1}$
Long time standard earth fault	$t = TMS \times \frac{120}{I_r - 1}$

The time for a relay to operate or trip depends on:

- Magnitude of fault current: How big the current is compared to the setting of PSM.
- TMS: Controls the angle the moving contact needs to travel to complete the tripping process and hence the time of relay operation.
- Plug Setting (PS) or Tap Setting (TS): Controls the current at which the relay starts to operate.

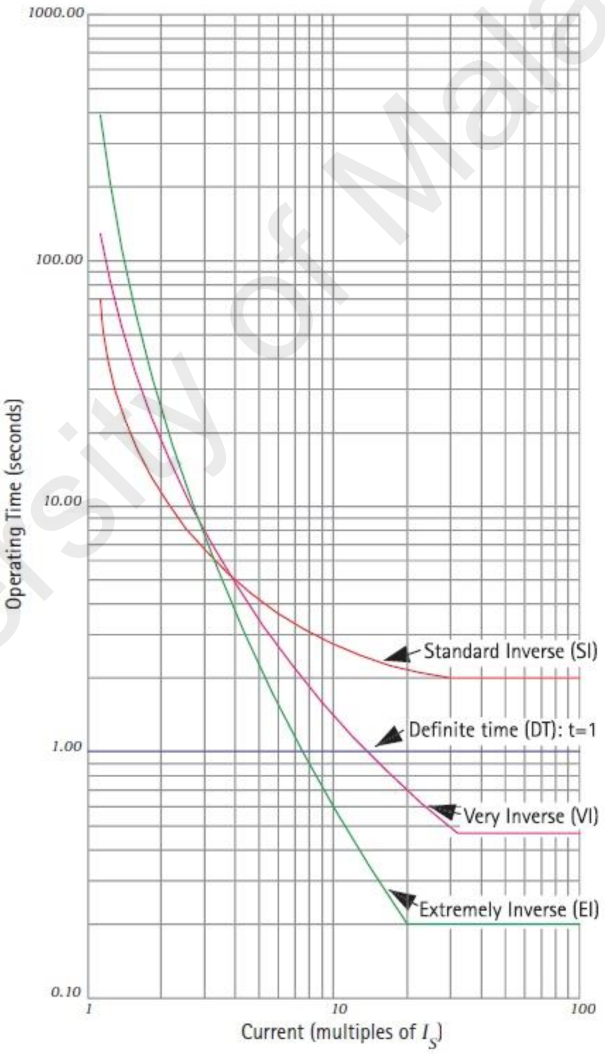

Figure 2.2: IDMT Relay Characteristics

The curve graph that shown in Figure 2.2 show that with using the Standard Inverse (SI) setting, the TMS will be a different in tripping characteristics. When the TMS using the Very Inverse (VI) or Extremely Inverse (EI) curve, the tripping characteristics for the relay will be more different in operating time over the current.

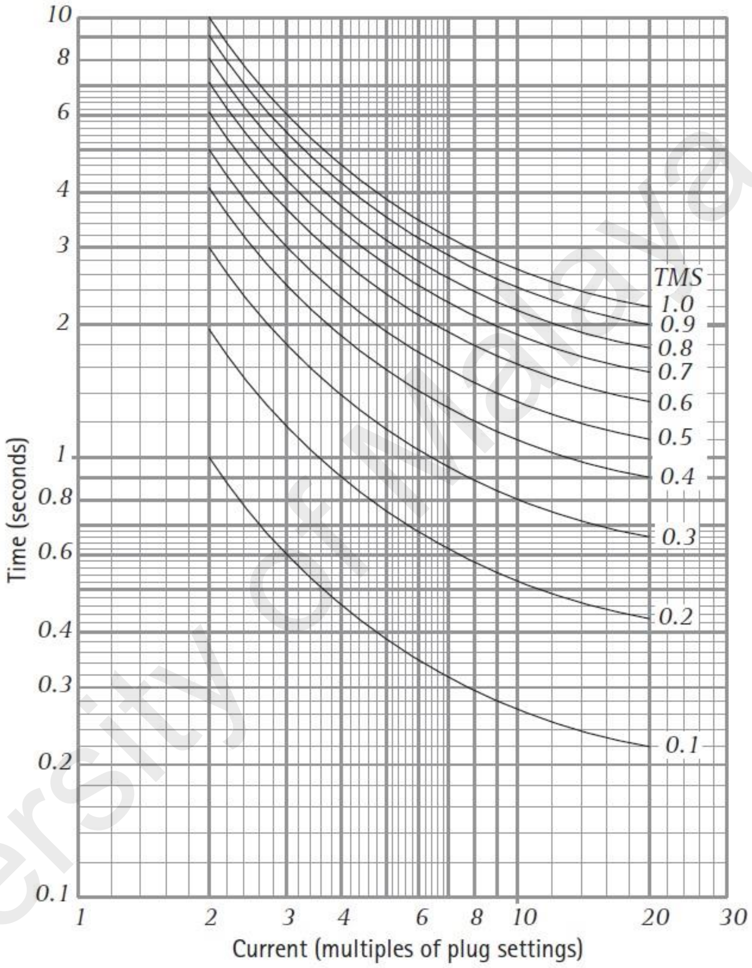

Figure 2.3: Typical Characteristics of Standard IDMT Relay for Time/Current

Figure 2.3 show that the graph to calculate manually the relay characteristics. Previously, the design engineers will base on the above graph to calculate which is the best time to relay operate when the TMS and PS already been selected based on any factor.

The satisfactory use of SI graph curve can be proven in many protection relay facts. However, when the grading satisfactory has not been successful the VI or EI graph curve will be used that might be guidance the problem happen (Glover et al., 2012).

Difference characteristics of the relay can be implement when the numeric relay and digital relay has been used. This also can be happened and plotted the new user determine graph curve. The Figure 2.4 shown that the relay characteristic for SI graph curve and VI graph curve.

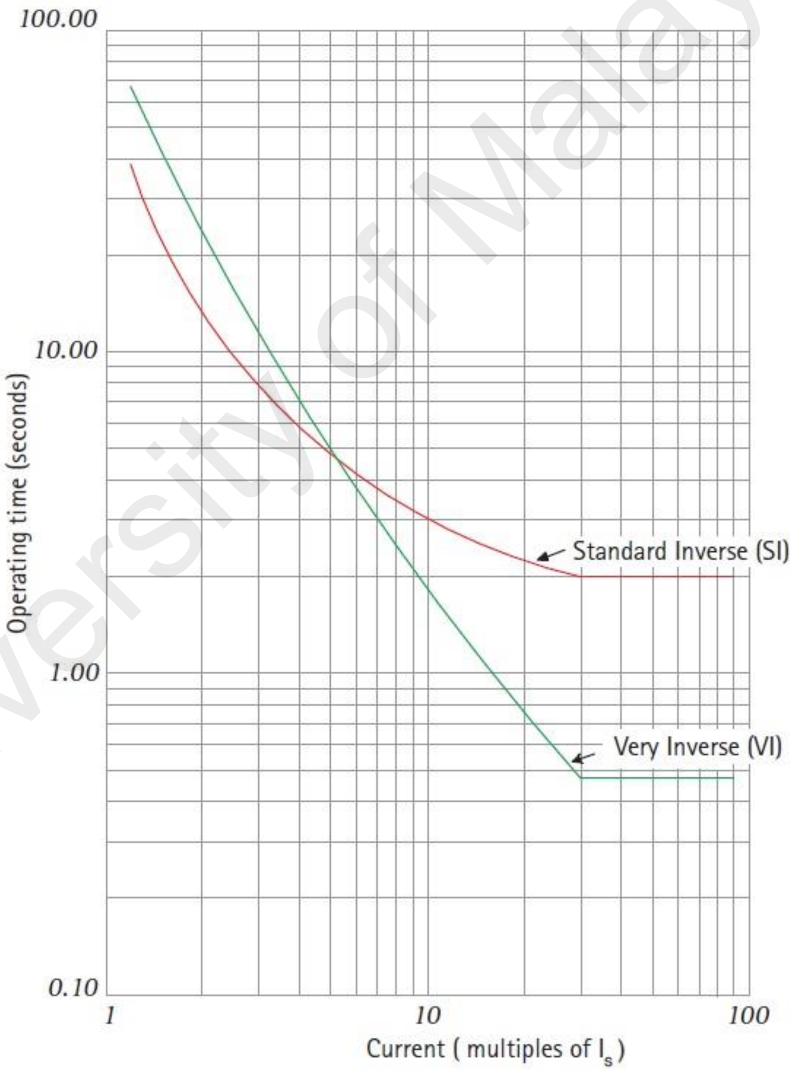

Figure 2.4: Comparison of SI and VI Relay Characteristics

Only the TMS individual value shown on the Figure 2.3 graph curve. For the electromechanical relay, the modification and improvement are possible to plot in continues study (Glover et al., 2012). To efficiently condition of another type of relay, the small setting process need to do to extended and continued adjustment. Furthermore, high-set immediate component is fixed in most of all overcurrent relays in electrical power system.

The characteristic in graph curves are typically shown with relay input current in ampere versus operating time in second as a multiple of current that have been selected. Also, for values exceeding the pickup current the graph curves are indicative to the vertical axis and decrease with some inverse power of current magnitude (Glover et al., 2012). Through some adjustment of TDS, the inverse time characteristic manages to shift up or shift down. Moreover, discrete TDS are shown in Figure 2.4, by interpolating between the discrete curves intermediate values can be obtained. TDS only uses in electromechanical relay.

The coordination problem in electrical power system network are be able to state as Equation 2.1 as below for directional overcurrent relays: -

$$\boldsymbol{Z_{min}} = \sum_{\boldsymbol{j=1}} \boldsymbol{t_{opj}} \qquad (2.1)$$

Where, t_{opj} the primary relay operating time for at k location in primary system. Normally, a coefficient is set to 1. This possibility is to indicate the existence the fault happens on a line in the electrical network system. Then the fault existence for every electrical distribution system line can be assume as identical possibility (Glover et al., 2012).

The convenient minimum current must be over the largest potential current load and also must be lower than minimum fault current. These conditions should beyond security margin (Damchi, Mashhadi, Sadeh, & Bashir, 2011). The bounds for the relays operating time can be stated by Equation 2.2 as: -

$$\text{Minimum } t_{opj} \leq t_{opj} \leq \text{Maximum } t_{opj} \tag{2.2}$$

Where,

Minimum t_{opj} = minimum time needed for relay to operate at fault location ‘j’.

Maximum t_{opj} = maximum time needed for relay to operate at fault location ‘j’.

Hence, for Overcurrent Relay coordination condition, this is needed to specify and figure out the maximum load current and minimum fault current throughout electrical power system network and any kind of fault investigation.

The difference between primary relay operation time and backup relay condition necessity greater than or equal to the CTI. The Equation 2.3 is the constraints to keep the CTI value between the protection relays: -

$$t_{opjb} - t_{opj} \geq \Delta T \tag{2.3}$$

Where,

t_{opjb} = the backup relay operating time at fault location happen at ‘j’.

ΔT = CTI. The value is at interval 0.2 and 0.5 second.

A normal IDMT is the overcurrent relay that has characteristic satisfy and fulfill the standards of IEC 255-4 and can be calculated as Equation 2.4 below: -

$$Time = \frac{TMS \times \lambda}{\left(\frac{I_o}{I_{set}}\right)^{\gamma} - 1} \tag{2.4}$$

Where,

$Time$ = relay operating time

TMS = Time Multiplier Setting

I_o = input current

I_{set}= setting current

IDMT constant, $\gamma = 0.02$ and $\lambda = 0.04$ (Bedekar, Bhide, & Kale, 2009b)

Then the overcurrent relay will coordinate to take action and operate in sequence in the electrical distribution system. To obtain the successful relay coordination, the fault currents must be larger than normal load currents (Glover et al., 2012). For the numerical relay, the current setting multiplier (CSM) also known as TS in step 25% and range from 50% to 200% (Hussain et al., 2013; Razavi et al., 2008)

2.2 Conventional Methods

Within last fifty years ago, various technique for the coordination overcurrent protection relays system have been developed. There also may be categorized to three different methods. The methods are topological analysis, trial and error and lastly is optimization (Barzegari, Bathaee, & Alizadeh, 2010; Ezzeddine & Kaczmarek, 2011;

Singh, Panigrahi, & Abhyankar, 2011). The trial and error technique were once used however it has slow convergence rate due to huge number of iterations had to meet the satisfaction relay setting (Mansour, Mekhamer, & El-Kharbawe, 2007; Thangaraj et al., 2010). The coordination process is required to reduce the quantity number of iterations. To break all the loops there are some technique term so-called break point and detect the primary or main relays at those area or location is usually suggested.

First important element is to begin with the coordination process which is to find the breakpoints. For the topological methods, to determine the break point which are include functional and graph theory (Mansour et al., 2007). With using the topological methods, the result for the solution found so far are the finest settings options although that is not reach the optimum level. This is because, the value of Time Dial Settings (TDS) also known as TMS for that relays are large.

Besides, because of the difficulty and complication of the electrical network system, so much time consuming for analysis for topological method technique and the trial and error method and this is not balance and optimum.

When more than one electrical power source is connected to the network system, the directional overcurrent relay will become the best options and appliance preference. In the earlier research on directional overcurrent relay, there can be divide to three classification or class (Birla, Maheshwari, & Gupta, 2005). They can be classified as graph theoretical technique, curve fitting technique and optimization technique. For the graph theoretical techniques, which can be found on research in (Jenkins, Khincha, Shivakumar, & Dash, 1992). The breakpoints minimum value and information for the system structure must be utilized. The arrangement of overcurrent setting relay including the primary or backup relays must be utilized. The directional relays for the line directionality also must be utilized to get the optimal setting result.

The curve fitting techniques normally apply to figure out and to select data or value for the best setting of overcurrent relay. The polynomial form for protection relay characteristic can be modelled mathematically by using curve fitting techniques (Smolleck, 1979; Zocholl et al., 1989).

Hence, the optimization techniques were widely used around the world in this digital era with the assistance and support of the computer calculation and algorithm.

2.3 Optimization Techniques

Nowadays, this techniques already overwhelmed the conventional method that overcurrent relays have been organized and align in order prior into consideration for coordination (Mohammadi, Abyaneh, Rudsari, Fathi, & Rastegar, 2011). Because of its advantages, this technique becomes favored between researchers to discover more. Furthermore, optimization techniques ignore and discard the occasion to search and find the set of break points. (Urdaneta, Nadira, & Jimenez, 1988) were the first researchers to specify and represent the coordination of overcurrent relay and the function and operation for optimization theory techniques.

On the other hand, a few researchers try to use non-linear programming to determine and clarify coordination overcurrent relay difficulty and complication and they found non-linear programming technique are complicated and time consuming (Abyaneh, Al-Dabbagh, Karegar, Sadeghi, & Khan, 2003). Nonetheless, if the binary value are used to the equation of the isolated pickup currents, I_{pick} will boost and will make the coordination in complexity problem (Birla et al., 2005).

The downside of those techniques is it will base totally based on an assumption on initial value and will additionally to be flopped into nearby minimum value (Moravej, Jazaeri, & Gholamzadeh, 2012). In these methods, the operating time for every overcurrent relay can be deliberate to the linear function. The TMS and also pickup current, I_{pick} value need to assume to the known value. The technique of Simplex, Dual Simplex and Two-Phase Simplex method was proposed by (Bedekar, Bhide, & Kale, 2009a; Bedekar et al., 2009b; Bedekar, Bhide, & Kale, 2009c). The technique has been used to resolve the difficulty and complication in ring fed electrical power system network for the directional overcurrent. Further, (Ezzeddine & Kaczmarek, 2011) did declare that despite Linear Programming (LP) techniques is the most simple and can converge to optimum solutions without any difficulty. Only the value of the TMS should be optimize. However, pickup current, I_{pick} need to choose by involvement of any fault happen at current data or at power source load.

2.4 Evolutionary Programming

American scholars (Fogel, Owens, & Walsh, 1966) is the first person to develop Evolutionary Programming (EP) the in United States in 1960s. EP was stimulated of biological systems by the evolutionary principles. Numerous dissimilar replicated evolutionary algorithms now already expanding and grow very quickly within the decade. Imitation of EA have reach the optimization goals by way of the imitate performance of populations that consist of many entities. The imitation of EA has proven by the researcher that found so many advantages that no condition to derivative of the information for objective functions, suitability for application and simplicity, broader adoption, strong courage, easy operation, and etc. The EP techniques have been successful in many applications.

The primary EA which is consist of EP, GA and ES. The term GA was proposed by (Bremermann, 1962; Fraser, 1960; Holland, 1975). These procedures were described because of the same algorithms that can replicate genetic systems. That algorithms already utilized in numerous area such as combination of optimization, machine learning, artificial life and adaptive control (Holland & Goldberg, 1989). (Rechenberg, 1965) were discovered and proposed of the Evolution Strategies (ES). The improvement of the EP was attributed to the effort of Fogel and many others. In EP and ES, the actual values are used for variable coding so they are very convenient to create the function optimization.

Theoretical, the ideas of EP are to find and searching the best point of optimization algorithm and the program are capable to break out from limited optimum point problem. Evolutionary Programming is a most fulfilling solution by way of evolving a number of population from selected clarification by a quantity of generations or iterations that called "Parent". A new population called "Children" will develop from an old existing generation known as 'Parent' in the time between every iteration. This operation is called mutation. The mutation operator develops a new result by threatening every factor from a current generation result with using random quantity. Every level of optimization for each result generate for the individuals is calculated with using their own suitability.

This technique also known as iterative process and the generation process will be finished by a stopping rule. Usually the rules are used to finish or ended the process is either: -

1. Stop the iterations when specified number is defined
2. When no significant generation number changes for the solution

CHAPTER 3: METHODOLOGY

3.1 Radial Electrical Power System Data

The Figure 3.1 below shown a 60 Hz electrical schematic diagram for a radial electrical distribution network system that had been taken from the book Power System Analysis & Design SI Edition (Glover et al., 2012).

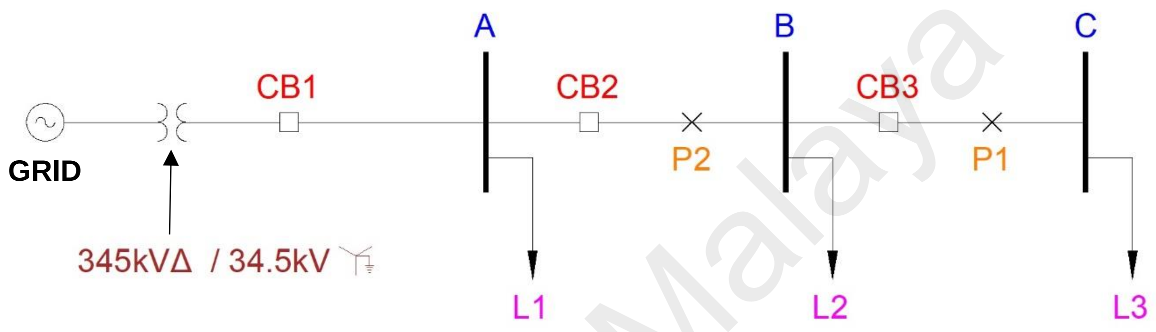

Figure 3.1: Single Line for Radial Electrical Power System Studies

For the system as figure above, a fault happens at P1 location near the right of breaker CB3 as Figure 3.1. When fault happens, the breaker CB3 should be open first while breaker CB2 (also breaker CB1) remains closed. Only load L3 will interrupted under these conditions. The time delay for the breaker CB2 should be setting to be longer than breaker CB3, so that breaker CB3 can operates first. Thus, when any fault happens to the right of breaker CB3, the breaker CB3 will provides primary protection for the system. However, if breaker CB3 fails to open or operate, breaker CB2 will be operate after time delay then providing the backup protection for the system. In the same way, when fault consider at P2 location between breaker CB2 and breaker CB3. The breaker CB2 have to operate while breaker CB1 remains closed. Underneath of these conditions, the system at source bus B and source bus C which is at L2 and L3 will be stopped.

Meanwhile when fault happen at location which nearer to the main source, the current fault will be bigger rather than the previous fault location. When breaker CB2 will be operate for the previous fault location, the smaller fault current will flow after the time delay. The time for breaker CB2 will operate more rapidly for this fault. The selection for the breaker CB1 setting must be longer time delay than breaker CB2, so that breaker CB2 will operate first. Therefore, breaker CB2 implement primary protection for faults happen between breaker CB2 and breaker CB3 in that system, will be protection if any faults happen at breaker CB3 right location. Likewise, breaker CB1 also implement primary protection for faults happen between breaker CB1 and breaker CB2, will be backup protection for faults happen to more downstream faults (Madhumitha, Sharma, Mewara, Swathika, & Hemamalini, 2015).

All these data will be use to compare the final calculation result from the reference book and the final output of optimization technique with using EP algorithm. All the provided data are in the tables given as below: -

Table 3.1: Data for The Maximum Loads

Source Bus	Apparent Power, S (MVA)	Power Factor (Lagging)
A	11.0	0.95
B	4.0	0.95
C	6.0	0.95

Table 3.2: Data for Fault Currents of The System

Source Bus	Fault Current at Maximum, (A) (Three Phase Bolted)	Minimum Fault Current, (A) (L-L or L-G)
A	3000	2200
B	2000	1500
C	1000	700

Table 3.3: Data for Circuit Breaker and CT Ratio

Circuit Breaker	Time Operation of Circuit Breaker	CT Ratio
CB1	5 cycles	400:5
CB2	5 cycles	200:5
CB3	5 cycles	200:5

To calculate the TS, consider the fault happen at P1 location as in Figure 3.2. Then for the maximum load at L3, the primary and secondary CT current can be calculated.

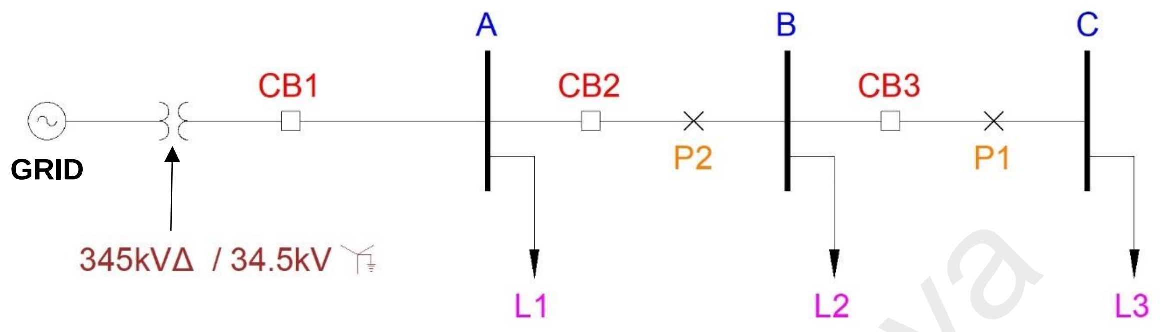

Figure 3.2: When Fault at Location P1 or P2 in The System (Glover et al., 2012)

The equation to find line current is: -

$$I_L = \frac{S_L}{\sqrt{3} \times V} \tag{3.1}$$

Where,

I_L= Line Current

S_L= Line Apparent Power

V= Source Voltage

Then to find current Tap Setting (TS) the equation is: -

$$I_L' = \frac{I_L}{CT\ Ratio} \tag{3.2}$$

Thus, because of the load power factor are equal at B2, $|S_{Li} + S_{Lj}| = |S_{Li}| + |S_{Lj}|$. To find the maximum load at B2, the primary and secondary CT current are: -

$$I_L = \frac{S_{Li} + S_{Lj}}{\sqrt{3} \times V} \tag{3.3}$$

For maximum load at B1, the primary and secondary CT current are: -

$$I_L = \frac{S_{Li} + S_{Lj} + S_{Lk}}{\sqrt{3} \times V} \tag{3.4}$$

3.2 Relay Characteristics

The relay characteristics for all the normal IDMT relay will follow standards of the IEC 255-4 and then can be assumed $\gamma = 0.02$ and $\lambda = 0.04$ (Bedekar et al., 2009b).

$$\alpha = \frac{\lambda}{(PSM)^{\gamma} - 1} \tag{3.5}$$

As we know that the PSM equation is given by: -

$$PSM = \frac{I_f}{(CT\ Ratio)\ X\ (Relay\ Setting)} \tag{3.6}$$

Where I_f is fault current in Ampere (A).

Then the t_{opj} can be determined: -

$$t_{opj} = \frac{\lambda \times (TMS)}{(PSM)^{\gamma} - 1} \tag{3.7}$$

From equation above, we can get the t_{opj} as Equation 3.8 below: -

$$t_{opj} = \alpha(TMS) \tag{3.8}$$

Then the real value of Time Multiplier Setting (TMS) can be calculated.

This is known as the Objective Function (OF) that can optimize the relay coordination problem, the total time operation for all the relays need to be minimized as formula given as Equation 3.9 below: -

$$\boldsymbol{Z_{min}} = \sum_{\boldsymbol{j=1}}^{\boldsymbol{n=3}} \boldsymbol{t_{opj}} \tag{3.9}$$

Where,

t_{opj} = operating time for primary relay which is happen within location 'j'

n = number of bus in radial system

3.3 Bound of Operating Time

The bound operation time is to find the minimum and maximum operating time relay at any fault location. Then the range for t_{opj} should be from 0.01 to 1.

$$\text{Minimum } t_{opj} \leq t_{opj} \leq \text{Maximum } t_{opj} \tag{3.10}$$

Where,

Minimum t_{opj} = minimum time needed for relay to operate at fault location 'j'

Maximum t_{opj} = maximum time needed for relay to operate at fault location 'j'

3.4 Coordination Time Criteria

A constrain is needed to maintain the criteria between CTI and the protection relays. The CTI difference value are must be greater than or equal at intervals of the operation times for primary relay and backup relay as explained on Figure 3.3.

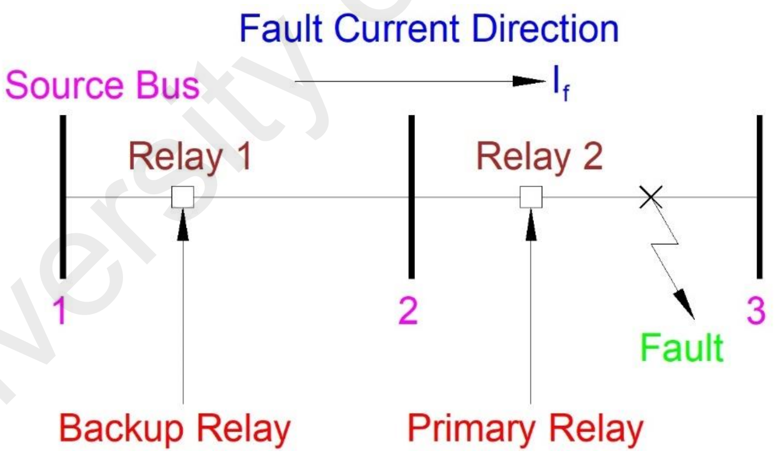

Figure 3.3: When Fault Happen In Electrical Power System

Figure 3.3 shown that the Relay 2 is being the primary relay when current fault happens slightly at the right location of Relay 2. The primary relay should operate first when fault happen (Banerjee, Narayanasamy, & Swathika, 2017).

Then Relay 1 will be function or break the network system when value of CTI will be the same value of the sum of Circuit Breaker (CB) operating time which at Source Bus 2. The CTI selected in this research is 0.3 second. This is the protection relay constrain for the CTI.

Then below is the equation: -

$$t_{opjb} - t_{opj} \geq \Delta t \quad (3.11)$$

Where,

t_{opjb} = Backup Relay j operation time of to operate at location 'Fault'

Δt = CTI

Moreover, we can conclude that the equation for the Relay 1 will operate is: -

$$T_{R1} = T_{R2} + T_{CB} + \Delta t \quad (3.12)$$

Where,

T_{R1} = Total time for the operating time of Relay 1 to operate

T_{R2} = Time for the operating time of Relay 2 to operate

T_{CB} = Operating time for Circuit Breaker (CB) to operate

Δt = CTI that has been selected

3.5 Operation of Evolutionary Programming

The EP algorithm technique is an iterative process that will perform until the required conditions are satisfied or the final iteration is reached to the maximum indicated number. There are several stages for EP algorithm technique to meet the objective function and the constrain (Srinivas & Swarup, 2017). Figure 3.4 depict the flow chart of the EP algorithm technique.

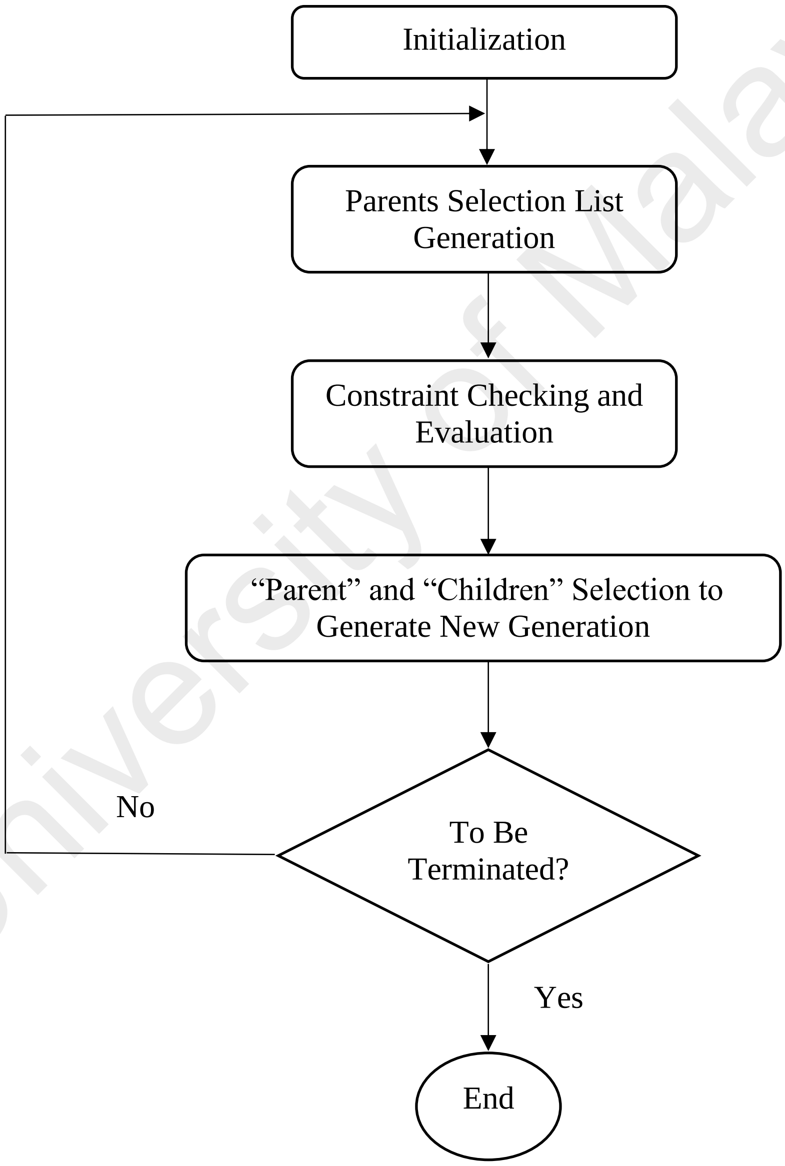

Figure 3.4: Flow Chart of Evolutionary Programming

3.5.1 Initialization

From a random number, the first chromosome for the EP will be generated from assorted number of relay setting. This chromosome is called “Parent”. Because of the input, entire constraints will completely satisfy when sets of the relay settings will selected randomly. From the ‘Parent’ chromosome, the relay setting for every set of information will be filled. During initialization and optimization, the constraint checking must always must be implemented. For achieving discrimination between two relays, there are basic requirement to concern. First, for the circuit breaker time margin is always to maintain. Second is resetting of the relays. The operating time between circuit breaker time margin and relays resetting time must have a specified distinction.

3.5.2 Parent Selection List Generation

At each generation, the calculated objective values of “Parents” are more distinct than the others. When the ideal objective criteria value has in the chromosome of ‘Parent’, those ‘Parent’ have a great change to sustain to live in the set. Then they be able to generate more ideal set of the additional offspring that call “Children”. This style of generation approach is known as Elitism (Geyer-Schulz, 1997). With the improved selection list, the roulette wheel selection by (Geyer-Schulz, 1997) should be used. This process is also called “Mutation”. In this research, the Gaussian function will be used.

3.5.3 Constraint Checking and Evaluation

By using the genetic operation crossover and mutation (Geyer-Schulz, 1997), the reproduction is important method for producing offspring or “Children”. To create the chromosome poll that call “Children”, the individually new offspring that fulfill the criteria required to check and evaluate to give the ideal generation. The adjustment for mutation and crossover must be made and follow with satisfactory factor, then the offspring or "Children" may be improved and better.

The mutation process sometime invents new genetic information and data toward an assorted population. This might also introduce to create a poor quality of chromosomes genetic information. The expectation for the mutation is must no longer to be overemphasized. Furthermore, all the mutated genetic offspring or "Children" will be tried and verify for the fulfillment the constraint criteria. Moreover, which "Children" that have been unsuccessful will be eliminated and rejected to be selected.

3.5.4 "Parent" and "Children" Selection to Generate New Generation

For optimization techniques, there are several typical problems have been discovered. The problem is the objective value is easily affected and the value is depending only to one parameter. At the same time as, the adjustment is required to change the effect of significant outcome in another parameter. GA as well encounter the significant issue. Then, to counter with that similar inconsistencies, the pre-scaling technique was engaged. The OF for every chromosome included the "Parents" must be transformed to raw fitness. This process also known as Fitness Test (FT). Lastly, the final 'Parent' selection must be based on the likely value in the fitness test. (Masters, 1993).

3.5.5 Termination

Mutation progression will stop when the setting value for generations meet setting criteria. This is also known as convergence test. The new evolution process will reiterate again until all the conditions and criteria have been fulfilled. Due to the fact that improvement for every new generation of mutation might be find out rapidly. Extra generations mutation to iterate are preferred. The chromosome pool will be more enhance and the better genetic data will be prepared for next chromosome generation when more iteration happen. the population scale size and the complexity of the system will be the main factor that the specified generation number may be different in any system.

3.6 MATLAB

The method implemented to carry out the research in this work is by using the MATLAB computer software to design algorithms for EP for the radial distribution system study as mention in circuit diagram in Figure 3.1.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Preliminaries

The result that obtain from the book Power System Analysis & Design SI Edition by (Glover et al., 2012) page 533 to 537 will be state in this research to compare and discuss with the result that obtain from the EP algorithm that have been programmed with using MATLAB software. The 60 Hz circuit diagram for the radial network system show as Figure 4.1: -

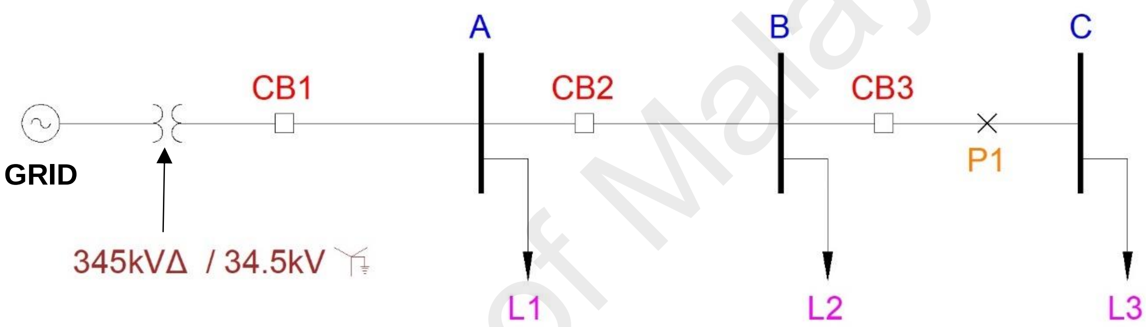

Figure 4.1: Fault at P1 Location

When fault current happens in P1, the calculated value as in Table 4.1 below: -

Table 4.1: Calculated and Selected Tap Setting (TS)

Circuit Breaker	Calculated TS	Selected TS
CB3	2.51	3
CB2	4.18	5
CB1	4.39	5

Refer to the book, the selected CTI for each relay is 0.3 second and the selected TS was selected base on next nearest graph curve from the calculated TS. The graph can be referred as Figure 2.5: -

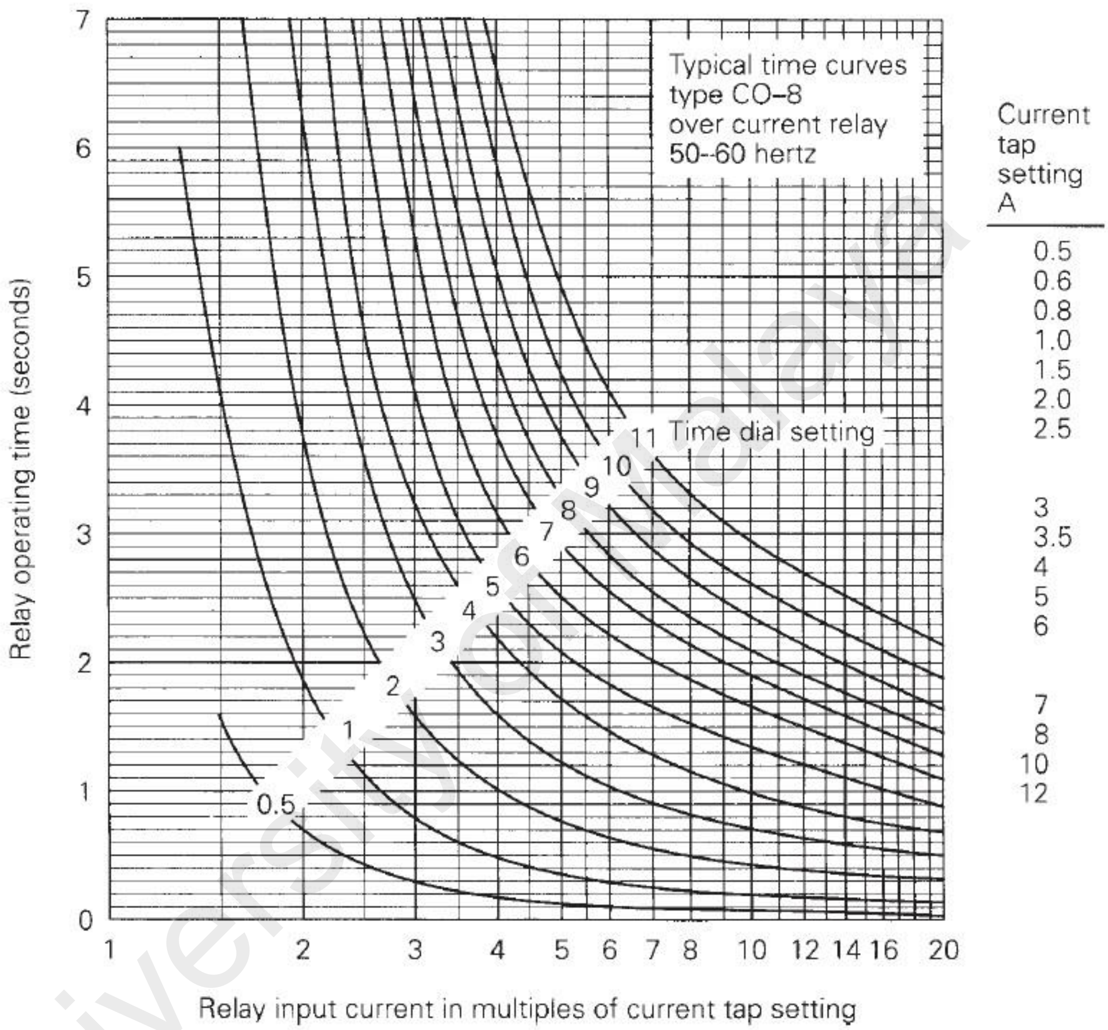

Figure 4.2: Relay Operating Time versus Relay Input Current

Then the TDS was selected base on to clear the fault current as fast as possible. The book was used the TDS term because of the reference relay was used in the calculation is electromechanical relay. The term for TDS is also known as TMS for the numerical relay. Then the selected TDS base on the curve graph as shown in Table 4.2. For every CB, the operating time is 5 cycles and PMS value from the calculation also shown in Table 4.2.

Table 4.2: Value of CB Operation Time, TDS and PSM at Load L2

Circuit Breaker	Circuit Breaker Operating Time, (sec)	Calculated PSM	Selected TMS, (sec)
CB3, (Primary)	0.083	16.7	0.5
CB2, (Backup)	0.083	10.0	2

When the fault current goes through the load L2, the pickup current also different then need to calculate. Then the value as shown in table below: -

Table 4.3: Value of CB Operation Time, TDS and PSM at Load L1

Circuit Breaker	Circuit Breaker Operating Time, (sec)	Calculated PSM	Selected TMS, (sec)
CB2, (Primary)	0.083	15.0	2
CB1, (Backup)	0.083	7.5	3

For the total coordination time for all circuit breaker when the fault happen at P1 location as Figure 4.1 are in table below: -

Table 4.4: Total Coordination Time for All Circuit Breaker

Circuit Breaker	Coordination Time, (Sec)
CB3	0.133
CB2	0.43
CB1	0.76
Total Coordination Time	**1.323**

From the manual calculation as refer to the book, the total coordination time for the all circuit breaker is 1.323 second. This result will be compare with the EP algorithm using MATLAB programming.

4.2 Evolutionary Programming Result

All the similar data have been followed as calculated in methodology section. The calculated value was insert to running the EP algorithm to compare the result. The Gaussian function have been used along with the EP algorithm. The number of population is set to 1000 populations and the maximum iteration number always been set to 500 iterations.

4.2.1 Case Study 1

All the data from the reference book was use back to compare the result with EP optimization.

Then the output result for relay coordination time of EP optimization as Figure 4.3: -

Relay Coordination Time

Relay 1(Sec)	Relay 2(Sec)	Relay 3(Sec)	Total Time(Sec)
0.78	0.378	0.0903	1.249

Time Multiplier Setting Value

TMS Relay 1	TMS Relay 2	TMS Relay 3
0.23	0.15	0.037

Figure 4.3: Optimization Result for EP Case Study 1

When compare with the result as in the Power System Analysis & Design SI Edition, the result for relay coordination time of the EP optimization is better than the previous calculated result. The EP total coordination time is only 1.249 second compare to the coordination time as discussed on reference case is only 1.323 second. This result already achieved and meets the objective that the best time in coordination time for all overcurrent protection relays. The TMS value also more accurate than the value that only base on the curve graph.

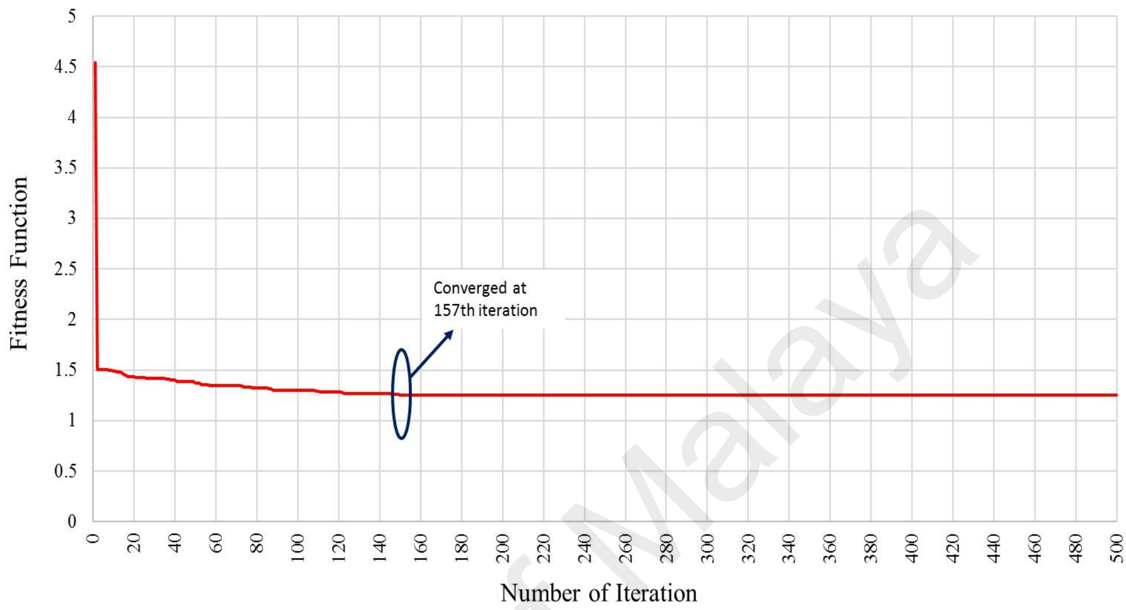

Figure 4.4: Number of Iteration versus Fitness Graph for Case Study 1

Figure 4.4 show the convergence graph for fitness versus number of iteration happen in Case Study 1. The converged is happen at 157th iteration.

4.2.2 Case Study 2

For this case study, the TS value will be change to the calculated value. Then the PSM value is also changed according to the PSM Equation 3.6. The exactly calculated TS value and PSM value stated as in Table 4.5 and Table 4.6. Compared to the Case Study 1 the value of TS are used the next value of the curve graph as Figure 4.2.

Table 4.5: TS Value at 100% and Calculated PSM Value at Load L2

Circuit Breaker	Calculated TS	Calculated PSM
CB3, (Primary)	2.51	19.92
CB2, (Backup)	4.18	11.96

Table 4.6: TS Value at 100% and Calculated PSM Value at Load L1

Circuit Breaker	Calculated TS	Calculated PSM
CB3, (Primary)	4.18	17.94
CB2, (Backup)	4.39	8.54

Then the output result for relay coordination time of EP optimization as Figure 4.5: -

Relay Coordination Time

Relay 1(Sec)	Relay 2(Sec)	Relay 3(Sec)	Total Time(Sec)
0.674	0.337	0.0968	1.074

Time Multiplier Setting Value

TMS Relay 1	TMS Relay 2	TMS Relay 3
0.21	0.14	0.043

Figure 4.5: Optimization Result for EP Case Study 2

From the Figure 4.5, the total relay coordination time is only 1.074 second. This result shown that the optimization coordination for all CB is faster when we compare to the case study 1 and result from the reference data for Study Case 1. When the value of TS change to smaller value, the TMS value also change to get the faster time. However, this result cannot consider the best time for optimization because of the safety factor for the system to trip when fault happen is not included.

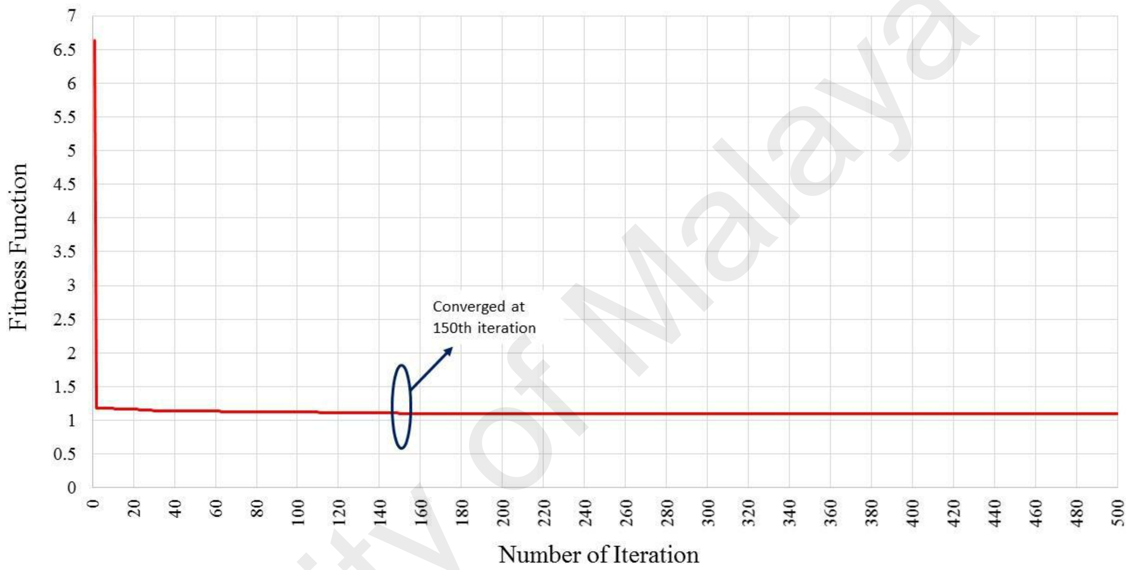

Figure 4.6: Number of Iteration versus Fitness Graph for Case Study 2

Figure 4.6 show the convergence graph for fitness versus number of iteration happen in Case Study 2 and converged at the 150th iteration.

4.2.3 Case Study 3

For this study, the TS value will be added 125% from calculated value. This is because, TS is in steps of 25% with range from 50% to 200%. Then the PSM value also changed according to the PSM Equation 3.6. The exactly calculated TS value and PSM value will be use as in Table 4.5. Compare to the reference book and Case Study 1 that only use the next value in the curve graph as Figure 4.2.

Table 4.7: TS Value at 125% and Calculated PSM Value at Load L2

Circuit Breaker	Calculated TS	Calculated PSM
CB3, (Primary)	3.14	15.92
CB2, (Backup)	5.23	9.56

Table 4.8: TS Value at 125% and Calculated PSM Value at Load L1

Circuit Breaker	Calculated TS	Calculated PSM
CB2, (Primary)	5.23	14.34
CB1, (Backup)	5.49	6.83

Then the output result for relay coordination time of EP optimization from MATLAB software as Figure 4.7: -

Relay Coordination Time

Relay 1(Sec)	Relay 2(Sec)	Relay 3(Sec)	Total Time(Sec)
0.799	0.451	0.0958	1.262

Time Multiplier Setting Value

TMS Relay 1	TMS Relay 2	TMS Relay 3
0.22	0.18	0.039

Figure 4.7: Optimization Result for EP Case Study 3

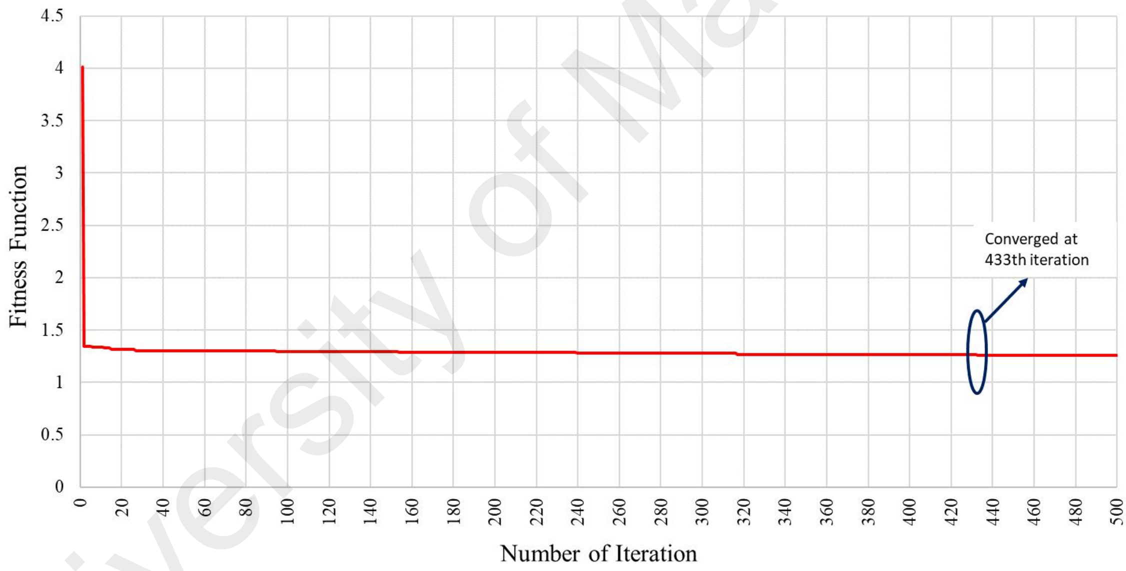

Figure 4.8: Number of Iteration versus Fitness Graph for Case Study 3

Figure 4.8 show the convergence graph for fitness versus number of iteration happen in Case Study 3. The converged happen at 433th iteration.

The total relay coordination time from Figure 4.7 is 1.262 second. For the numerical relay, this is the best possible relay coordination time with TS setting set to 125%.

CHAPTER 5: CONCLUSIONS AND FUTURE WORKS

5.1 Conclusion

From all case study form the result and discussion section, can be concluded that the EP optimization can give the best time coordination between all the overcurrent protection relay in this radial distribution system. The best result recorded in case study 3 that optimizing and give the best possible time coordination for all overcurrent protection relays.

Furthermore, The PSM value also a factor that can give a best optimization coordination time between all the relays. This is can be explained because when the PSM value is more accurate, the TSM value also will be accurate and then can give a better time coordination to all the relays in radial distribution system.

When the plug setting or tap setting (TS) becomes more accurate, the time coordination between overcurrent protection relay become better compare to the reference case study. The TS value is the main factor to optimize the coordination time between all relays in the system. When the TS value is smaller, the total coordination time for all overcurrent protection relay will be faster. The fastest total coordination time cannot be concluded that the system is better. This is because the safety factor also need to be consider to design the ideal case for the protection system.

For the reference case study, the curve graph are used to take the TS value to next nearest curve graph value. Also, this is because the reference case study only uses the electromechanical relay and can only set for the TS and TDS with only an even value.

This also shown that the numerical relay is more accurate in coordination time compare to the electromechanical relay. The numerical relay can give best optimization time and can freely to set what the needed setting for overcurrent protection relay.

For the EP algorithm, the result gain from all the study cases give a better coordination time for all overcurrent protection relay. The optimization time recorded for every relay also better from the reference case study.

The limitation of the EP algorithm is, when the population number is large, the EP will take more time to give the output result for this research. This is because the EP algorithm will check one by one number and only take the best random number between the best. Furthermore, the EP take the random number in the algorithm to be a parent and children to do the iteration until the fitness is converged.

However, all the objectives are archive and the best coordination time between the overcurrent protection relay in electrical radial distribution system using Evolutionary Programming Optimization already meet the best result for this research.

5.2 Future Work

Future work will be work on the electrical ring distribution system with a large number of overcurrent protection relays and large number of power sources and buses. Also, will be work on more complex electrical distribution system design nowadays.

The others algorithm programming for metaheuristic optimization also can be chosen that can do faster output result and accurate results to more complex electrical distribution system.

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