OPTIMAL RECLOSER PLACEMENT FOR IMPROVING DISTRIBUTION SYSTEM RELIABILITY USING PARTICLE SWARM OPTIMIZATION

NUR AFIFAH AUNI BINTI MOHD NASIR

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

2017

OPTIMAL RECLOSER PLACEMENT FOR IMPROVING DISTRIBUTION SYSTEM RELIABILITY USING PARTICLE SWARM OPTIMIZATION

NUR AFIFAH AUNI BINTI MOHD NASIR

RESEARCH PROJECT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR DEGREE OF MASTER ENGINEERING (POWER SYSTEM ENGINEERING)

FACULTY OF ENGINEERING

UNIVERSITY OF MALAYA

KUALA LUMPUR

2017

UNIVERSITY OF MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: **NUR AFIFAH AUNI BINTI MOHD NASIR**

Matric No: **KQI160004**

Name of Degree: **POWER SYSTEM ENGINEERING**

Title of Project Paper/Research Report/Dissertation/Thesis ("this Work"):

OPTIMAL RECLOSER PLACEMENT FOR IMPROVING DISTRIBUTION SYSTEM USING PARTICLE SWARM OPTIMIZATION

Field of Study: **POWER SYSTEM**

I do solemnly and sincerely declare that:

(1) I am the sole author/writer of this Work;
(2) This Work is original;
(3) Any use of any work in which copyright exists was done by way of fair dealing and for permitted purposes and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this Work;
(4) I do not have any actual knowledge nor do I ought reasonably to know that the making of this work constitutes an infringement of any copyright work;
(5) I hereby assign all and every rights in the copyright to this Work to the University of Malaya ("UM"), who henceforth shall be owner of the copyright in this Work and that any reproduction or use in any form or by any means whatsoever is prohibited without the written consent of UM having been first had and obtained;
(6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature Date:

Subscribed and solemnly declared before,

Witness's Signature Date:

Name:

Designation:

ABSTRACT

Growing energy demand leading to increase attention to adequate reliability and efficient protection of electrical system. Improving the reliability can increase customer satisfaction. System reliability of distribution network improved by installing optimal number and location of protective equipment which is recloser. Since recloser can reduce the number and duration of power outages in the distribution system, this thesis presents optimal recloser placement which can reduce the reliability indices, System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI). The optimization method is solved using Particle Swarm Optimization (PSO) algorithm that has gained much popularity among researchers since after its introduction. The Roy Billinton Test System (RBTS) had been used for studying the impact of optimal recloser placement to the distribution system reliability. In order to investigate the impact of different number of optimal recloser placement, up to six number of recloser are used in this project. From the simulation, PSO has successfully obtained the location of recloser based on minimum value of SAIFI and SAIDI.

ABSTRAK

Permintaan tenaga yang semakin meningkat menyebabkan peningkatan perhatian terhadap kebolehpercayaan dan perlindungan untuk sistem elektrik. Meningkatkan kebolehpercayaan dapat meningkatkan kepuasan pelanggan. Kebolehpercayaan sistem rangkaian pengedaran ditingkatkan dengan memasang nombor dan lokasi yang sesuai dengan peralatan pelindung yang merupakan penutup semula. Oleh kerana penutup semula boleh mengurangkan bilangan dan tempoh gangguan kuasa dalam sistem pengedaran, tesis ini membentangkan penempatan penutup semula optimum yang boleh mengurangkan indeks kebolehpercayaan, Sistem Purata Gangguan Kekerapan Indeks (SAIFI) dan Sistem Purata Gangguan Tempoh Indeks (SAIDI). Kaedah pengoptimuman diselesaikan menggunakan algoritma Pengoptimuman Kawanan Partikel (PSO) yang telah mendapat banyak populariti di kalangan penyelidik sejak selepas pengenalannya. Roy Billinton Test System (RBTS) telah digunakan untuk mengkaji kesan penempatan penutup semula optimum kepada kebolehpercayaan sistem pengedaran. Untuk menyiasat kesan bilangan penempatan penutup semula optimum yang berbeza, sehingga enam bilangan penutup semula digunakan dalam projek ini. Dari simulasi, PSO telah berjaya memperoleh lokasi peninjau berdasarkan nilai minimum SAIFI dan SAIDI.

ACKNOWLEDGEMENTS

First of all, I would like to express the deepest appreciation to my research project supervisor, Prof. IR. DR. Hazlie Mokhlis, who has guided me throughout the whole research project period. Without her guidance and persistent help, my research project would not have been possible and of course I will not be able to gain knowledge and experience from the research project too.

My appreciation also goes to family and friends who giving me morale support, shared a lot of knowledge, ideas and their opinion throughout the completion of research project. Without their support, I won’t be able to have such courageous and ambitious to overcome the hard time and finish this complicated research project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

CAIDI : Customer Average Interruption Duration Index

E : Energy

kV : Kilo Volt

MW : Mega Watt

PSO : Particle Swarm Optimization

SAIDI : System Average Interruption Duration Index

SAIFI : System Average Interruption Frequency Index

U : Unavailability

λ : Failure rate

r : Outage time

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1 Introduction

The necessity to provide reliability in distribution system and in power can be defined as the system capability in generation, transmission and distribution of electrical energy to the consumers. The main factors to judge system reliability in the distribution part are frequency of occurrence of terminations and interruptions and the time period of termination which may resulting customer dissatisfaction. Improving the reliability can increase customer satisfaction, prevent additional costs caused by power outages and improve the economic performance. Other factor that contribute in reduction of network reliability such as disorder and distribution by third part are atmospheric and environmental condition such as temperature, humidity, lightning and storms. Therefore, determine the optimal recloser placement in distribution network can maximize the system reliability and establishing its continuity when fault occurs.

Recloser is a switching and protective equipment in distribution system used to expedite fault isolation and system reconfiguration is installed on overhead lines and can reduce the number or duration of power outages in the distribution network. It handle any fault that occurs in the distribution network either permanent and temporary faults. Statistics from power outages show that more than 70 percent of interruptions in overhead lines are caused by transient faults. Any transient fault on the main or subsidiary lines, a recloser cut out the power of its downstream line and isolates the faulty section and power supply by the upstream line do not suffer from power interruption. Then, recloser reconnects the network as soon as line status becomes normal. The advantages of using recloser are not limited to control transient faults, it also affect the impact of permanent faults on consumers. When fault occur at the downstream line, the recloser has a permanent nature. After a number of switching, recloser keeps its switch in open position and thus prevent any interruption in power supply to customers using its upstream line. Thus, these increase system reliability that provided to customers by reducing the number and duration of outages in the section of network where it is installed.

Reliability can be defined as the ability of system to provide an adequate supply of electrical energy. The reliability evaluation is normally based on indices that represent the reliability of the system. These reliability indices define as the system ability to supply electrical energy to the load points in the system. The indices can describe either for separate load points or for overall of system. Typically, power system in industries use standardized indices such as SAIFI, SAIDI and CAIDI. System Average Interruption Frequency Index (SAIFI) is defined as the expected number of interruptions of supply for an average customer in the system. System Average Interruption Duration Index (SAIDI) is defined as the expected unavailability of supply for an average customer in the system. Then, Customer Average Interruption Duration Index (CAIDI) described as the expected unavailability of supply for an average customer in the system per expected number of interruptions of supply for an average customer in the system.

1.2 Problem statement

Installation protective equipment of recloser on the distribution network reduces the duration of outages and improves system reliability. However, high of equipment purchase, installation cost and maintaining recloser encourages to optimize their location placement. Different allocation of recloser will provide different reliability indices. What is the best location of recloser placement to maximize the system reliability? Hence, the optimization method must be apply to find the best recloser location in the distribution system.

1.3 Objectives

The objectives of this project are:

1) To propose Particle Swarm Optimization technique to find optimal recloser placement in distribution system.

2) To analyze the impact of optimal recloser placement to the distribution system reliability.

3) To investigate the impact of different number of optimal recloser placement to the distribution system reliability.

The aim of this project to analyze the impact of optimal recloser placement to the distribution system reliability. The Particle Swarm Optimization (PSO) is apply to optimize the best location of recloser that can maximize the reliability power system. The algorithm will be implemented in MATLAB.

1.4 Scope of project

Scope of the project are based on following consideration:

i. Index consideration

The power system in industries use standardized indices such as SAIFI, SAIDI and CAIDI. However, in this project reliability index of SAIFI and SAIDI had been simulated.

ii. Test system consideration

The Roy Billinton Test System (RBTS) bus 5 test system was used to study the impact of optimal recloser placement to the distribution system reliability.

iii. Maximum recloser consideration

Different allocation of recloser provide different reliability indices and directly maximize the reliability. In order to analyze the impact of recloser based on reliability index, there are six number of recloser used in this project.

iv. Optimization method consideration

In order to find the best location of recloser, Particle Swarm Optimization (PSO) is apply to RBTS bus 5 test system which implemented in the MATLAB software.

1.5 Thesis organization

The organization of the thesis are breaks down into several chapters accordingly in order to present the thesis in more clearly and organized ways. There are four chapters in this thesis which involved Introduction, Literature Review, Methodology, Results and Discussion, and Conclusion.

Chapter 1 presented the introduction to the project. The background and the basic ideology of the project will be briefly explained and discussed inside. Besides that, problem statement, scope of the project and the objectives of project will also be stated in this chapter.

Chapter 2 consists of literature review of the project in which other researcher finding and work which related to the project will be reviewed as references inside this chapter. The basic concept of power reliability evaluation and distribution recloser will be discussed in this chapter. Meanwhile, a review of main power system model which is Roy Billinton Test System (RBTS) bus 5 will be stated in this chapter.

Chapter 3 is the methodology of the project which presented all the steps required to set up the project to success it. Before evaluating MATLAB coding, several calculations of reliability indices have been show. The process of algorithm in details will be involved in this chapter.

Chapter 4 present the results and discussion of the project from simulation based on case study. There are two case studies which are to analyze the impact of optimal recloser placement to the distribution network system reliability and to investigate the impact of different number of optimal recloser placement to the distribution system reliability. Summarizing and analyzing of collected data will draw conclusion on the project will help to determine the achievement and successfulness of the project.

Chapter 5 is the conclusion of the project which will summarize all the finding. Future recommendation of the research is included in this chapter as it is important to improve the quality for the future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

A modern electrical power system has to supply electrical energy either large or small as economically with an acceptable degree of reliability to customer. This is because of pattern social and working habits has to supply electrical energy continuously. Therefore, power utilities has to provide uninterrupted power supply to their customers. In power system design and operation, maintaining a reliable power supply is very important aspect.

There are two important aspects in order to obtain the highest possible system reliability which are continuity, quality of supply and reliability assessment. Reliability assessment consist of planning, design, control, operation and maintenance of electrical power system network. Reliability in power system is ability of the system to provide an adequate supply of electrical energy. Many issues in power system that significantly affected by a large scale of outage events such as incorrect planning, operational error, equipment failures, weather effects, environmental conditions and load locations.

2.2 Basics of power system reliability

The term of reliability mentions to the ability of a component or a system to achieve its intended functions under stated conditions for a specified period of time. Then, evaluation in power system refers to analyze the ability of the system to accomplish the load demands (Lindsay & Parvathy). Besides that, North American Electric Reliability Corporation (NERC) defines reliability in power system as the degree to which the performance of the electrical system results in power being supplied to customers within accepted standards and in the amount preferred.

Power system reliability can be divided to two categories which are system security and system adequacy. System security is the ability of the system to respond perturbations arising within a system and system adequacy refers to presence of sufficient facilities within a system to meet system load demand. Figure 2.1 shows system reliability evaluation. The reliability evaluation is conducted either system adequacy or system security. Mostly conducted in system adequacy since these concept not independent each other.

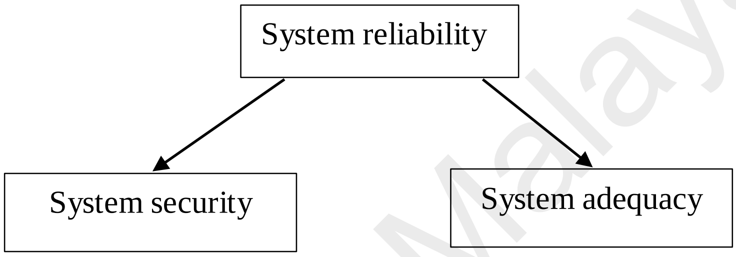


Figure 2.1: System reliability evaluation

Overall power system in planning and operation, reliability evaluation of generation, transmission and distribution facilities is a necessity. There are many advantages related with the ability to perform overall system reliability evaluation. (Billinton & Jonnavithula, 1996) have presents educational test system by studying the concept of overall power system reliability. The paper covers an existing test system by developing the necessary distribution and sub transmission networks. The extended test system has all the main facilities such as generation, switching stations, transmission, sub transmission and radial distribution network found in practical system. Nowadays, it is important concern in electric utility environment by providing acceptable customer service in overall power system reliability evaluation.

2.2.1 Reliability indices

System reliability indices show the performance of distribution system or shortcomings of the system in form of average number of interruptions and the average outage duration (Gludpetch & Tayjasant, 2013). Reliability indices are measures power quality and it is standardized indices that generally used in industry of distribution system.

1) System average interruption frequency index

$$SAIFI = \frac{\sum \lambda_i N_i}{\sum N_T} \tag{2.1}$$

2) System average duration frequency index

$$SAIDI = \frac{\sum U_i N_i}{\sum N_T} \tag{2.2}$$

3) Customer average interruption duration index

$$CAIDI = \frac{SAIDI}{SAIFI} = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \tag{2.3}$$

Where N_i is the number of interrupted customers of load point i, N_T is total number of customer, λ_i is the failure rate of customers i and U_i refers to the outage time of customer i. Then, CAIDI can be defined as the average time required to restore service to the average of the customer divided by sustained interruption.

2.2.2 Symmetrical and Unsymmetrical fault

Symmetrical and unsymmetrical fault are types of fault in power system. At nominal values or states, electrical fault is the deviation of voltages and currents. Power system in safer operation when carry normal voltage and current to the line or equipment. However, excessive high current will flow when fault occurs can damage the equipment and devices. Therefore, fault detection and analysis is important to design suitable equipment and devices.

1) Symmetrical fault

These also called balanced faults and less common faults that occur in power system. If these fault occur, system is still balanced but result in severe damage to the electrical power system equipment and devices. There are two types of three phase symmetrical fault which are line to line to line to ground (L-L-L-G) and line to line to line (L-L-L). Analysis of these fault is easy and usually carried by per phase basis. Figure 2.2 shows the symmetrical fault.

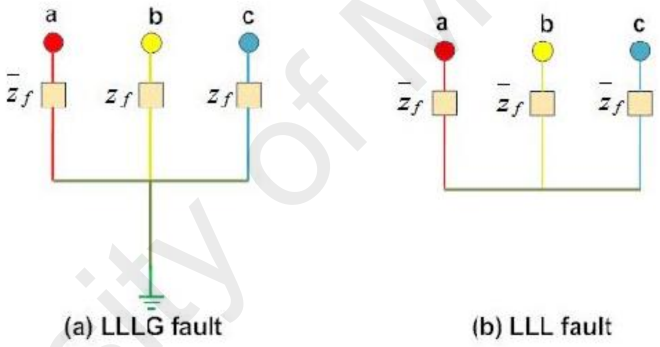


Figure 2.2: Symmetrical fault

2) Unsymmetrical fault

These faults are very commonly occur in power system which are also called unbalanced fault. Unbalance of the system refers to the impedance values that are different in each phase causing unbalance current to flow in the phases. There are three types of unsymmetrical faults which are line to ground (L-G), line to line (L-L) and double line to ground (LL-G). Most common line to ground (L-G) fault occurs of this type. Analysis of these fault are more difficult and similar to three phase balanced faults that carried by per phase basis. Figure 2.3 shows unsymmetrical fault.

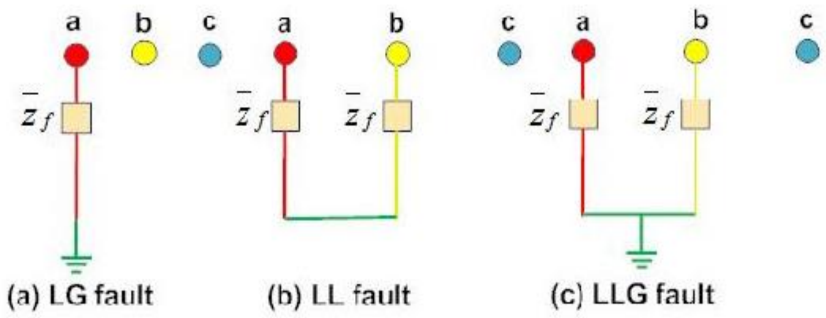


Figure 2.3: Unsymmetrical fault

2.2.3 Impacts of electrical faults

1) Overcurrent flow

A low impedance path for the current flow was created when fault occurs. Resulting high current have been drawn from the supply and causes tripping of relays, damaging insulation and components of the equipment.

2) Risk to operating personnel

Fault occur can cause shocks to individuals and even may lead to death. Severity of the shock depends on the current and voltage at fault location.

3) Damage equipment and device

Due to short circuit current, excessive current result in components being burnt completely which leads to incorrect working of equipment or device. Sometimes the equipment burn out caused by fire.

4) Interrupts connected active circuits

Faults not only affect at the location occur but also interrupts the active interconnected circuits to the faulted line.

5) Electrical fires

A fire from short circuit cause by flashovers and sparks due to ionization of air between two conducting paths.

2.3 Recloser allocation and placement in distribution system

Recloser is the switching device in major distribution system used to expedite fault isolation and system reconfiguration. It combines with circuit breaker to trip if short circuit occur in a section of the network. It has electronically controlled function and after fault is clear, quickly it restores power to the affected line.

2.3.1 Hierarchical structure of recloser

The arrangement of reclosers by a utility can be described as a three hierarchical structure process. Figure 2.4 shows hierarchical structure of recloser. The first level allocates the recloser to small area based on statistical information. The second level optimize the placement of recloser based on comprehensive topology of the feeders in each area and the third level deals with detailed coordination of recloser and other devices. In order to minimize value of reliability indices, limited number of recloser will be allocated (Qin & Wu, 2015).

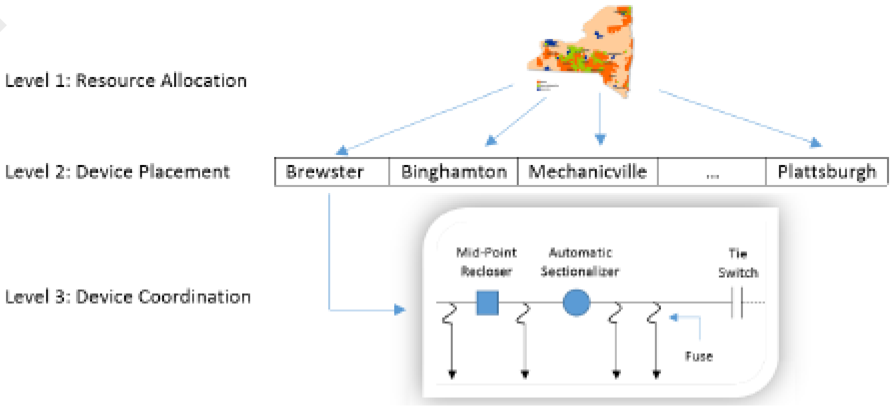


Figure 2.4: Hierarchical structure of recloser (Qin & Wu, 2015)

2.3.2 Improve system reliability with recloser

According to (Qin & Wu, 2015), the most topology of rural distribution system are radial networks. As shown in Figure 2.5 shows a typical radial feeder in rural area which consist one main feeder and several lateral feeders. A fuse is installed at each of lateral feeders. This typical model will be used to study the improvement on system reliability by placing recloser. Usually, recloser eliminates disruption caused by temporary fault.

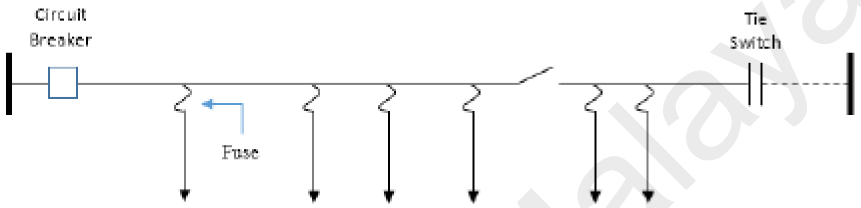


Figure 2.5: Typical model radial feeder in rural area (Qin & Wu, 2015)

In general, reclosers should be set up with higher priority at the main feeder. The fuse must isolate the fault without causing continual interruption on the main feeder and other lateral feeders when each lateral feeder is equipped with a fuse for a sustained fault at lateral feeder. For example recloser is installed at the substation or the substation breaker is capable for reclosing, a fault at lateral feeder will always have the same effect on SAIFI and SAIDI regardless of where the reclosers are installed on the main feeder.

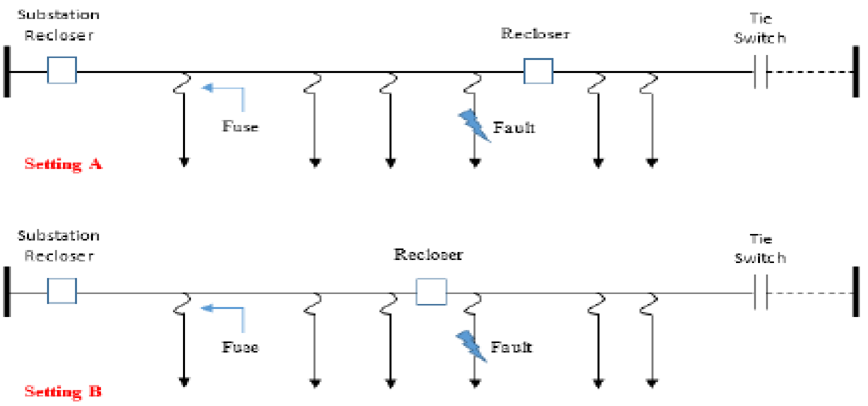


Figure 2.6: Different recloser setting at faulted lateral feeder (Qin & Wu, 2015)

Figure 2.6 shows fault occurs at lateral feeder and both setting A and setting B have same sustained interruption. Only customers on the faulted lateral feeder will be interrupted although the momentary fault will be different. Therefore, value of SAIFI can be calculated by adding SAIFI at main feeder ($SAIFI_M$) and SAIFI at lateral feeder ($SAIFI_L$).

$$SAIFI = SAIFI_M + SAIFI_L \tag{2.4}$$

Where,

$$SAIFI_M = \frac{\sum \lambda_{i,main} N_i}{\sum N_i}, \; SAIFI_L = \frac{\sum \lambda_{i,lateral} N_i}{\sum N_i} \tag{2.5}$$

For *i*th feeder, $\lambda_{i,main}$ is the interruption rate corresponding to failure at main feeder, $\lambda_{i,lateral}$ is the interruption rate corresponding to failure at lateral feeder, N_i is the number of customers. Note that, failures at the *i*th lateral feeder only causes interruptions on the *i*th feeder.

Recloser installed at the main feeder improve SAIFI by reducing $\lambda_{i,main}$, while $\lambda_{i,lateral}$ is remain the same. This show that only faults at main feeder will cause different impact on SAIFI and SAIDI for different recloser configuration on the main feeder. The expression for SAIDI can be obtained similarly (Qin & Wu, 2015).

2.3.3 Impacts on CAIDI by using recloser

According to (Tippachon & Rerkpreedapong, 2009), placement of recloser is not giving any impact to the CAIDI. Using reclosers limits the number of customer being interrupted but interruption duration is not affected. Usually, CAIDI depends on the repair time of fault. In some cases, when upgrading devices on feeders by replacing manual switches by reclosers, CAIDI can increase after installing reclosers. This is because the reclosers eliminate the interruptions caused by manually operating the switches. In general, distribution automation increases the system reliability by eliminating small interruptions, which results in longer average interruption durations. The most effective way to improve CAIDI is to improve the repair or recovery process for sustained faults not by installing new reclosers. Therefore, this project only focus on SAIFI and SAIDI.

2.3.4 A review on recloser placement

(Hashemi et al., 2016) proposed a genetic algorithm to determine the optimal number and placement of switching and protective equipment such as sectionalizers, fuses and recloser in distribution network. The duration of the outages distribution network reduced when installed switching and protective devises. Thus, maximized reliability network. However, high cost of some these devices encourages any attempt to optimize their number and placement. The success of any recovery operation in distribution network depends on the number and placement of these devises. Therefore, determining the optimal position of the equipment on a network can improve efficiency of recovery operations and increase the reliability of distribution network.

(Dehghani & Dashti, 2011) have presented simple method for placing an optimal number of recloser. Authors solved that optimization by genetic algorithm. Most of the outages events by customers are caused by electrical distribution failures. In order to reduce interruption events, increasing network reliability is necessity. Distribution network automation can trim down outage events and increase system reliability. Network automation has to be done using optimization approaches. Installation of recloser is required to increase reliability in transmission of electrical energy and establishing it continuity. There are two views in the positioning recloser in the system:

1) Positioning of recloser from the view of cost reduction.

2) Positioning of recloser in order to reduce transient faults, reduction of undistributed energy and customers satisfaction.

(Qin & Wu, 2015) determined the impact of installing reclosers in rural distribution network in term of reliability indices, SAIFI and CAIDI. SAIFI indicates the number of interruption that a customer would experience each year and CAIDI indicates the duration that a customer would experience for an interruption. This paper focused on minimizing value of SAIFI. CAIDI not affected by placement of recloser because generally recloser limits the number of customer being interrupted but the interruption duration is not affected. CAIDI mainly depends on the repair time of fault. The allocation and placement is demonstrated on the Roy Billinton Test System (RBTS).

(Falah, Hajivand, Karimi & Reihaneh, 2014) have presented simple Differential Evolutionary (DE) algorithm to solve optimal recloser placement. A recloser is a device with the functions to detect phase and phase to earth overcurrent conditions, interrupt the circuit if the overcurrent persists after a predetermined time, and automatically reclose to reenergize the line. If the fault that originated the operation still exists, then the recloser will stay open after a reset number of operations, thus isolating the faulted section from the rest of the system. The proposed objective function in this has been formulated to improve four reliability indices which are System Average Interruption Duration Index (SAIDI), Cost of Energy Not Supplied (CENS), Average Interruption Frequency Index (MAIFI) and System Average Interruption Frequency Index (SAIFI).

2.4 Reliability test system

The Roy Billinton Test System (RBTS) is a basic reliability test system. The RBTS is a 6 bus test system with five load buses (bus 2- bus 6). Bus 2 and Bus 4 are mixed commercial and residential distribution networks. Bus 3 represents a network for typical and large users. Bus 5 is a typical urban type network and Bus 6 indicates typical rural area network. It has eleven generators and nine transmission lines. The installed capacity is 240 MW and peak load of the system is 185 MW. This system has five voltage levels which are 230 kV, 138 kV, 33 kV and 11 kV (Billinton & Jonnavithula, 1996). The overall and complete single line diagram of the RBTS as shown in Figure 2.7.

The design of these distribution networks follow general utility principles and practices regarding topology, ratings and loading levels (Gonen, 1986). The developed sub stations for these distribution networks are as shown in Figure 2.7. The failure rates and repair durations of the various distribution components such as transformers, breakers, bus bars, and feeder sections follows the same data presented in (Allan, Billinton, Sjarief, Goel & So, 1991). A wide range of reliability indices can be calculated for the radial distribution networks at buses 3, 5 and 6. These are both load point and system indices. Load point indices include failure rate (λ), outage time (r), annual unavailability (U) and energy not supplied (E). Table 2.1 shows customer data of the system.

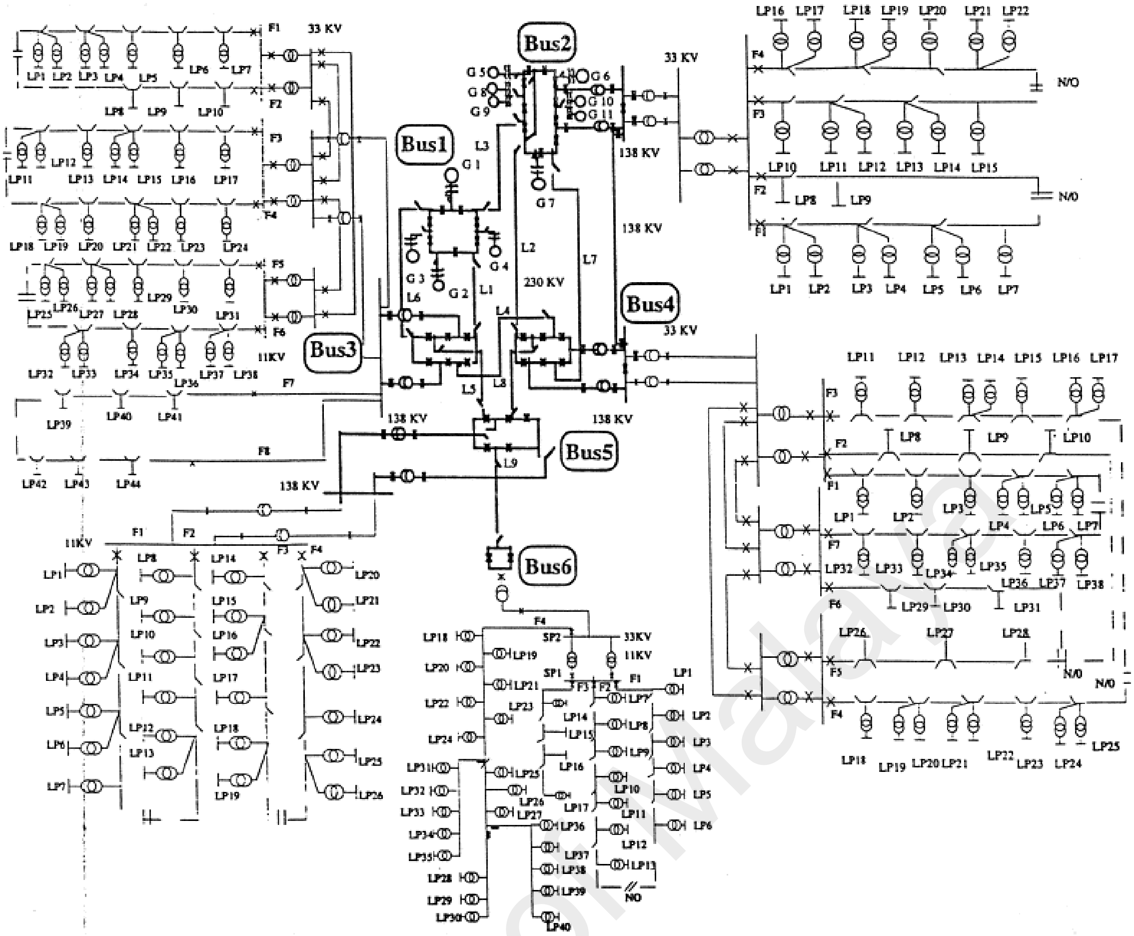
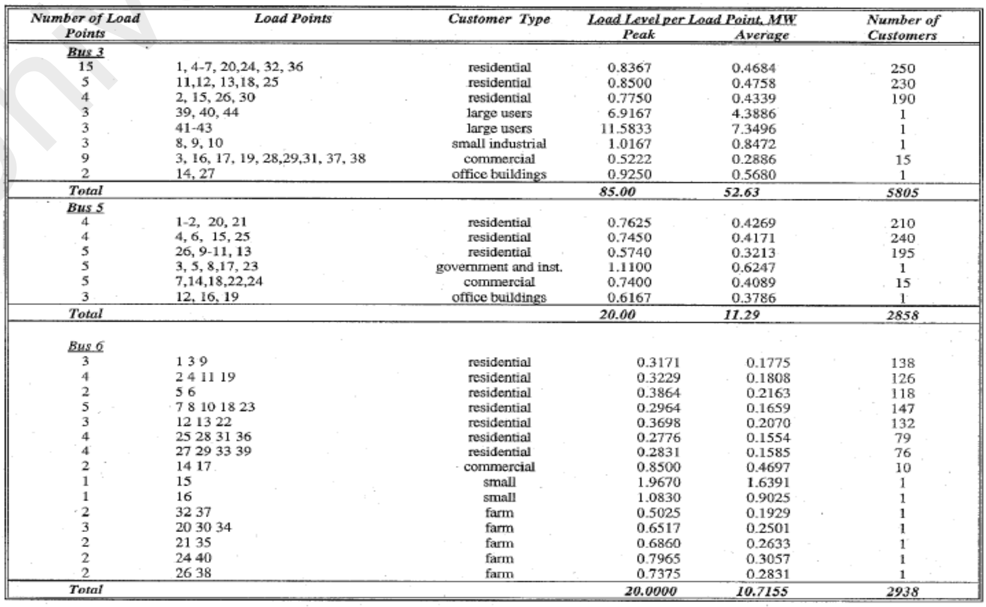


Figure 2.7: Overall and complete single line diagram of the RBTS (Billinton & Jonnavithula, 1996)

Table 2.1: Customer data (Billinton & Jonnavithula, 1996)



Number of Load Points	Load Points	Customer Type	Load Level per Load Point, MW Peak	 Average	Number of Customers
Bus 3					
15	1, 4-7, 20,24, 32, 36	residential	0.8367	0.4684	250
5	11,12, 13,18, 25	residential	0.8500	0.4758	230
4	2, 15, 26, 30	residential	0.7750	0.4339	190
3	39, 40, 44	large users	6.9167	4.3886	1
3	41-43	large users	11.5833	7.3496	1
3	8, 9, 10	small industrial	1.0167	0.8472	1
9	3, 16, 17, 19, 28,29,31, 37, 38	commercial	0.5222	0.2886	15
2	14, 27	office buildings	0.9250	0.5680	1
Total			*85.00*	*52.63*	*5805*
Bus 5					
4	1-2, 20, 21	residential	0.7625	0.4269	210
4	4, 6, 15, 25	residential	0.7450	0.4171	240
5	26, 9-11, 13	residential	0.5740	0.3213	195
5	3, 5, 8,17, 23	government and inst.	1.1100	0.6247	1
5	7,14,18,22,24	commercial	0.7400	0.4089	15
3	12, 16, 19	office buildings	0.6167	0.3786	1
Total			*20.00*	*11.29*	*2858*
Bus 6					
3	1 3 9	residential	0.3171	0.1775	138
4	2 4 11 19	residential	0.3229	0.1808	126
2	5 6	residential	0.3864	0.2163	118
5	7 8 10 18 23	residential	0.2964	0.1659	147
3	12 13 22	residential	0.3698	0.2070	132
4	25 28 31 36	residential	0.2776	0.1554	79
4	27 29 33 39	residential	0.2831	0.1585	76
2	14 17	commercial	0.8500	0.4697	10
1	15	small	1.9670	1.6391	1
1	16	small	1.0830	0.9025	1
2	32 37	farm	0.5025	0.1929	1
3	20 30 34	farm	0.6517	0.2501	1
2	21 35	farm	0.6860	0.2633	1
2	24 40	farm	0.7965	0.3057	1
2	26 38	farm	0.7375	0.2831	1
Total			*20.0000*	*10.7155*	*2938*

2.4.1 Reliability assessment at HLIII

Overall (HLIII) power system reliability is concerned with assessment at the actual customer level. Customer satisfaction is an important concern in today electric power utility environment. This requirement should be incorporated in both graduate and undergraduate lecture courses dealing with power system reliability evaluation. HLIII assessment incorporates the three functional zones of generation, transmission and distribution in the analysis (Billinton & Jonnavithula, 1996).

(Billinton & Jonnavithula, 1996) have presented the HLIII reliability assessment includes the independent outages of generating units, transmission lines, outages due to station originated failures, sub transmission and radial distribution element failures.

Figure 2.8 shows distribution system for RBTS bus 5. Table 2.2 shows base case reliability indices for radial distribution network at bus 5 and Table 2.3 shows a radial distribution system indices. This thesis focused on optimal recloser placement for improving distribution system reliability using Particle Swarm Optimization (PSO) at bus 5. All the data of bus 5 is used to analyze the impact of recloser placement in distribution network based on reliability indices. Additionally, it also used to investigate the impact of different number recloser placement in system reliability.

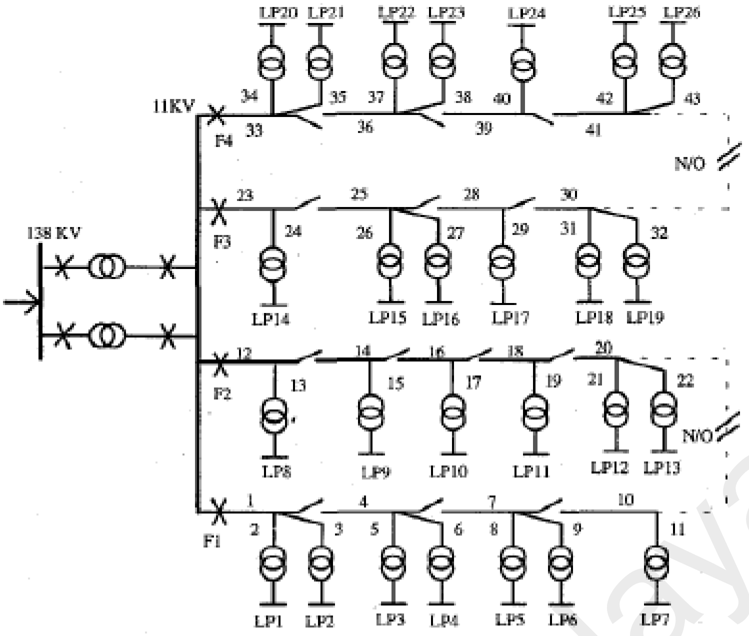
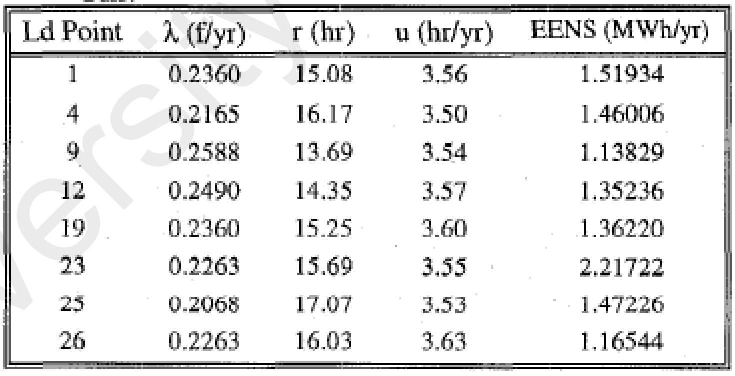


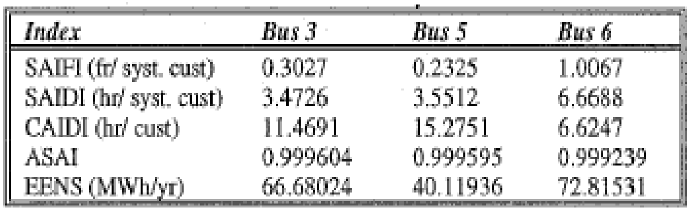
Figure 2.8: Distribution system for RBTS bus 5 (Billinton & Jonnavithula, 1996)

Table 2.2: Base case reliability indices for radial distribution network at bus 5 (Billinton & Jonnavithula, 1996)



Ld Point	λ (f/yr)	r (hr)	u (hr/yr)	EENS (MWh/yr)
1	0.2360	15.08	3.56	1.51934
4	0.2165	16.17	3.50	1.46006
9	0.2588	13.69	3.54	1.13829
12	0.2490	14.35	3.57	1.35236
19	0.2360	15.25	3.60	1.36220
23	0.2263	15.69	3.55	2.21722
25	0.2068	17.07	3.53	1.47226
26	0.2263	16.03	3.63	1.16544

Table 2.3: Radial distribution system indices



Index	*Bus 3*	*Bus 5*	*Bus 6*
SAIFI (fr/ syst. cust)	0.3027	0.2325	1.0067
SAIDI (hr/ syst. cust)	3.4726	3.5512	6.6688
CAIDI (hr/ cust)	11.4691	15.2751	6.6247
ASAI	0.999604	0.999595	0.999239
EENS (MWh/yr)	66.68024	40.11936	72.81531

2.5 Overview of Particle Swarm Optimization (PSO)

The concept of particle swarms is originated by a social psychologist, Kennedy and an electrical engineer, Eberhart to develop the idea of computational intelligence, utilizing the existing natural interactive systems. The first simulations are influence by social behavior and involved analogues of bird flocks searching for corn (Kennedy & Eberhart, 1995). This soon developed into a powerful optimization method which is Particle Swarm Optimization (PSO). PSO attempts to mimic the goal seeking behavior of biological swarms.

PSO algorithm is one of nature inspired techniques for distributed generation allocation. It also one of the heuristic methods used by researchers to solve many problems related to power systems. The basic idea of the PSO is based on the social behavior (foraging) of organisms such as fish (schooling) and bird (flocking). The birds or fish will move to the food in certain speed or position. Their movement will depend on their own experience and experience from other ‘friends’ in the group which are Pbest and Gbest (Wardiah & Hazlie, 2012).

According to (Gludpetch & Tayjasant, 2013), PSO is the population based search algorithm and initialized with the population of random solutions, called particles. Kennedy and Eberhart who were the first introduced this algorithm (Mohamed & Abdelaziz, 2013). The concept of PSO is based on the metaphor of social interaction, such as a flock of bird migration. Each particle has conceptual as moving point in search space. They are drawn stochastically toward the positions of their own and their neighbour last best performance. The former is local best or called Pbest. The latter is a global value or called Gbest.

In PSO algorithm, the collection of particles in search space aim to optimize a fitness function, in a way similar to movement of flocks of birds in natural environment in search of food. The particles are placed randomly in search space and they evaluate their quality or fitness at that position. Then, for a predefined number of iterations, each particle moves to a new location which gives better fitness than the previous position. This movement is based on the history of particles own best and current locations with those of the best positions attained by other particles in the swarm, with some random perturbations. Thus in subsequent iterations the swarm achieves the most optimum solution to the fitness function in the problem space, with a defined number of particles working together. The fitness or objective function in PSO algorithm is a performance evaluation criterion that depends on the application area of the algorithm. The performance criterion is usually defined by a mathematical formulation to quantify the system performance achieved through a performance index (Juneja & Nagar, 2016).

2.5.1 Particle Swarm Optimization algorithm

The basic particle swarm optimization algorithm consists of a swarm of 'n' particles and the position of each particle represents a possible solution of the fitness function in D-dimensional search space. The particle changes its condition under the influence of three factors:

1) Its own inertia.
2) Personal most optimal position.
3) Swarm's most optimal position.

The velocity update in PSO consists of three parts:

1) Momentum: It represents the tendency of particle to move in the same direction as it was moving in the previous iteration. It incorporates the effect of previous velocity on current velocity of the particle.

2) Cognitive part: It represents the pull to particle velocity towards its own personal best (Pbest). Referred to as memory, self-knowledge or remembrance.

3) Social part: It represents the pull to particle velocity towards swarm best (Gbest). Referred to as cooperation, social knowledge or shared information.

2.5.2 Theory of initialization Particle Swarm Optimization algorithm

1) Inertia weight

In the search space particle velocity on every dimension is fasten on a maximum velocity (Vmax). This maximum velocity determines the resolution or determined with which regions between the present position and the target position can be sorted out (Qinghai Bai, 2010). However, the use of hard bounds presents some problems. For instance if Vmax is too high then particles might slip away from some good food locations, whereas if Vmax is too low then some good distant location will always be out of reach. Thus, in order to reduce the importance of Vmax, and better to say in order to knock out it altogether, and to sharpen the foraging ability of particles, a weight term was added to the PSO update equations. This weight term is called inertia weight (w) and it controls the effect which the last iteration speed has on the current speed. Larger value of w improves global search capability and smaller value of w improves the partial search capability of PSO algorithm. Generally, it is equal to 1, but eventually the search ability decreases and the particle get stuck at a non-optimum location. In experimental work, w is kept in between 0.9 to 0.4 and the values are decreased linearly so that the algorithm allows the particles to explore wider areas in beginning and nearby areas in later stages with reduced speeds. This setting gives a greater likelihood of reaching the target optimum position quickly.

2) Acceleration constant c_1 and c_2

These constants are related to the speed of flying of particles to the most optimist position of swarm and its own best position. They regulate the length and time taken by particle to reach most optimum position (Shi & Eberhart, 1999). So that the particle land in a correct position, these constants must be properly selected. For too big a value of acceleration constants, the particle may fly past the correct position and for too small values, the particle will not be able to reach the target position. Generally, each of these constants are set to 2 to make the times taken to move towards the particle personal best and swarm global best as equal and half the total time. These acceleration constants represent the weighing of acceleration terms towards Pbest and Gbest locations.

3) Random numbers r_1 and r_2

The pull on the particles towards Pbest and Gbest positions are regulated by adding random numbers in the update rules (Yadav, Patidar & Ardil, 2009). These are random fiction and determine the magnitude of random forces towards the two best positions. They add a random component to the PSO algorithm and help prevent the algorithm from getting stuck at a non-optimal local minimum or maximum solution.

4) Size of population

This is often set empirically on the basis of the dimensionality and perceived difficulty of a problem. Values in the range 20 to 50 are quite common. Swarm size varies from one application to the other.

2.5.3 Advantages and Disadvantages of Particle Swarm Optimization algorithm

The PSO algorithm used in various optimization problems has certain advantages and disadvantages:

Advantages

- PSO algorithm does not involve selection operation or mutation calculation. The search can be carried out by repeatedly varying particle speed.
- By learning from group experiences, particles fly only to good areas where there is a possibility of finding food.
- PSO algorithm is based on artificial intelligence and thus, can be applied into both scientific research and engineering applications.
- Simple calculations are involved in PSO algorithm and with development of newer evaluation techniques they are be done easily.

Disadvantages

- Standard PSO suffers from a substantial rise in search complexity with increase in dimension of search space.
- The method is vulnerable to partial optimism, which leads to a much less accurate regulation of its speed and the direction.
- Due to the lack of dimensionality this method cannot be used for problems of non-coordinate system, such as the solution to the energy field and the moving rules of the particles in the energy field.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter discussed the method that used in this project based on knowledge gathered from studied through reference books, journals and articles in previous chapter.

The first stage of the project discussed on the literature review of the project about power system reliability, the impact of optimal recloser placement to the distribution system reliability and the analytical analysis of reliability indices in The Roy Billinton Test System (RBTS) bus 5 system. In order to ensure all the data based on calculations and simulations are accepted, the understanding calculation of reliability indices are very important. All the data and description of RBTS bus 5 system is presented in previous chapter.

Next stage is design MATLAB software to implement optimization of PSO. In order to analyze the impact of optimal recloser placement in distribution system reliability, optimization method of PSO is applied. PSO algorithm is used to determine the possible location for installing recloser placement based on reliability indices of SAIFI and SAIDI.

Lastly, all the procedures, specifications and data obtained will be analyzed, documented and presented in a proper mannered way in the form of final report and presentation.

3.2 Analytical techniques on the impact of recloser

Analytical or deterministic techniques are the basis method to calculate reliability indices in power system by using mathematical models. Table 3.1 shows base case reliability indices for the radial distribution network at bus 5 and Figure 3.1 shows distribution system for RBTS bus 5 with fault label. The fault are label with red colour.

Table 3.1: Base case reliability indices for the radial distribution network at bus 5

	Load point	Failure rate λ (f/yr)	Outage time, r (hr)	Annual unavailability, U (hr/yr)	Energy not supply, EENS (MWh/yr)	Number of customer
Feeder 1	1	0.2360	15.08	3.56	1.51934	210
	2	-	-	-	-	210
	3	-	-	-	-	1
	4	0.2165	16.17	3.50	1.46006	240
	5	-	-	-	-	1
	6	-	-	-	-	240
	7	-	-	-	-	15
Feeder 2	8	-	-	-	-	1
	9	0.2588	13.69	3.54	1.13829	195
	10	-	-	-	-	195
	11	-	-	-	-	195
	12	0.2490	14.35	3.57	1.35236	1
	13	-	-	-	-	195
Feeder 3	14	-	-	-	-	15
	15	-	-	-	-	240
	16	-	-	-	-	1
	17	-	-	-	-	1
	18	-	-	-	-	15
	19	0.2360	15.25	3.60	1.36220	1
Feeder 4	20	-	-	-	-	210
	21	-	-	-	-	210
	22	-	-	-	-	15
	23	0.2263	15.69	3.55	2.21722	1
	24	-	-	-	-	15
	25	0.2068	17.07	3.53	1.47226	240
	26	0.2263	16.03	3.63	1.16544	195
Number of customer for all feeder						2858

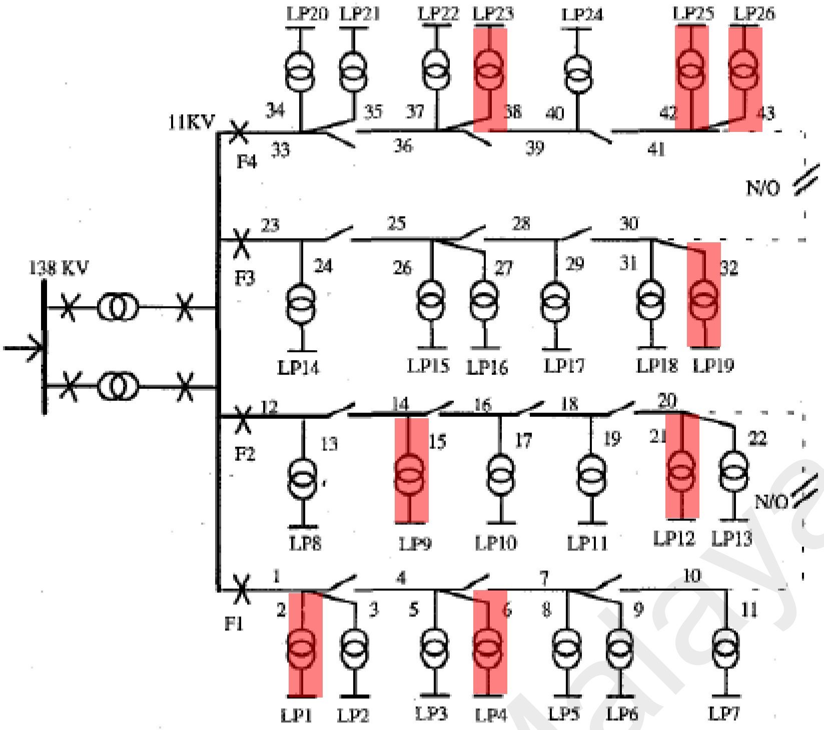


Figure 3.1: Distribution system for RBTS bus 5 with fault label

The customer oriented indices based on RBTS bus 5 data:

- System average interruption frequency index (SAIFI) [λ/yr, customers]

$$SAIFI = \frac{\sum \lambda_{lpi} N_{lpi}}{N_{lpi}} = \frac{246.4578}{1083} = 0.2276$$

- System average interruption duration index (SAIDI) [h/yr, customers]

$$SAIDI = \frac{\sum U_{lpi} N_{lpi}}{N_{lpi}} = \frac{3843.67}{1083} = 3.5490$$

- Customer average interruption duration index (CAIDI) [h/λ]

$$CAIDI = \frac{SAIDI}{SAIFI} = \frac{3.5490}{0.2276} = 15.593$$

Figure 3.2 shows distribution system for RBTS bus 5 by considering there is no switch for each feeder because one the objective of this project is to analyze the impact of recloser placement in distribution network based on reliability indices. Therefore, the network is assumed not have any protective devices before recloser placement.

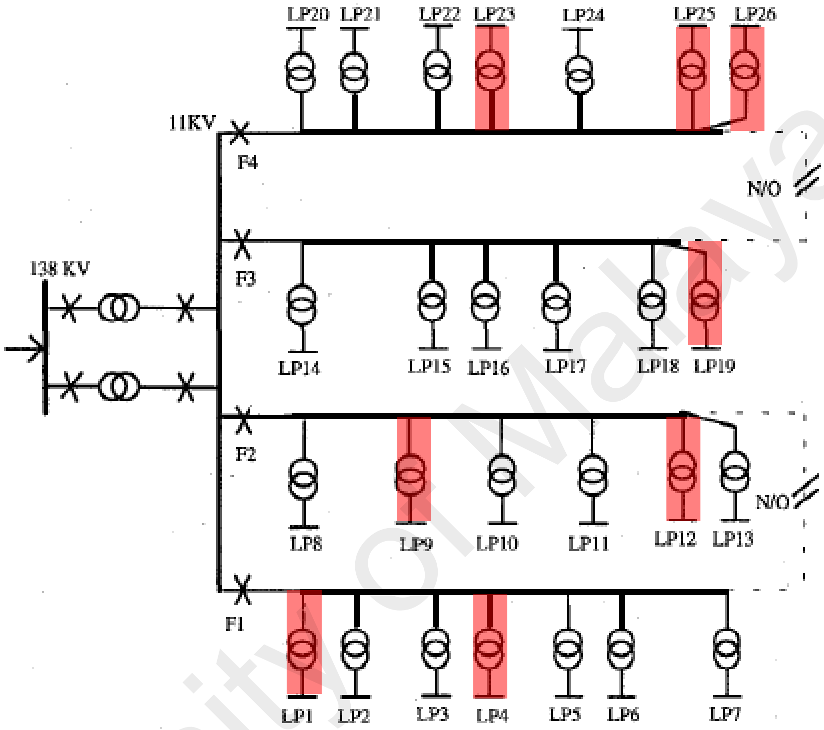


Figure 3.2: Distribution system for RBTS bus 5 by considering there is no switch for each feeder with fault label

The new customer oriented indices based on RBTS bus 5 data:

- System average interruption frequency index (SAIFI) [λ/yr, customers]

$$SAIFI = \frac{\sum \lambda_{lpi} N_{lpi}}{N_{lpo}} = \frac{1460.7238}{2858} = 0.5111$$

- System average interruption duration index (SAIDI) [h/yr, customers]

$$SAIDI = \frac{\sum U_{lpi} N_{lpi}}{N_{lpi}} = \frac{22505.8926}{2858} = 7.8747$$

- Customer average interruption duration index (CAIDI) [h/λ]

$$CAIDI = \frac{SAIDI}{SAIFI} = \frac{7.8747}{0.5111} = 15.407$$

Table 3.2 below shows analytical failure rate at each feeder.

Table 3.2: Failure rate at each feeder

Feeder	Failure rate at each feeder = $\Sigma\lambda_{lpi}N_{lpi}$ (f/yr)
Feeder 1	(0.2360 + 0.2165) (210 + 210 + 1 + 240 + 1 + 240 + 15) = (0.4525)(917) = 414.9425
Feeder 2	(0.2588 + 0.2490) (1 + 195 + 195 + 195 + 1 +195) = (0.5078)(782) = 397.0996
Feeder 3	(0.2360)(15 + 240 + 1 + 1 +15 + 1) = (0.2360)(273) = 64.428
Feeder 4	(0.2263 + 0.2068 + 0.2263)(210 + 210 + 15 + 1 + 15 + 240 + 195) = (0.6594)(886) = 584.2284

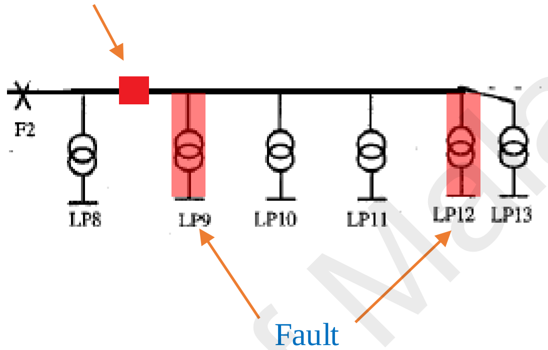
As explained in previous chapter, recloser is function to detect and interrupt momentary fault on overhead distribution system. Then, automatically restoring power to the line after a momentary fault. There are three considerations on calculating recloser placement based on reliability indices of SAIFI and SAIDI:

I. The recloser placement before fault
II. The recloser placement after fault
III. The recloser placement before and after fault

Next part have been shows the calculation and explanation about reliability index of SAIFI for these three considerations at feeder 2 of RBTS bus 5.

3.2.1 The recloser placement before fault

Figure 3.3 shows location of recloser placement before fault occurs. Fault occurred at LP9 and LP12.



Recloser placement before fault

Fault

Figure 3.3: Location of recloser placement before fault

The reliability index of SAIFI is:

$$SAIFI = \frac{\sum \lambda_{feeder1} N_{feeder1} + \sum \lambda_{feeder2} N_{feeder2} + \sum \lambda_{feeder3} N_{feeder3} + \sum \lambda_{feeder4} N_{feeder4}}{N_{total}}$$

Where,

$$\sum \lambda_{feeder3} N_{feeder3} = \sum_{LP9+LP12}^{LP13} \lambda_{lpi} N_{lpi}$$

$$= (0.2588 + 0.2490)\ (195 + 195 + 195 + 1 + 195)$$

$$= 396.5918$$

And,

$$SAIFI = \frac{414.9425 + 396.5918 + 397.0996 + 584.2284}{2858} = 0.6273$$

Notes: The number of customer N_{lpi} depends on the location of recloser placement.

3.2.2 The recloser placement after fault

Figure 3.4 shows location of recloser placement after fault occurs. Fault occurred at LP9 and LP12.

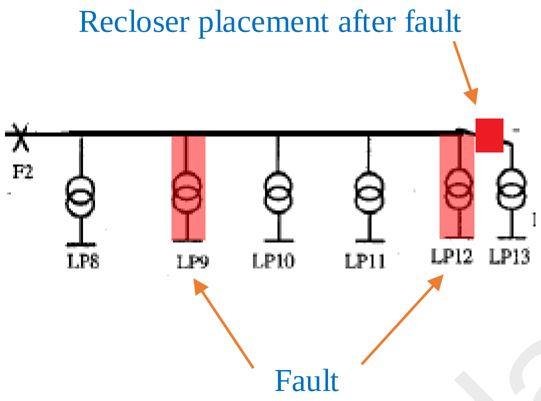


Figure 3.4: Location of recloser placement after fault

The reliability index of SAIFI is:

$$SAIFI = \frac{\sum\lambda_{feeder1}N_{feeder1}+\sum\lambda_{feeder2}N_{feeder2}+\sum\lambda_{feeder3}N_{feeder3}+\sum\lambda_{feeder4}N_{feeder4}}{N_{total}}$$

Where,

$$\sum\lambda_{feeder1}N_{feeder1}=\sum^{LP13}\lambda_{lpi}N_{lpi}$$

$$= (0.2588 + 0.2490)\,(1 + 195 + 195 + 195 + 1 + 195)$$

$$= 397.0996$$

And,

$$SAIFI = \frac{414.9425+397.0996+64.428+584.2284}{2858} = 0.5111$$

Notes: The number of customer N_{lpi} depends on the location of recloser placement.

3.2.3 The recloser placement before and after fault

Figure 3.4 shows location of recloser placement before and after fault occurs. Fault occurred at LP9 and LP12.

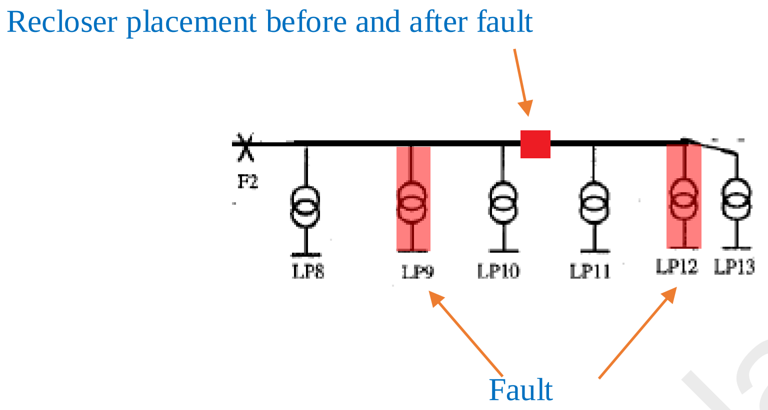


Figure 3.5: Location of recloser placement before and after fault

The reliability index of SAIFI is:

$$SAIFI = \frac{\sum \lambda_{feeder1} N_{feeder1} + \sum \lambda_{feeder2} N_{feeder2} + \sum \lambda_{feeder3} N_{feeder3} + \sum \lambda_{feeder4} N_{feeder4}}{N_{total}}$$

Where,

$$\sum \lambda_{feeder1} N_{feeder1} = \sum_{LP8}^{LP13} \lambda_{lpi} N_{lpi} + \sum_{LP11}^{LP13} \lambda_{lpi} N_{lpi}$$

= (0.2588) (1 + 195 + 195 + 195 + 1 +195) + (0.2588 + 0.2490) (195 + 195 + 1)

= 299.7406

And,

$$SAIFI = \frac{414.9425 + 299.7406 + 64.428 + 584.2284}{2858} = 0.4770$$

Notes: The number of customer N_{lpi} depends on the location of recloser placement. The concept calculation for SAIDI is same as SAIFI.

3.3 MATLAB flow chart

Figure 3.6 shows MATLAB flow chart. It started with understanding of literature review and analytical analysis the reliability indices of SAIFI and SAIDI. In order to analyze the impact of optimal recloser placement in distribution network, MATLAB coding is evaluating from calculations of three considerations recloser placement which are before fault, after fault and before and after fault for both case studies. After successfully stimulated, optimization of PSO is applied to find the best possible location at different recloser placement with the single objective SAIFI and SAIDI.

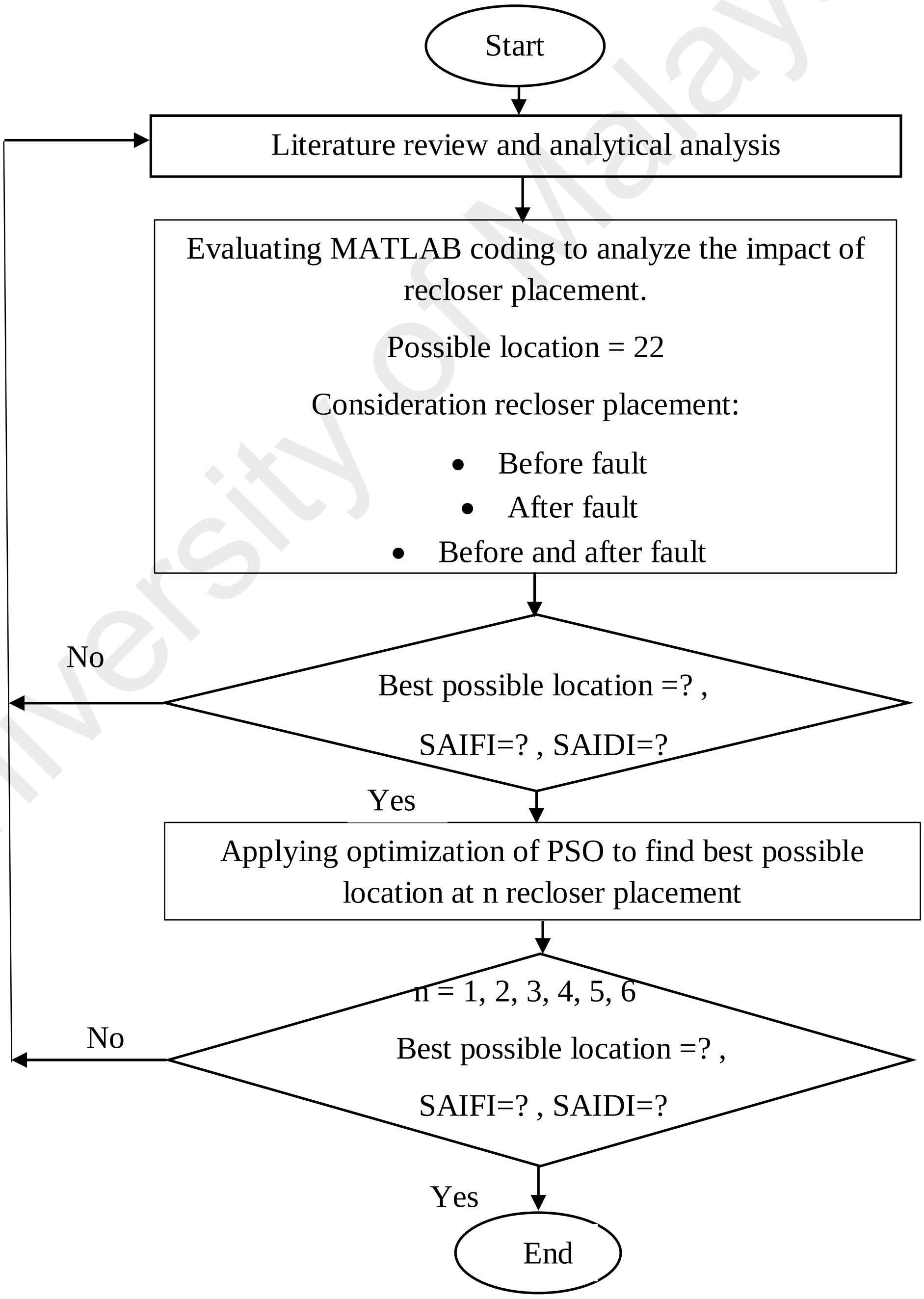


Figure 3.6: MATLAB flow chart

3.4 Application of Particle Swarm Optimization (PSO) for implementation recloser placement

Figure 3.7 shows Particle Swarm Optimization algorithm flow chart.

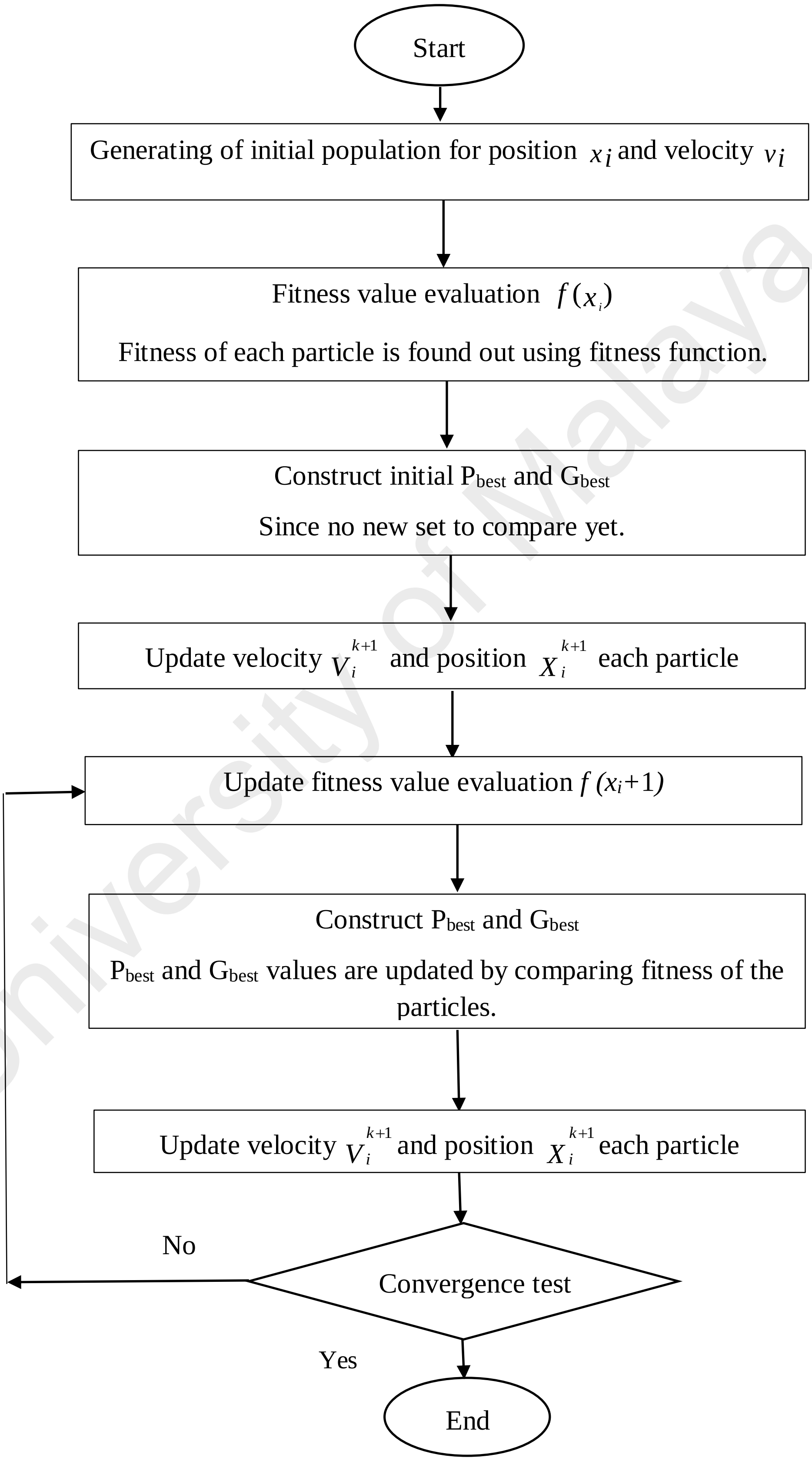


Figure 3.7: Particle Swarm Optimization algorithm flow chart

The process of implementation of PSO algorithm is as follows:

a) Initial population

Generate the initial population for the position and velocity vectors:

$x_i = [x_1, x_2, ..., x_n]$ where i = 1, 2, …., m (3.1)

$v_i = [r_1, r_2, ... r_n]$ (3.2)

where i is the particle index of objective variables and it present possible location of recloser at RBTS bus 5, v is swarm velocity and n is the optimization problem dimension. Set k = 1 and parameters of PSO is setup such as number of population which is 50, weighting factors and acceleration constant.

b) Fitness value evaluation

The fitness has been evaluating for each particle of the population based on objective function $f(x_i)$. The mathematical models of objective function as follows:

1. System average interruption frequency index (SAIFI) measures the average frequency of sustained interruption per customer. The index calculated by using following equation:

$$SAIFI = \frac{\sum_{i=1}^{n}(\sum_{s=1}^{m}\lambda_{is})N_i}{\sum_{i=1}^{n}N_i} \tag{3.3}$$

where λ_{is} is failure rate of customer i due to outages in section s. It depends on the location of recloser. N_i is number of customer at load point i, n and m represent number or load point and sections.

2. System average interruption duration index (SAIDI) measures the average times that customer interruption during year. The index calculated by using following equation:

$$SAIDI = \frac{\sum_{i=1}^{n}(\sum_{s=1}^{m} U_{is}) N_i}{\sum_{i=1}^{n} N_i} \tag{3.4}$$

where U_{is} is outage time of customer i due to outages in section s. It also depends on the location of reclosers.

c) Initial P_{best} and G_{best}

Construct initial P_{best} and G_{best} value by assuming all initial position as Pbest value since no new set to compare yet. Then, find the Gbest value which is most minimum value among the particles in the population.

d) Compare and update

In PSO, population is a swarm of particles. Each particle has position and velocity. It moves to a new position using velocity. Once a new position reached, the best position of each particle and the swarm are updated (P_{best} and G_{best}). The velocity of each particle is then adjusted based on the experiences of the particle. The process is repeated until a stopping criterion is met. Equation (3.1) and (3.2) show the new velocity, V_i^{k+1} and the new position for the particle, X_i^{k+1}.

$$V_i^{k+1} = \omega \times V_i^k + C_1 \times rand_1 \times (P_{besti}^k - X_i^k) + C_2 \times rand_2 \times (G_{best}^k - X_i^k) \tag{3.5}$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \tag{3.6}$$

where V_i^k is the velocity of particle *i* in iteration *k*, X_i^k is the position of particle *i* in iteration *k*. Constants C_1 and C_2 are weighting factors of the random acceleration term which are set 1.4. $rand_1$ and $rand_2$ are random numbers between 0 and 1. P_{besti}^k is the best value of the fitness function that has been achieved by any particle *i* before iteration *k*. G_{best}^k is the best value of the fitness function that has been achieved by any particle. The inertia weight is set according following equation:

$$\omega(t+1) = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{t_{\max}} \times t \tag{3.7}$$

In Equation (3.7), *t* is the current iteration number, t_{max} is the maximum number of iterations. ω_{max} is maximum of the inertia weight which is set 0.9 and $\omega_{min}$is minimum of the inertia weight which is set 0.4. The values are decreased linearly so that algorithm allows the particles to explore wider areas in beginning and nearby areas in later stages with reduced speeds. This setting gives a greater likelihood of reaching the target optimum position quickly. Figure 3.8 shows searching point by PSO algorithm when modified position and velocity of individual *i* based on equation (3.5) and (3.6).

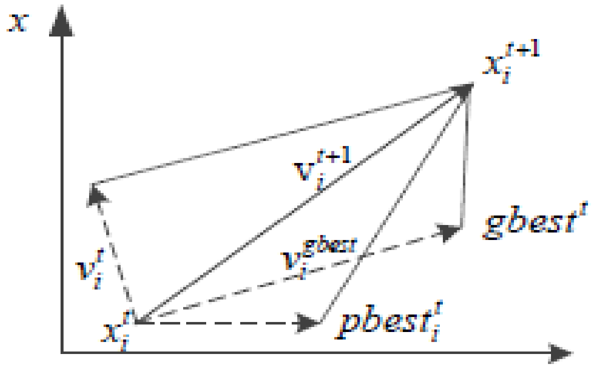


Figure 3.8: Searching point of the PSO algorithm

e) Update fitness value evaluation

The fitness of each particle $f\,(x_i+1)$ was calculated.

f) Construct P_{best} and G_{best}

Matrix composed of P_{best} and G_{best} value. Gbest value is selecting from the most minimum value among the particles in the population.

g) Update velocity and position each particle

The velocity V_i^{k+1} and position X_i^{k+1} for each particle was calculated.

CHAPTER 4: RESULT AND DISCUSSION

4.1 Introduction

This chapter presents the result for (1) Analysis of recloser placement with different combination based on reliability indices of SAIFI and SAIDI. The simulation results of these reliability indices are test on a distribution network of RBTS at bus 5 only. There are 22 possible locations of recloser placement tested and (2) Performance of PSO algorithm in determining optimal location of recloser placement with respect to 2, 3, 4, 5 and 6 recloser.

4.2 Analysis on the impact of recloser

Figure 4.1 shows 22 possible location of recloser placement at bus 5 which labels as P1 to P22. Different allocation gives different reliability indices.

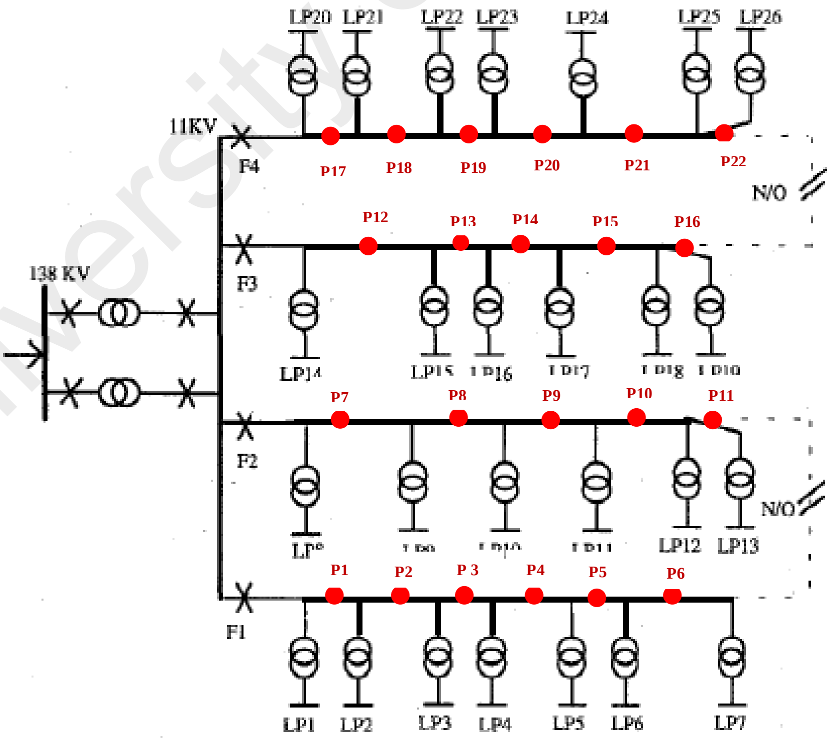
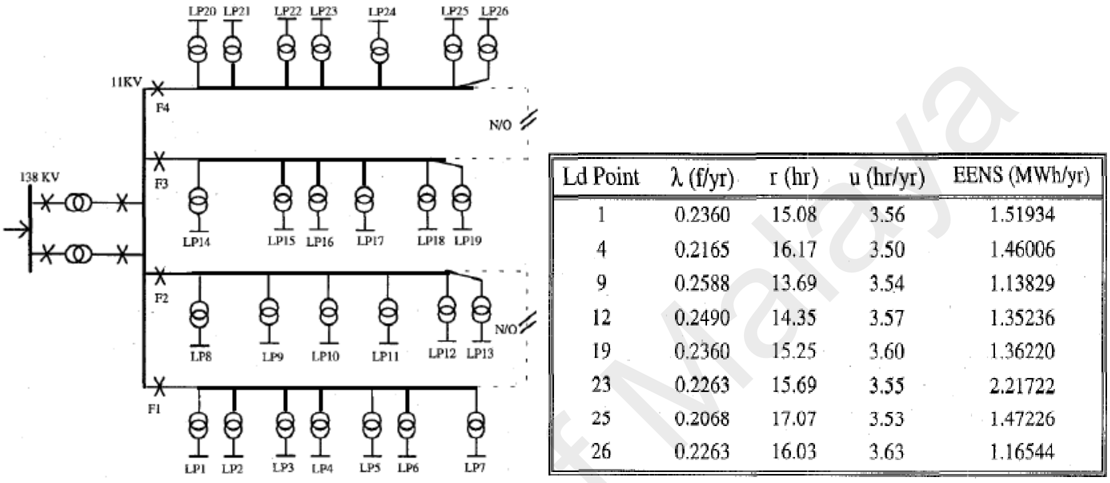


Figure 4.1: Possible location of recloser placement at bus 5

Figure 4.2 shows distribution network at bus 5 of RBTS and base case reliability indices for the radial distribution network at bus 5 as shown in the table. The distribution network consists of 4 feeder (F) and 26 load point (LP). Load point indices include failure rate (λ), outage time (r), annual unavailability (U) and energy not supplied (E).



Ld Point	λ (f/yr)	r (hr)	u (hr/yr)	EENS (MWh/yr)
1	0.2360	15.08	3.56	1.51934
4	0.2165	16.17	3.50	1.46006
9	0.2588	13.69	3.54	1.13829
12	0.2490	14.35	3.57	1.35236
19	0.2360	15.25	3.60	1.36220
23	0.2263	15.69	3.55	2.21722
25	0.2068	17.07	3.53	1.47226
26	0.2263	16.03	3.63	1.16544

Figure 4.2: Distribution network for RBTS and base case reliability indices for the radial distribution network at bus 5 (Billinton & Jonnavithula, 1996)

Table 4.1 shows the reliability indices of distribution network at bus 5 before recloser placement which means distribution network does not have any protective devices.

Table 4.1: Reliability indices of radial distribution network

Reliability indices	Simulation result
SAIFI	0.5111 λ/yr, customers
SAIDI	7.8747 h/yr, customers
CAIDI	15.4076 h/λ

Figure 4.3 and Figure 4.4 shows one recloser placement for reliability indices of SAIFI and SAIDI. From Figure 4.3, when recloser placed at point P1, the reliability indices of SAIFI, SAIDI and CAIDI are 0.4952, 7.6175 and 15.3833. When recloser placed at point P2, the reliability indices of SAIFI, SAIDI and CAIDI are 0.4952, 7.3604 and 15.3573. Therefore, it shows that different allocation of recloser gives different value of reliability indices. The highest value reliability indices of SAIFI, SAIDI and CAIDI are 0.5111, 7.8747 and 15.4076 which at point P4, P5, P6 and P11. The lowest value reliability indices of SAIFI, SAIDI and CAIDI are 0.4107, 6.2446 and 15.2037 which at point P19. From IEEE-Std, the best location of recloser is referred to the lowest value of SAIFI and SAIDI. Therefore, the best location of recloser placement at point P19. The objective of minimizing the reliability indices of SAIFI and SAIDI will directly maximized the reliability. The detail value of result can referring in *Appendices: Appendix A*

Figure 4.3: Reliability indices (SAIFI) for one recloser placement

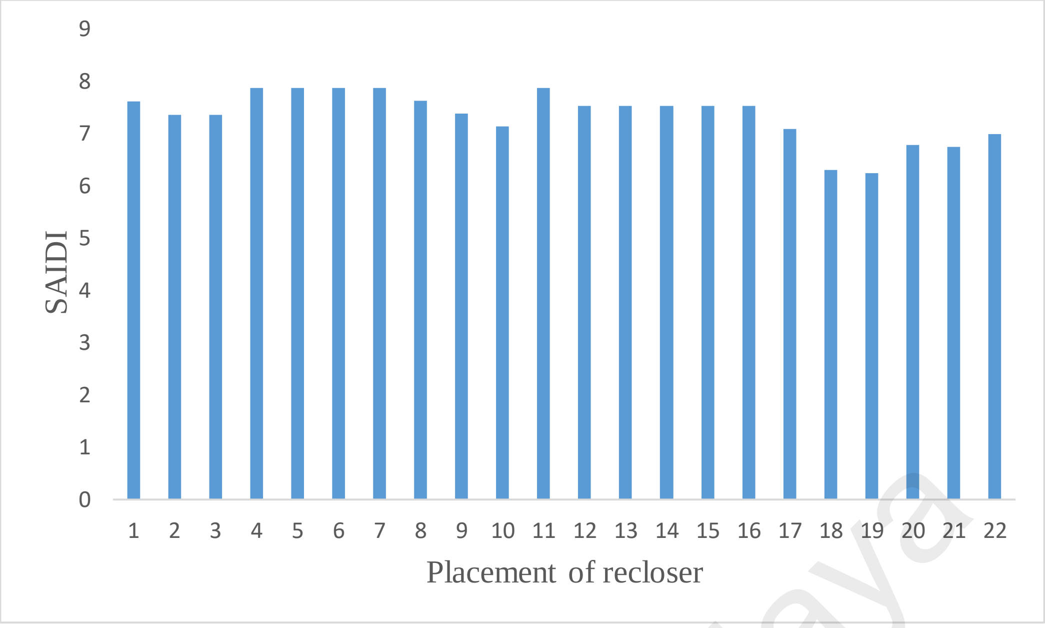


Figure 4.4: Reliability indices (SAIDI) for one recloser placement

4.3 Recloser placement using optimization PSO

This part will discuss the test result of recloser placement using optimization PSO. The number of recloser that have been test are 2, 3, 4, 5 and 6. The possible location of recloser as shown in Figure 4.1. For PSO setting the number of population N is set to 50 and the maximum iteration is set to100.

4.3.1 Two reclosers placement

Figure 4.5 and Figure 4.6 shows the convergence characteristic for single objective of SAIFI and SAIDI. The optimal recloser placement for reliability indices of SAIFI and SAIDI found at point P3 and P10 which is 0.2969 and 4.4230. The fitness value is converging at iteration 50 for SAIFI and SAIDI where the optimal location is found. The value of SAIFI is reduced about 41.91% from the initial value which is 0.5111. Value for SAIDI is reduced about 43.83% from initial value which is 7.8747.Therefore, from this result it shows that when adding more reclosers into the system, it reduced more reliability indices of SAIFI and SAIDI. Thus, this maximized system reliability.

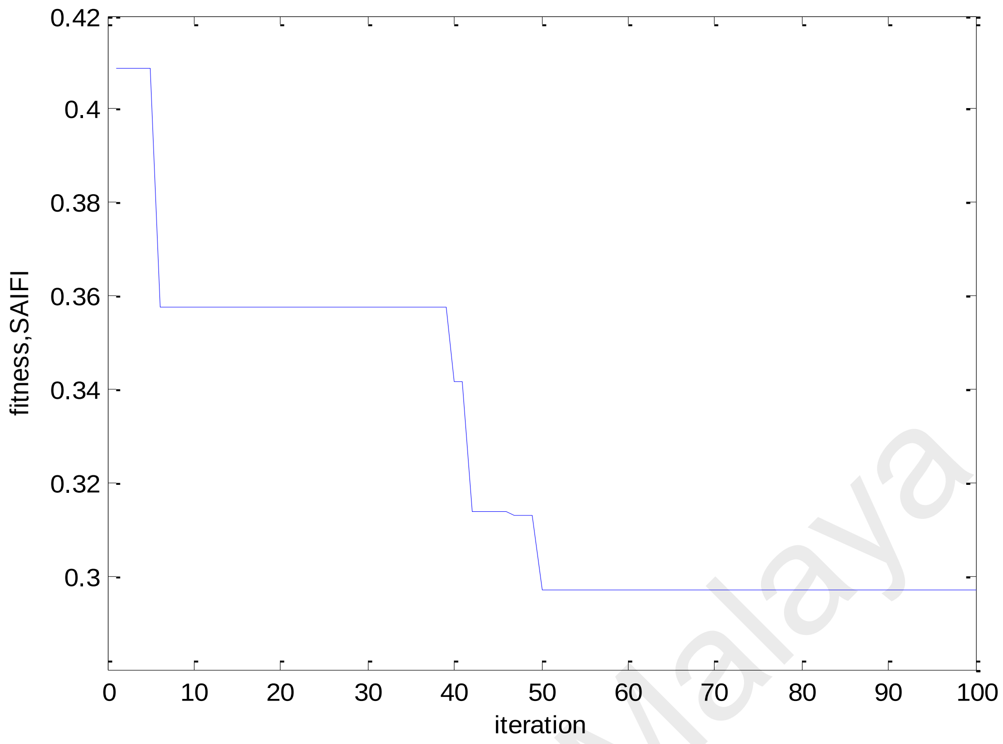


Figure 4.5: Convergence characteristic of fitness (SAIFI) for two reclosers placement

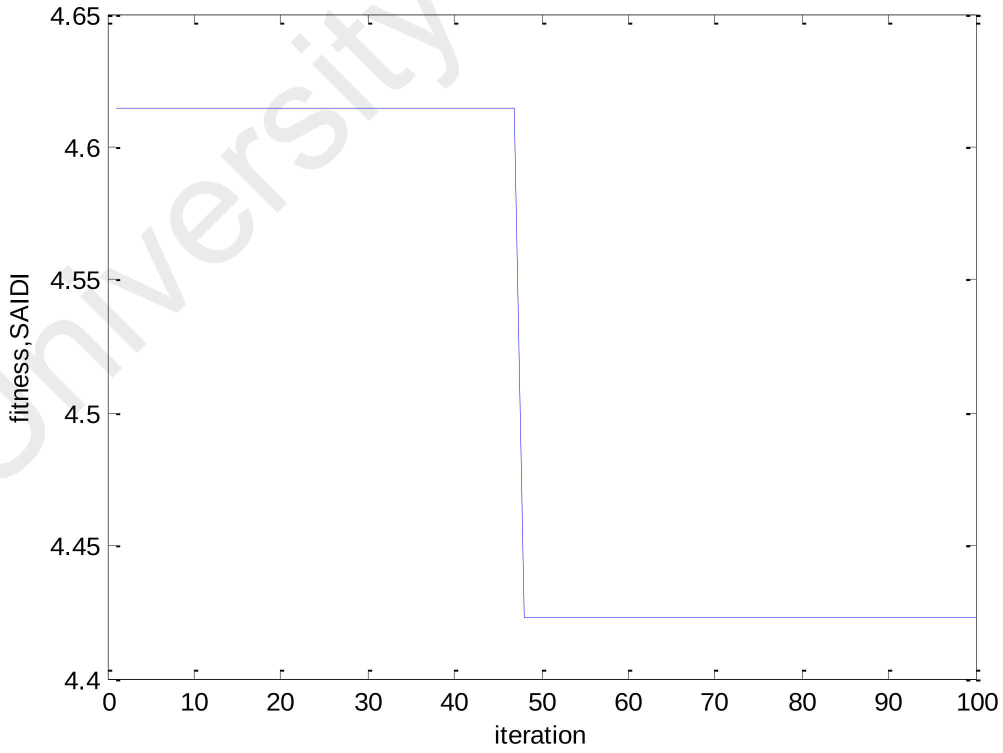


Figure 4.6: Convergence characteristic of fitness (SAIDI) for two reclosers placement

To analyze the consistency result by using PSO, the test is repeated for 50 times. Figure 4.7 and Figure 4.8 shows consistency fitness of SAIFI and SAIDI for two reclosers placement. After 50 times, the consistency result found at same possible location which is P3 and P10. The detail result can referring in *Appendices: Appendix B.*

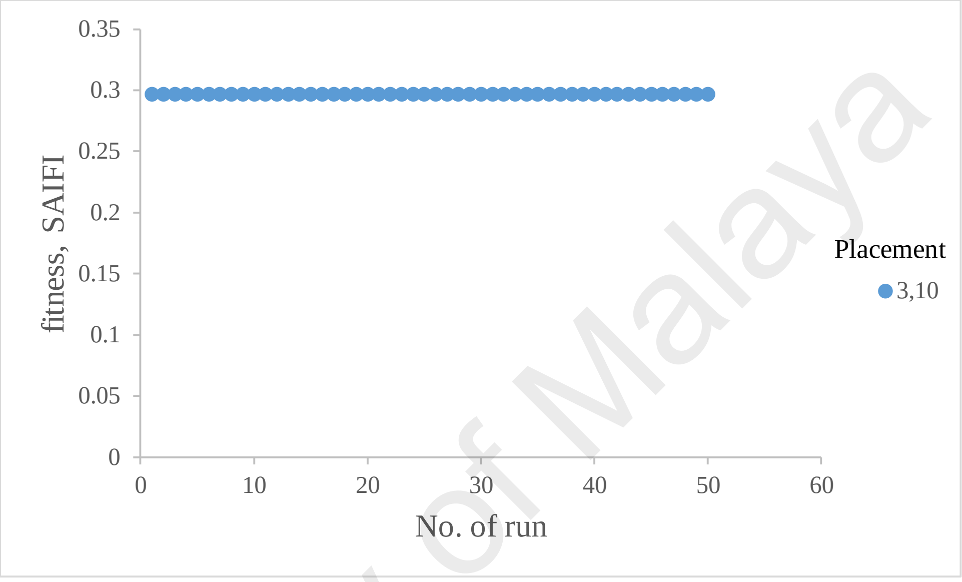


Figure 4.7: Consistency fitness of SAIFI for two reclosers placement

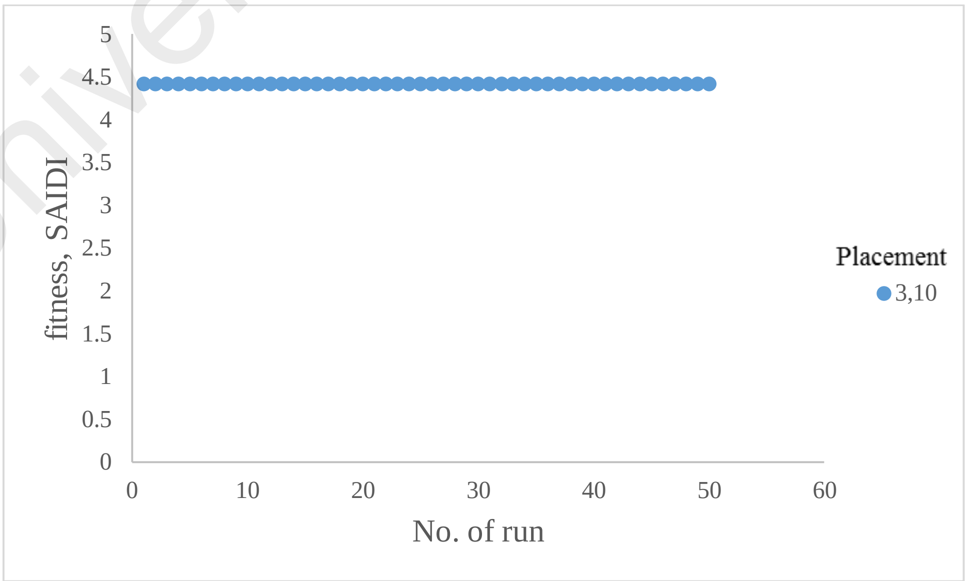


Figure 4.8: Consistency fitness of SAIDI for two reclosers placement

4.3.2 Three reclosers placement

Figure 4.9 and Figure 4.10 shows the convergence characteristic for single objective of SAIFI and SAIDI. The optimal recloser placement for reliability indices of SAIFI and SAIDI found at point P3, P10 and P16 which is 0.2744 and 4.0804. The fitness value is converging at iteration 38 for SAIFI and for SAIDI at iteration 2 where the optimal location is found. The value of SAIFI is reduced about 46.31% from the initial value which is 0.5111. Then, value of SAIDI is reduced about 48.18% from initial value which is 7.8747. Based on the result, three reclosers placement more reliability indices compared to two reclosers placement.

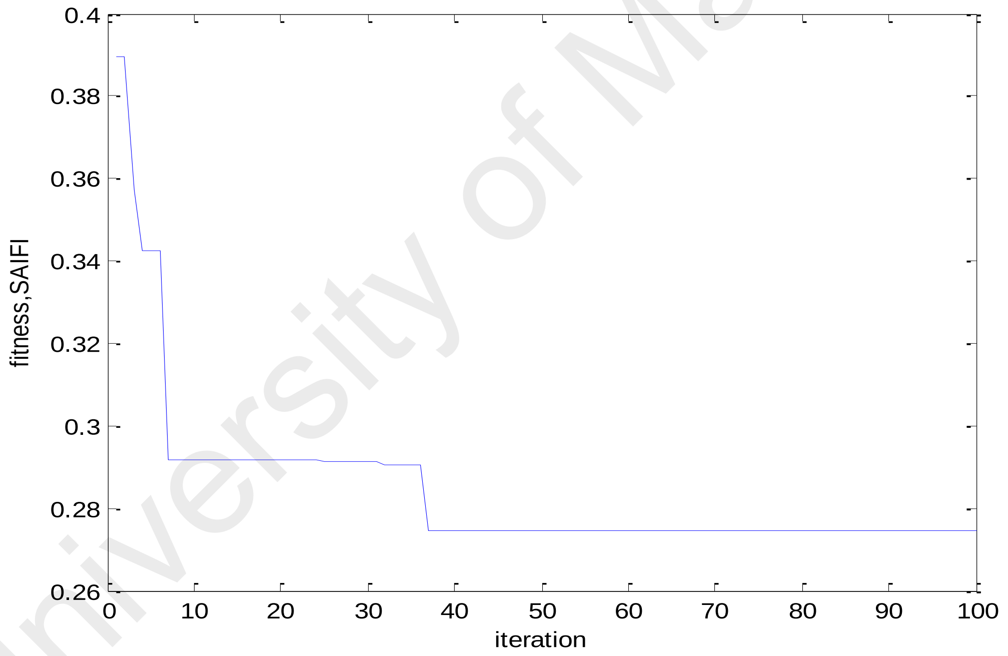


Figure 4.9: Convergence characteristic of fitness (SAIFI) for three reclosers placement

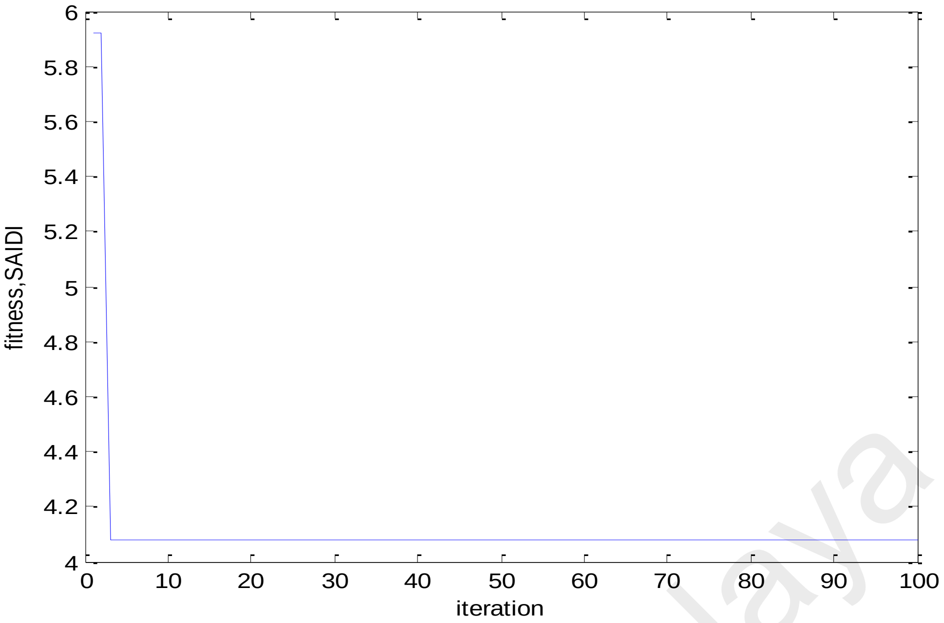


Figure 4.10: Convergence characteristic of fitness (SAIDI) for three reclosers placement

To analyze the consistency result by using PSO, the test is repeated for 50 times. Figure 4.7 and Figure 4.8 shows consistency fitness of SAIFI and SAIDI for three reclosers placement. After 50 times, the consistency result found at lowest reliability indices which is P3, P10 and P16. The detail result can referring in *Appendices: Appendix C.*

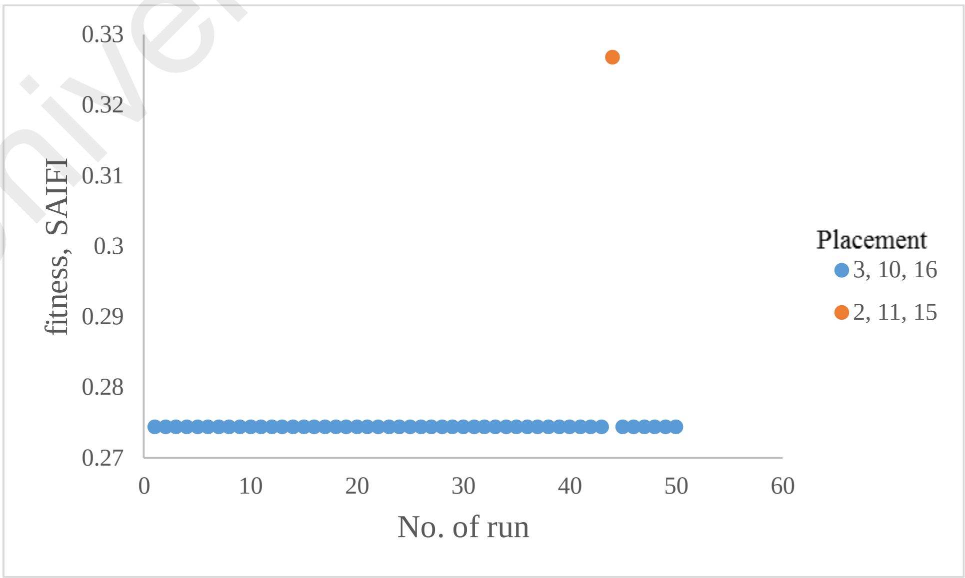


Figure 4.11: Consistency fitness of SAIFI for three reclosers placement

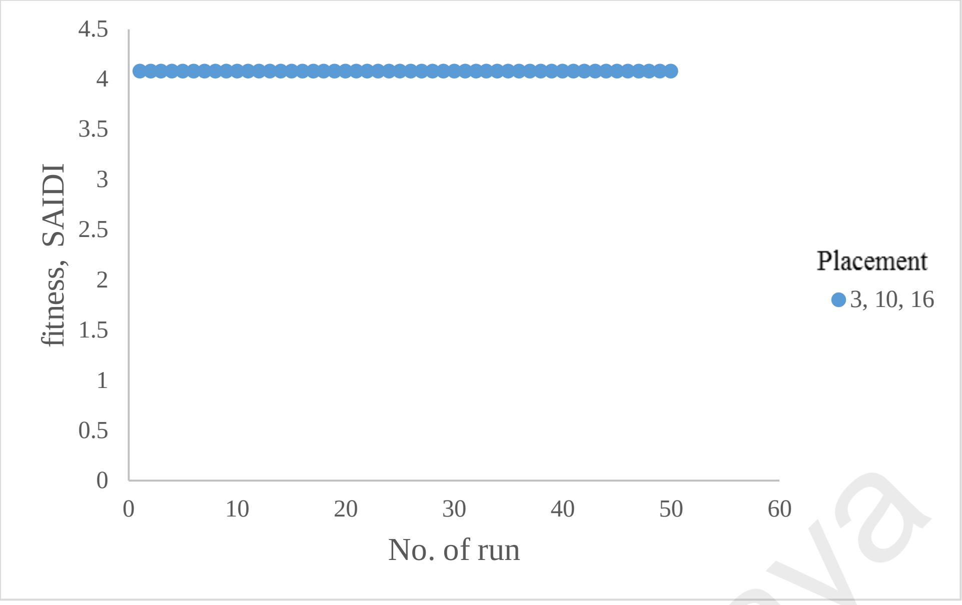


Figure 4.12: Consistency fitness of SAIDI for three reclosers placement

4.3.3 Four reclosers placement

Figure 4.13 and Figure 4.14 shows the convergence characteristic for single objective of SAIFI and SAIDI. The optimal recloser placement for reliability indices of SAIFI and SAIDI found at point P3, P10, P16 and P19 which is 0.3053 and 4.6544. The fitness value is converging at iteration 10 for SAIFI while for SAIDI at iteration 12 where the optimal location is found. The value of SAIFI is reduced about 40.27% from the initial value which is 0.5111. Then, value of SAIDI is reduced about 40.89% from initial value which is 7.8747. The reduction of reliability indices a small drop compared to 1, 2 and 3 reclosers placement.

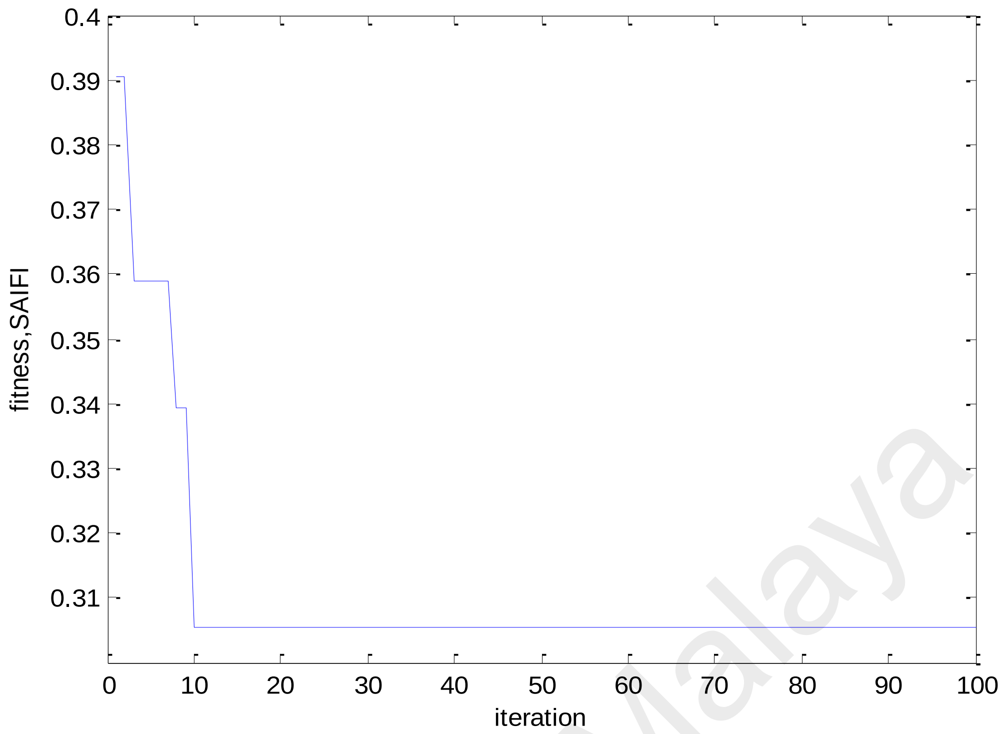


Figure 4.13: Convergence characteristic of fitness (SAIFI) for four reclosers placement

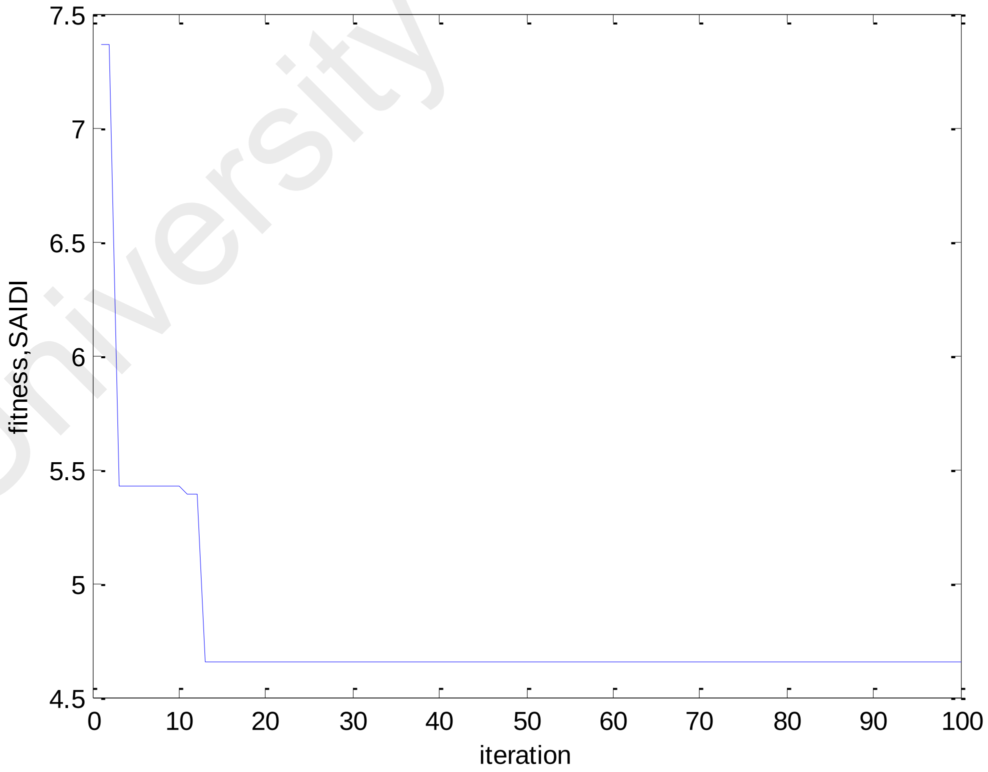


Figure 4.14: Convergence characteristic of fitness (SAIDI) for four reclosers placement

To analyze the consistency result by using PSO, the test is repeated for 50 times. Figure 4.15 and Figure 4.16 shows consistency fitness of SAIFI and SAIDI for four reclosers placement. After 50 times, the consistency result found at lowest reliability indices which is P3, P10, P16 and P19. The detail result can referring in *Appendices: Appendix D.*

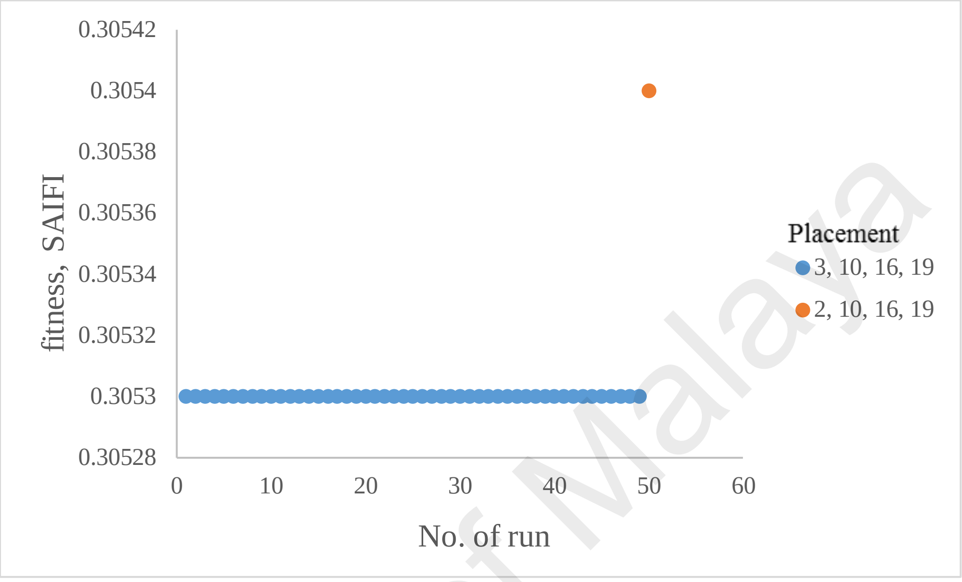


Figure 4.15: Consistency fitness of SAIFI for four reclosers placement

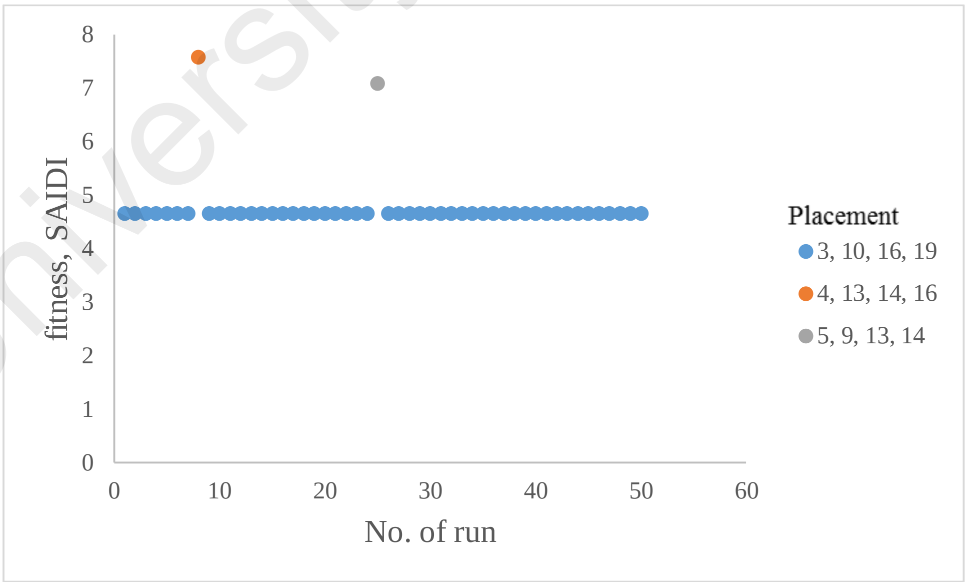


Figure 4.16: Consistency fitness of SAIDI for four reclosers placement

4.3.4 Five reclosers placement

Figure 4.17 and Figure 4.18 shows the convergence characteristic for single objective of SAIFI and SAIDI. The optimal recloser placement for reliability indices of SAIFI and SAIDI found at point P3, P10, P15, P16 and P19 which is 0.3066 and 4.6746. The fitness value is converging at iteration 70 for SAIFI while for SAIDI at iteration 12 where the optimal location is found. The value of SAIFI is reduced about 40.01% from the initial value which is 0.5111. Then, value of SAIDI is reduced about 40.64% from initial value which is 7.8747. Similar to 4 reclosers placement, the reduction of reliability indices a small drop compared to 1, 2 and 3 reclosers placement.

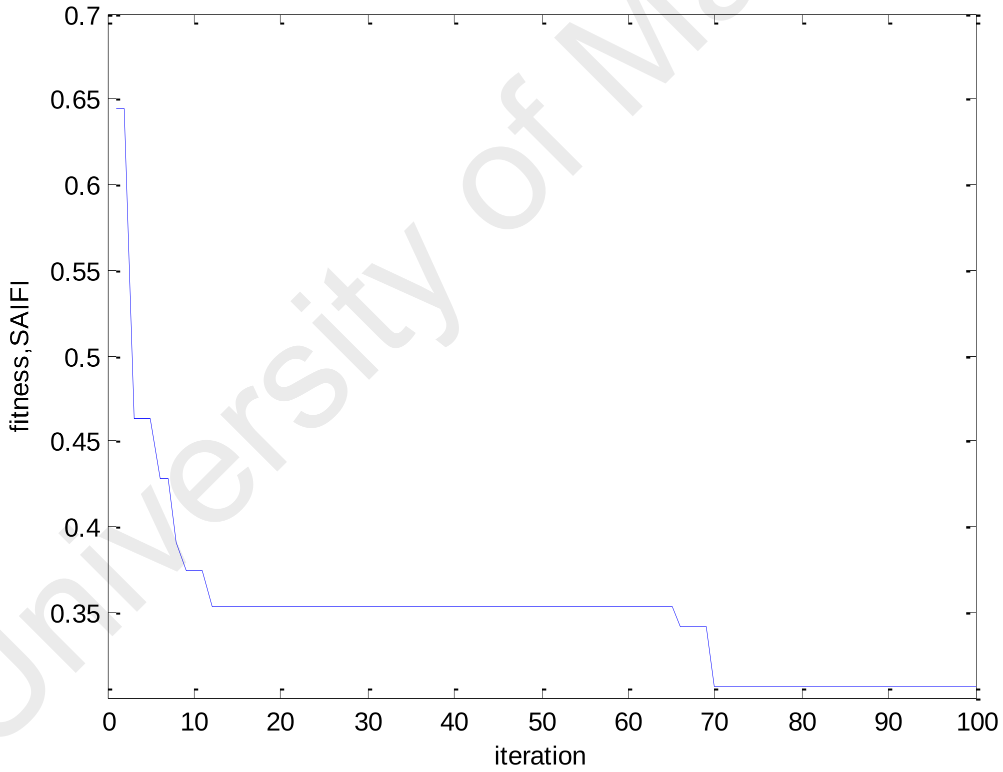


Figure 4.17: Convergence characteristic of fitness (SAIFI) for five reclosers placement

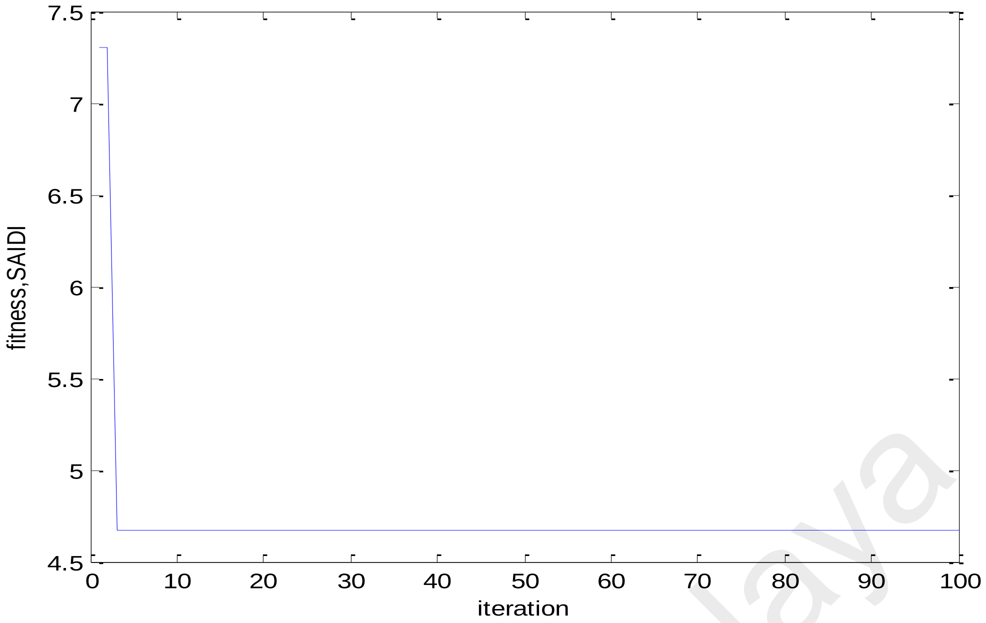


Figure 4.18: Convergence characteristic of fitness (SAIDI) for five reclosers placement

To analyze the consistency result by using PSO, the test is repeated for 50 times. Figure 4.19 and Figure 4.20 shows consistency fitness of SAIFI and SAIDI for five reclosers placement. After 50 times, the consistency result found at lowest reliability indices which is P3, P10, P15, P16 and P19. The detail result can referring in *Appendices: Appendix E.*

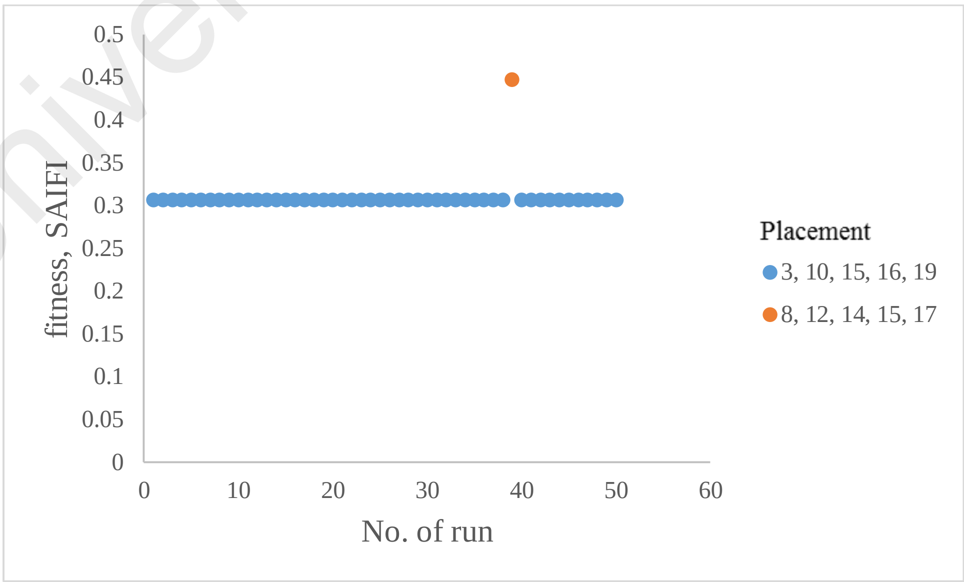


Figure 4.19: Consistency fitness of SAIFI for five reclosers placement

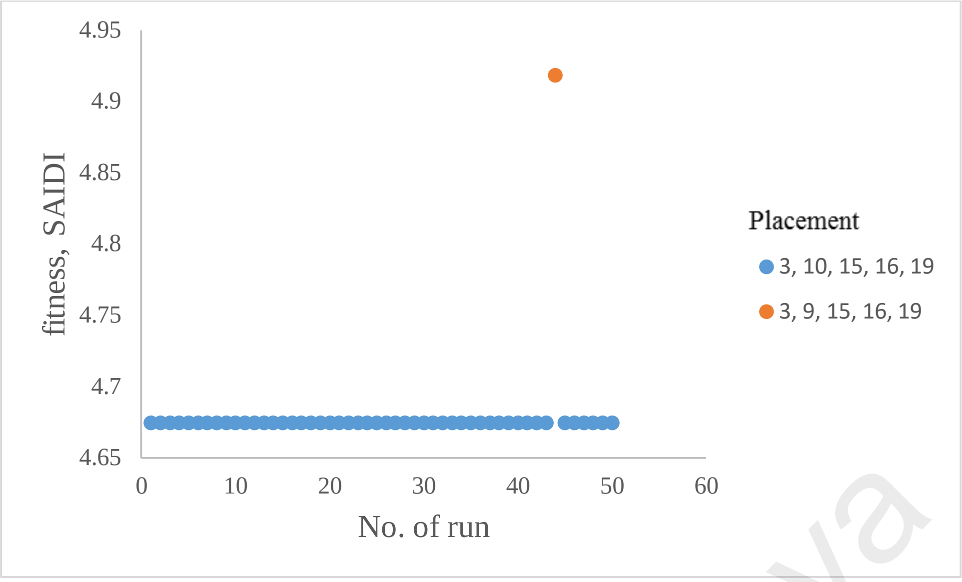


Figure 4.20: Consistency fitness of SAIDI for five reclosers placement

4.3.5 Six reclosers placement

Figure 4.21 and Figure 4.22 shows the convergence characteristic for single objective of SAIFI and SAIDI. The optimal recloser placement for reliability indices of SAIFI found at point P3, P10, P14, P15, P16 and P22 which is 0.2202 and for SAIDI at P3, P10, P14, P15, P16 and P19 which is 4.6960. The fitness value is converging at iteration 5 for SAIFI and for SAIDI at iteration 15 where the optimal location is found. The value of SAIFI is reduced about 56.92% from the initial value which is 0.5111. Then, value of SAIDI is reduced about 40.37% from initial value which is 7.8747.

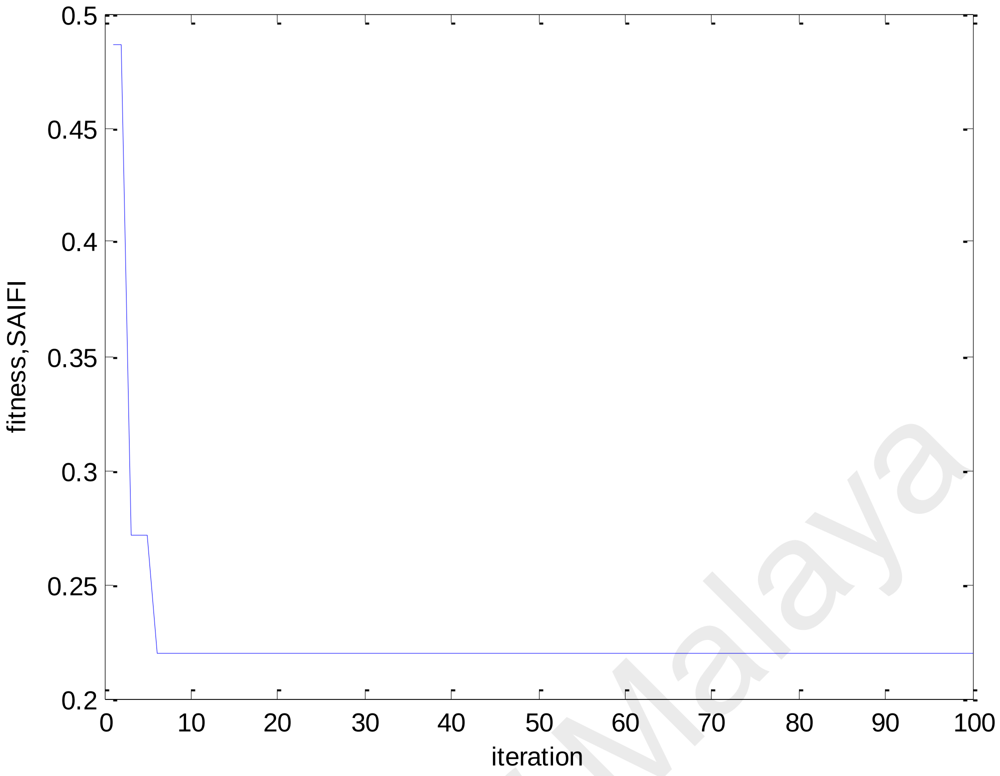


Figure 4.21: Convergence characteristic of fitness (SAIFI) for six reclosers placement

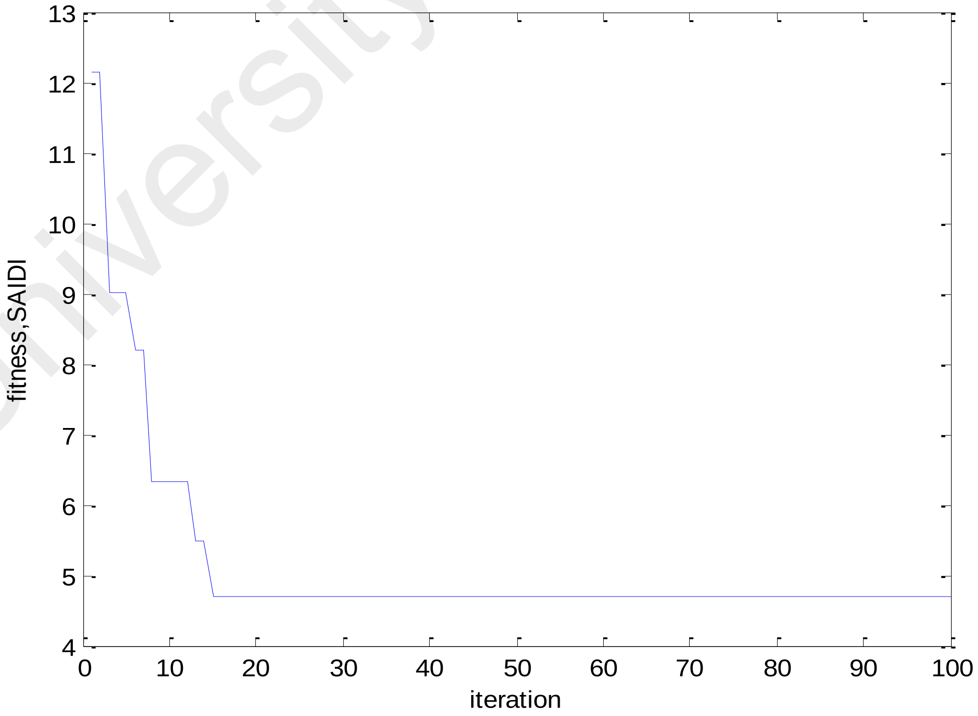


Figure 4.22: Convergence characteristic of fitness (SAIDI) for six reclosers placement

To analyze the consistency result by using PSO, the test is repeated for 50 times. Figure 4.23 and Figure 4.24 shows consistency fitness of SAIFI and SAIDI for six reclosers placement. For SAIFI, the consistency result found at lowest reliability indices which is P3, P10, P14, P15, P16 and P22. For SAIDI the consistency result at P3, P10, P14, P15, P16 and P19. The detail result can referring in *Appendices: Appendix F*.

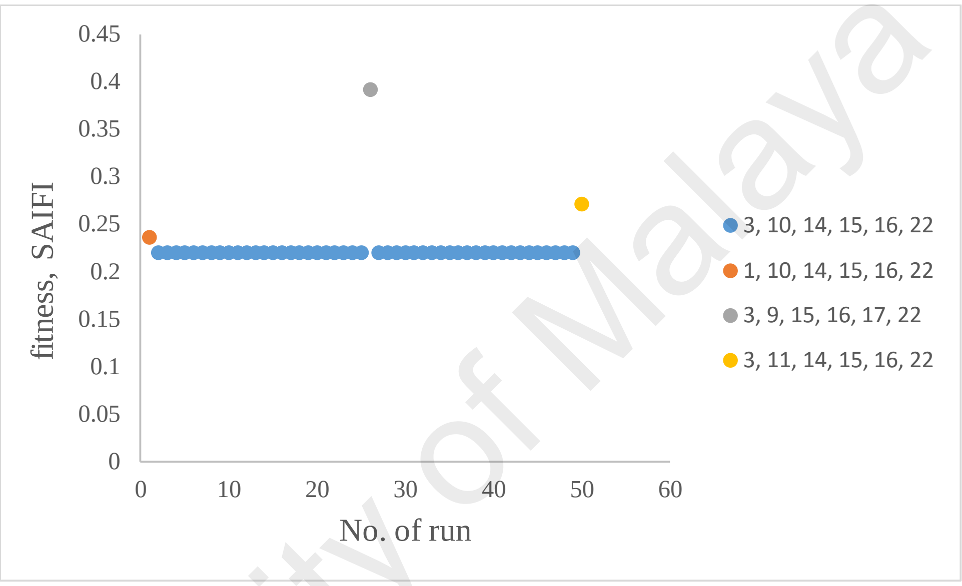


Figure 4.23: Consistency fitness of SAIFI for six reclosers placement

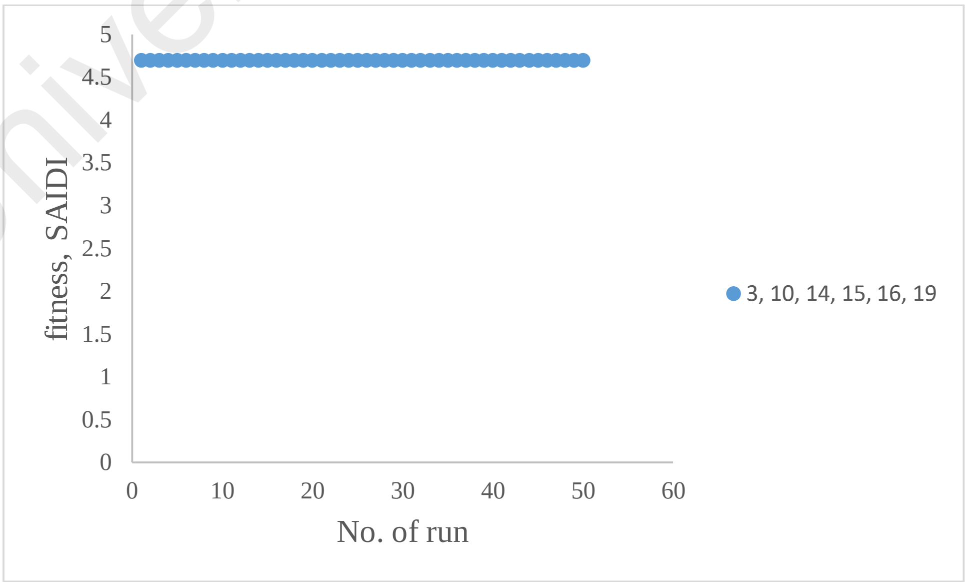


Figure 4.24: Consistency fitness of SAIDI for six reclosers placement

4.4 Result summary

This section discusses about the result reliability indices of different number of optimal recloser placement.

4.4.1 Overall result

Table 4.2 and Table 4.3 below show the result summary for the impact of recloser placement in distribution network based on reliability indices of SAIFI and SAIDI. The number of recloser placement is analyzed up to six recloser placement by using PSO method.

Table 4.2: Result summary of SAIFI

Number of recloser placement	Fitness, SAIFI		The best point location of recloser	Reduced percentage, %
	Without recloser	With recloser		
One	0.5111	0.4107	P19	19.64%
Two	0.5111	0.2969	P3, P10	41.91%
Three	0.5111	0.2744	P3, P10, P16	46.31%
Four	0.5111	0.3053	P3, P10, P16, P19	40.27%
Five	0.5111	0.3066	P3, P10, P15, P16, P19	40.01%
Six	0.5111	0.2202	P3, P10, P14, P15, P16, P22	56.92%

Table 4.3: Result summary of SAIDI

Number of recloser placement	Fitness, SAIDI		The best point location of recloser	Reduced percentage, %
	Without recloser	With recloser		
One	7.8747	6.2446	P19	20.70%
Two	7.8747	4.4230	P3, P10	43.83%
Three	7.8747	4.0804	P3, P10, P16	48.18%
Four	7.8747	4.6544	P3, P10, P16, P19	40.89%
Five	7.8747	4.6746	P3, P10, P15, P16, P19	40.64%
Six	7.8747	4.6960	P3, P10, P14, P15, P16, P19	40.36%

Figure 4.25 and Figure 4.26 below show the results obviously presented in plotted graph. Figure 4.25 shows the graph of number of impact recloser placement in reliability indices, SAIFI while Figure 4.26 shows the graph of number of impact recloser placement in reliability indices, SAIDI. In figure, the blue line refers to the fitness value of SAIFI and SAIDI without recloser placement while the red line refers to the fitness value of SAIFI and SAIDI with different number of recloser placement. From the graph, it clearly show that when adding more recloser placement in distribution network, the value of reliability indices reduced. Thus, it maximized system reliability.

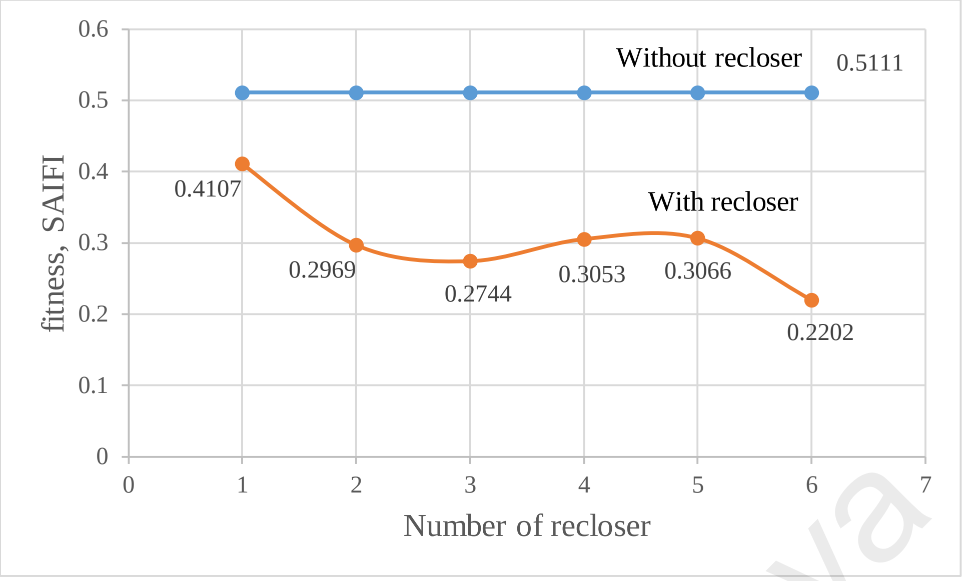


Figure 4.25: Number of impact recloser placement in reliability indices, SAIFI

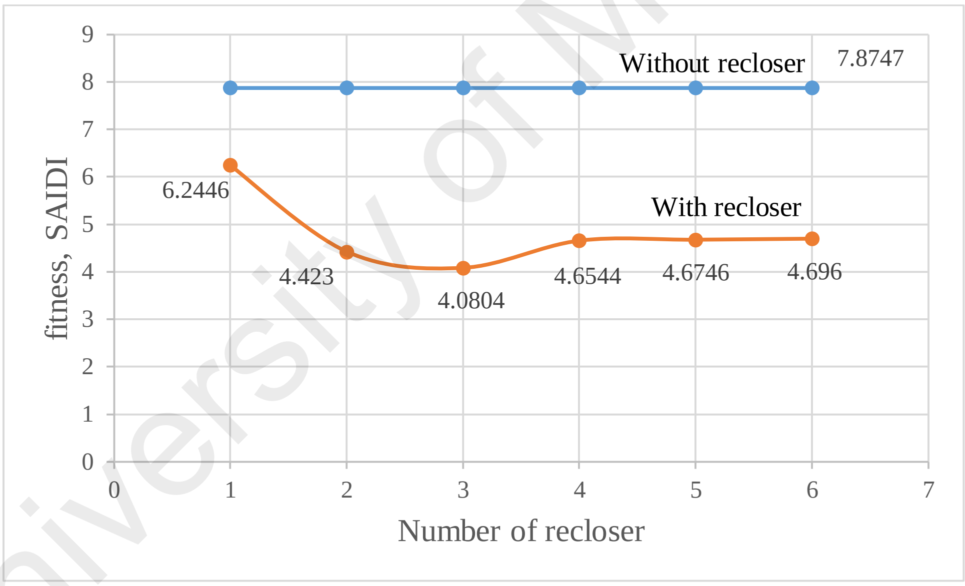


Figure 4.26: Number of impact recloser placement in reliability indices, SAIDI

Reliability index, SAIFI for one recloser placement is 0.4107 which reduced 19.64% from original value which is 0.5111 and reliability index, SAIDI is 6.2446 reduced 20.70% from original value of 7.8747. These reliability indices give the same optimal location recloser placement which is P19.

For two recloser placement, the value for SAIFI is 0.2969 reduced 41.91% from original value which is 0.5111 and for SAIDI reduced 43.83% from original value 7.8747 to 4.4230. Both analysis also give the same optimal recloser placement which at P3 and P10. As for three recloser placement, the reliability indices for SAIFI and SAIDI reduced about 46.31% and 48.18%. These also give the same position of optimal recloser placement. The best location for three recloser placement at P3, P10 and P16.

As the number of recloser placement is increased to four and five, the reduction of percentage from original value to reliability indices value is slightly decreased which only 40% compared to one, two and three number of recloser placement. Thus, the result show that as the number of recloser placement increase, these not necessarily give the higher percentage of reduction value. These causes to fault and location of recloser placement that also give an effect to reliability indices. However, the reliability indices still decreases from the original value which is without recloser placement. Thus, maximized the system reliability.

For six recloser placement, the reliability index for SAIFI is 0.2202 which reduced 56.92% from initial value of 0.5111. The best location of recloser placement at P3, P10, P14, P15, P16 and P22. The reliability index for SAIDI is 4.6960 which reduced 40.36% from 7.8747. The best of location of recloser placement is different from SAIFI which at P3, P10, P14, P15, P16 and P19. However, the reliability index of SAIFI is mostly preferred as the reference in locating any switching devices compared to SAIDI. This is because SAIFI is referred as an expected number of interruption of supply for an average customer in system while for SAIDI is referred to expected unavailability of supply for an average customer in the system. Therefore, by comparing value of SAIFI and SAIDI, SAIFI has the highest reduced of reliability index. Thus, system reliability performance is maximizes.

As a result, different number of recloser placement give different value of reliability indices. For one, two and three recloser placement, the reduced percentage of reliability index value is high as the number of recloser increase. However, four and five recloser placement give small reduced percentage compared to others. This due to fault occurs at the location in system. Hence, increase number of recloser placement is not necessarily reduced the reliability indices. When the number of recloser placement increase to six, the reliability indices give the better value. Noted that increase the number of recloser will increase the cost too.

CHAPTER 5: CONCLUSION

5.1 Summary

In this project, the Roy Billinton Test System (RBTS) bus 5 had been studied in order to analyze the impact of different number of recloser placement in distribution network. The maximum number of recloser placement have been tested up to six recloser placement. Different number allocation of recloser placement give different value of reliability indices. The Particle Swarm Optimization (PSO) method was used to determine the optimal placement of recloser in order to maximize the system reliability. As a result, minimum value of reliability indices of SAIFI and SAIDI was achieved. Therefore, the best placement of recloser had been successfully obtained in this study by using PSO method.

The PSO method was optimized to find the best recloser placement with different number of recloser. The performance of different number recloser placement was analyzed based on reliability indices SAIFI and SAIDI. Result show that by installing more recloser, the value of reliability indices are reduced. The improvement by using optimal recloser placement up to six recloser are 19.64%, 41.91%, 46.31%, 40.27%, 40.01% and 56.92% for SAIFI and for SAIDI are 20.70%, 43.83%, 48.18%, 40.89%, 40.64% and 40.36%. This gives positive impact to the system reliability. However, as the number recloser increase up to five, the value of reliability indices is not necessarily decreasing. This due to location of fault available in the system. Besides, the increment number of recloser will be imposed huge cost as well. Therefore, installation of recloser based on reliability indices plays important role to the distribution network.

The PSO method also show the minimum solution at less iteration based on convergence characteristic. It can be concluded that PSO method had successfully obtained the best possible location of recloser placement based on minimum value of reliability indices. Moreover, most of researchers work on PSO algorithm because PSO uses shorter time to simulate compare to other algorithms (Zonkoly, 2011).

5.2 Recommendation for future

The minimum value of reliability indices, SAIFI and SAIDI of the optimal recloser placement using PSO can be improved by considering the following considerations:

1) In the PSO algorithm can also include other factors such as sectionalizers and cut out fuses in order to maximize system reliability because according to (Hashemi et al., 2016), simultaneous placement of sectionalizers, cut out fuses and recloser can reduced more reliability indices.

2) The reliability indices are typically measured by analytical or simulation method. Various algorithm can also solve optimization of recloser placement in the distribution network such as ant colony algorithm, tabu search algorithm and others.

3) A multi-objective function of PSO can be design to improve optimization of recloser placement.

REFERENCES

Amanifar, O., & Golshan, H. Optimal DG Allocation and Sizing for Mitigating Voltage Sag in Distribution Systems with Respect to Economic Consideration Using Particle Swarm Optimization.

Billinton, R., & Jonnavithula, S. (1993). Adequacy evaluation in generation, transmission and distribution systems of an electric power system.

Billinton, R., & Jonnavithula, S. (1996). A test system for teaching overall power system reliability assessment. *IEEE Transactions on Power Systems, 11*(4), 1670-1676. doi: 10.1109/59.544626

Dahalan, W., & Mokhlis, H. (2012, 2-5 December 2012). *Network reconfiguration for loss reduction with distributed generations using PSO*. Paper presented at the 2012 IEEE International Conference on Power and Energy (PECon).

Dan, A., Hartmann, B., Kiss, J., & Vokony, I. (2015, June 29 2015-July 2 2015). *Recloser application possibilities and the related benefits at a Hungarian MV network.* Paper presented at the PowerTech, 2015 IEEE Eindhoven.

Gludpetch, S., & Tayjasanant, T. (2013). Optimal Placement of protective devices for improving reliability indices in microgrid system.

Golestani, S., & Tadayon, M. (2011, 25-27 May 2011). *Optimal switch placement in distribution power system using linear fragmented particle swarm optimization algorithm preprocessed by GA*. Paper presented at the 2011 8th International Conference on the European Energy Market (EEM).

Gonen, T. (1986). Electric Power Distribution System Engineering. New York: McGraw Hill Book CO.

Hashemi, S., Barati, S., & Talati, S. (2016). A genetic algorithm approach to optimal placement of switching and protective equipment on a distribution network. *ARPN Journal of Engeneering and Applied Sciences, 11*(3).

Juneja, M., & Nagar, S. K. (2016). *Particle swarm optimization algorithm and its parameters: A review.* Paper presented at the 2016 International Conference on Control, Computing, Communication and Materials (ICCCCM).

K. Jithendra Gowd, C. S. B., S. Sivanagaraju. (2014). Reliability Analysis of the Unbalanced Distribution Systems considering Distributed Generators. *International Journal of Recent Technology and Engineering (IJRTE), 3*(4).

Lindsay, N. M. Enhancing Power System Reliability using Multiple.

Moradi, M. H., & Abedini, M. (2012). A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems. *International Journal of Electrical Power & Energy Systems, 34*(1), 66-74.

Neha Munsi, M. J. (2014). Fault Tolerance in Distribution System. *2*(9), 289-293.

Nematollah Delghani, R. D. (2011). Optimization of Recloser Placement to Improve Reliability by Genetic Algorithm. *Energy and Power Engineering*, 508-512. doi:10.4236/epe.2011.34061

Qin, Q., & Wu, N. E. (2014, 27-31 July 2014). *Recloser and sectionalizer placement for reliability improvement using discrete event simulation.* Paper presented at the 2014 IEEE PES General Meeting | Conference & Exposition.

Qin, Q., & Wu, N. E. (2015, 26-30 July 2015). *Recloser allocation and placement for rural distribution systems.* Paper presented at the 2015 IEEE Power & Energy Society General Meeting.

Rajarakshmi, J., & Duraraj, S. (2016). Review on optimal distributed generation placement using Particle Swarm Optimization Algorithms.

Reddy, S. C., Prasad, P. V. N., & Laxmi, A. J. (2012). *Reliability Improvement of Distribution system by Optimal Placement of DGs using PSO and Neural Network*. Paper presented at the 2012 International Conference on Computing, Electronics and Electrical Technologies (ICCEET).

Robert, E., Goodin, L. M., Timothy, S., & Fahey, A. H. (January, 1999). Distribution Reliability using Reclosers and Sectionalizers: ABB.

Tippachon, W., & Rerkpreedapong, D. (2009). Multiobjective optimal placement of switches and protective devices in electric power distribution systems using ant colony optimization. *Electric Power Systems Research, 79*(7), 1171-1178. doi: http://dx.doi.org/10.1016/j.epsr.2009.02.006

Wang, T., & Singh, C. (2016). Reliability-Constrained Optimum Recloser Placement in Distributed Generation Using Ant Colony System Algorithm.

Zhang, L., Xu, Y., & Wang, Z. (2008, 6-9 April 2008). *Research on optimization of recloser placement of DG-enhanced distribution networks*. Paper presented at the Electric Utility Deregulation and Restructuring and Power Technologies, 2008. DPRT 2008. Third International Conference on.

Zhou, Q., Shirmohammadi, D., & Liu, W. H. E. (1997). Distribution Feeder Reconfiguration for Operation Cost Reduction. *IEEE Transactions on Power Systems, 12*(2), 730-735.