SUPERVISOR DECLARATION

"I hereby declare that I have read through this report entitle "Improvement of Radial Distribution Network with Distribution Generation (DG) by using Improved Genetic Algorithm (IGA)" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)"

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IMPROVEMENT OF RADIAL DISTRIBUTION NETWORK WITH DISTRIBUTED GENERATION (DG) BY USING IMPROVED GENETIC ALGORITHM (IGA)

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A report submitted in partial fulfillment of the requirement for the degree of Bachelor of Electrical Engineering (Power Industry)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

STUDENT DECLARATION

I declare that this report entitle "Improvement of Radial Distribution Network with Distributed Generation (DG) by Using Improved Genetic Algorithm (IGA)" is the result of my own project except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : MUHD AFIF FIKRI BIN AZAHAR

Date :

To my beloved mother and father

ACKNOWLEDGEMENT

Thanks to Allah S.W.T for give me the passion for completing this Final Year Project well.

Special thanks to my supervisor, Miss Nur Hazahsha Binti Shamsudin for guiding me in the thesis and project preparation. The person that give me a lot of advice and guidelines to make sure the project can be performed efficiently and produce the best result.

I would like to appreciate to my parent and whole family which always give a support continuously. Thank you for giving me the courage and strength that is necessary to complete this project.

Lastly, I would like to express my sincerity appreciation to all lecturers of Universiti Teknikal Malaysia Melaka (UTeM) and all of my friends for giving guidance, motivation and information to me. Thank you for all the help and support that was given.

ABSTRACT

The distribution systems deliver power to the customers from a set of distribution substations and these are normally configured radially for effective co-ordination of the protective systems. The distribution system contains two types of switches which are sectionalizing switches (normally closed) and tie switches (normally opened). The functions of these two switches are for protection and configuration management in the system. Power losses in electrical power network are mainly come from the distribution system due to the increment in load demand. The growth of load demand has led to poor performances and efficiency of the distribution system. Therefore, distribution network reconfiguration (DNR) is introduced to solve the problem of power losses in distribution system. Distribution network reconfiguration (DNR) is a technique that resolves the group of tie-switches in the network that perform as the best route of optimal solution for power losses. Furthermore, the implementation of Distribution Generation (DG) in distribution system also helps to cater the power losses and fulfill the customers' demand. Improved genetic algorithm (IGA) is proposed and tested on IEEE 33 and IEEE 69 bus system to ensure the validity and efficiency of the algorithm. There are two tested cases that are DNR without DG and DNR with DG. The results from the distribution network reconfiguration by using Improved Genetic Algorithm (IGA) help to reduce the total power losses and achieve faster computational time. Besides that, the presence of distribution generator (DG) makes the distribution system performs better than before DG installation. From the results, the performance of the crossover IGA is better than of the other approach that is GA.

Keywords: *Distribution Network Reconfiguration (DNR), Genetic Algorithm (GA), Improved Genetic Algorithm (IGA), Distributed Generator (DG)*

ABSTRAK

Sistem pengagihan berfungsi mengagihkan kuasa elektrik kepada pelanggan-pelanggan dari satu set pencawang pengagihan dan ini biasanya di konfigurasi secara jejari untuk penyelarasan sistem perlindungan yang berkesan. Sistem pengagihan mengandungi dua jenis suis yang iaitu suis 'sectionalizing' (biasanya ditutup) dan suis 'tie' (biasanya dibuka). Fungsi kedua-dua suis untuk perlindungan dan pengurusan konfigurasi dalam sistem. Kehilangan kuasa elektrik dalam rangkaian kuasa elektrik berpunca dari sistem pengagihan disebabkan oleh peningkatan dalam permintaan beban. Peningkatan permintaan beban telah membawa kepada prestasi buruk dan kecekapan sistem pengagihan. Oleh itu, konfigurasi semula rangkaian pengedaran (DNR) diperkenalkan untuk menyelesaikan masalah kehilangan kuasa dalam sistem pengagihan. Konfigurasi semula rangkaian pengedaran (DNR) adalah teknik yang memutuskan kumpulan tie-suis dalam rangkaian yang melaksanakan sebagai jalan terbaik penyelesaian optimum untuk kehilangan kuasa. Tambahan pula, pelaksanaan Generation Distribution (DG) dalam sistem pengagihan juga membantu untuk menampung kehilangan kuasa dan memenuhi permintaan pelanggan. Penambahbaikan algoritma genetik (IGA) dicadangkan dan diuji pada IEEE 33 dan IEEE sistem 69 bas untuk memastikan kesahihan dan kecekapan algoritma. Terdapat dua kes diuji yang DNR tanpa DG dan DNR dengan DG. Hasil daripada pengagihan rangkaian konfigurasi semula dengan menggunakan 'Improved Genetic Algorithm' IGA) membantu mengurangkan jumlah kehilangan kuasa. Selain itu, penggunaan 'Generation Distribution' (DG) membuat sistem pengagihan lebih baik daripada sebelum pemasangan DG. Daripada keputusan, prestasi IGA adalah lebih baik daripada GA.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Malaysia suffers from a total blackout after 35 years from the independent day which is in 1992 due to the lightning that strikes onto the transmission facility and leads failure to both transmission and distribution system. In 1996, the power system network tripped and caused blackout once again and consequently affected to Kuala Lumpur, Selangor, Putrajaya, Johor, Melaka and Negeri Sembilan for several hours. A power failure caused 5 hours of blackout in 2003 that affected southern parts of Peninsular Malaysia such as Malacca, Johor, Selangor, Negeri Sembilan and Kuala Lumpur [1]. Afterwards, the faults occurred at the main cable transmission line grid that caused blackout in northern peninsular including Perak, Penang, Kedah and Perlis in year 2005. These blackout occurrences from technical failure, bad weather, human failure and equipment fault. Fault can be considered by any inrush electric current that exists in electric power system caused from equipment failure. The blackout in the power system can cause power system equipment damage, heavy economic losses, and limit the communication between peoples or also known as consumers. A reliable and secure distribution system is needed to avoid any fault occurrence and also to make sure that the customers always get enough electric power supply without any disturbance.

Distribution network is known as connection between the transmission network and consumers. Out of totally generated electrical power, 13% of power is accounted for distribution losses [2].In order to reduce the power system cost, the losses that appear at distribution stage must be reduced. Distribution network reconfiguration is an important strategy in order to keep check on the problems arising due to the radial structure of the distribution system. The occurrence fault in the power system will enforce the system restoration to recover customer satisfactions. The system is attempted to restore network by isolating the affected area and give supply back to unaffected area. This is a response of the system due to blackout or fault. The power losses might be increase due to any blackout or fault in the distribution system. To reduce the distribution power losses, distribution network reconfiguration (DNR) need to be very effective. DNR is the method of changing the topological structure of the distribution network. The process in DNR is by closing the open or close status of sectionalizing and tie-switches for loss reduction. Other than DNR, distributed generator (DG) is another option to minimize the power losses in the distribution system.

DG is known as small scale generator which place near to the consumer's area. The effectiveness of DG implementation depends on the consistency of transmitting power with appropriate location and exact size of the DG. In [3], to find the best route and the most suitable size of DG, the distribution network can be reconfigured based on several ways of developing heuristic algorithms such as Tabu Search (TS), Simulating Anealing (SA), Genetic Algorithm (GA) and Improved Genetic Algorithm (IGA). Conventional GA is a calculation adjustment system that used research-based approaches direct binary coding. The principle used in GA is the evolution via natural selection, employing a population of individuals that undergo selection in the presence of operator such as mutation and crossover [4].

However, GA may take long time to evaluate the individuals due to the large population number required. Therefore, IGA is introduced in this paper to overcome the disadvantage of GA. The IGA consists of the same main idea as the GA but some improvement is done either at selection, crossover or mutation. In this project, the improvement is done at the crossover part. The results obtained are compared with the results of GA. IGA shows that the results are more accurate and the power losses are reduced.

1.2 Problem Statement

According to [6], successful arrangement of distribution network is compulsory to encounter the present rising domestic, industrial and commercial load day by day. The increment of load demand in the distribution system cause technical losses such as energy dissipated in the conductors, equipment used for transmission line, transformer, sub transmission line and distribution line and magnetic losses in transformers. The DNR method is the effective way that create new topology of network which able to reduce the power losses to optimum level. Other than that, the consideration of DG at the network is able to reduce power losses while DNR process takes place.

1.3 Objectives

The objectives below need to be successfully achieved in order to meet all requirement of minimizing the power losses of distribution network system.

1. To develop Improved Genetic Algorithm (IGA) for IEEE 33 and IEEE 69 buses test system of distribution network configuration in determining the best combination set of switches by using MATLAB vr2015b for load restoration via DNR.
2. To compare the reduction of power losses between the load restoration via DNR and without DNR.
3. To analyze the performance between IEEE 33 and IEEE 69 buses system via DNR with DG and DNR without DG using the improved genetic algorithm (IGA) and compare with genetic algorithm (GA).

1.4 Scope

For IEEE 33 and IEEE 69 buses system with base voltage of 132kV, the method of distribution network reconfiguration (DNR) is implemented in both networks. In this particular method, there are certain algorithms in finding the resolution of DNR such as Simulated Annealing (SA), Particle Swarm Optimization (PSO), Tabu Search (SA) and Genetic Algorithm (GA). Eventually, this DNR study only aim on using Improved Genetic Algorithm (IGA). Besides that, the DG sizing of both networks will be defined using the GA and IGA method with varies in DG position. MATLAB vr2015b is used to implement the improved genetic algorithm (IGA). Finally, the performance of system when including DG and without DG is compared in term of power losses.

1.5 Expected project outcome

At the end of this project, the load restoration distribution IEEE 33 and IEEE 69 buses are expected to be able reduces power losses via network reconfiguration (DNR). This system uses the method of improved genetic algorithm (IGA) to reconfigure the radial configuration system.

1.6 Significance of project

With the reconfiguration of the distribution network of IEEE 33 and IEEE 69 buses test system of distribution network configuration, a better optimization of power delivering and improving the minimizing of power losses is provided. Improved genetic algorithm (IGA) is used as an evolutionary search engine to accomplish the objective of the reconfiguration.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Based on the problem statement, objective and scope in the Chapter 1, a study on the theory and basic principle is done in order to fully understand the project. The theory on distribution network system (DNS), distribution network reconfiguration (DNR), genetic algorithm (GA) and improved genetic algorithm (IGA) are explained in this sub-chapter.

2.2 Distribution Network System

Distribution Network System (DNS) hold a very significant position in the power system since it is the main point of link between bulk power and consumers. The main function of the DNS is to provide or deliver the power to the consumers. Thus, distribution network system can be divided into three components: distribution substation, distribution primary and secondary. At the substation level, the voltage is reduced and the power is distributed in a smaller amount to the customers. Furthermore, the protection devices such as switchgear, fuse, relay and circuit breaker also were placed in the substation level. The primary distribution system includes feeders coming out from the substation and supplying power to several secondary distribution systems.

2.2.1 Radial distribution system

Radial distribution system is the most common system used because of the simplest and least expensive system to be built. In this system, the power in primary feeder is supplied from distribution substation to the load areas through the sub-feeders and branch circuit [5]. A radial system has only one power source for a group of customers. Radial feeders are characterized by having only one path for the power to flow from the source (distribution substation) to each customer. According to [6], radial system has its own advantages and disadvantages. The advantages of radial system are its simplicity and low cost, the amount of switching equipment required is small and protective relaying is simple. The major disadvantage of radial system is its lack of security of supply. It is not the most reliable system, because a fault or short circuit in a main feeder may result in a power outage to all the users served by the system. A schematic example of a radial distribution system is shown in Figure 2.1.

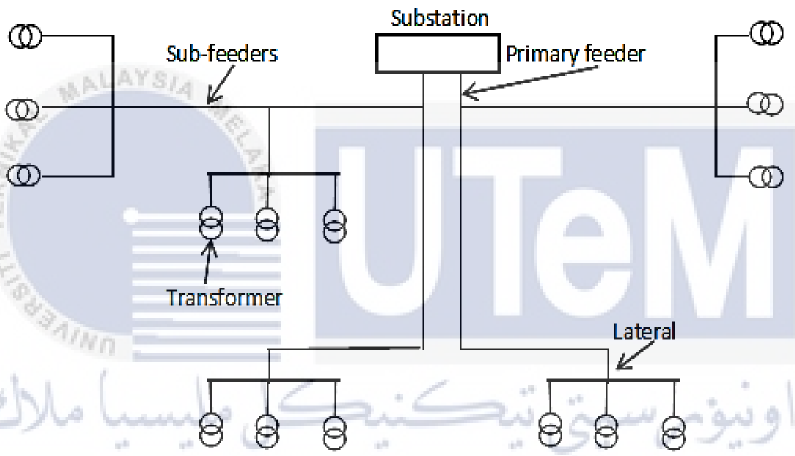

Figure 2.1: Radial distribution system [5]

2.2.2 Ring main system

The loop (or ring) distribution system is one that starts at a distribution substation, runs through or around an area serving one or more distribution transformers or load Centre, and returns to the same substation [5]. The advantages of main ring system are less voltage fluctuations at consumer's terminal and the system is very reliable because of the feeder always interconnected with each other. In case faults were happen at any section of feeder, the continuity of supply is maintained.

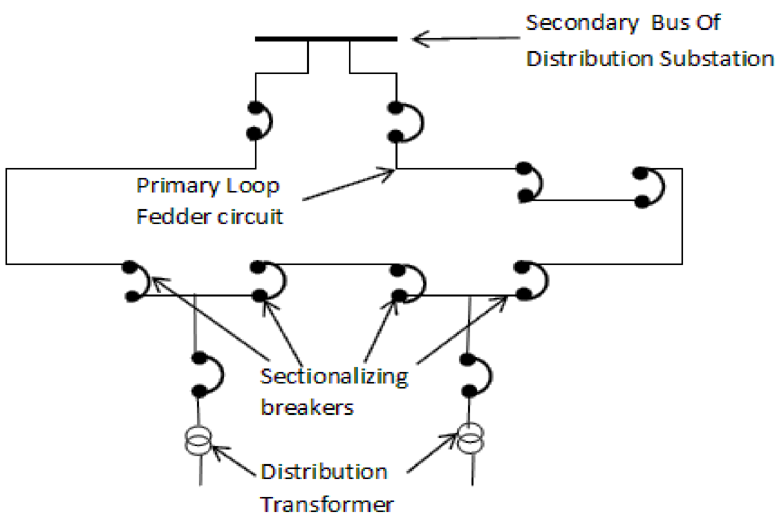

Figure 2.2: Ring main system [5]

2.2.3 Interconnected system

Interconnected system provides the reliability to the distribution system. The system is supplied from two or more distribution substations. Power can flow from any substation to any distribution transformer or load in the network system. The system is adapted to the additional and expansion of network due to many feeders connected.

For this reason, interconnected system is commonly used at high load density which town and residential area [6]. The energized feeder by two or more generating station or substation, it is well known as interconnected system.

2.3 Distribution network reconfiguration (DNR)

Network reconfiguration in distribution networks is recognized by changing the status of sectionalizing switches and is usually done for loss reduction. As there are multiple constraints in the distribution networks reconfiguration, it belongs to a complex combinatorial optimization problem. In network reconfiguration for loss reduction, the solution is required to search radial configurations for the network. Besides that, distribution network reconfiguration (DNR) also provide the solution for load balancing, service restoration and improve the quality and reliability of power supply. According to [7], one of the major problems in the reconfiguration criteria is the representation of the configuration which means the network must be operated in a radial manner. Otherwise, the entire system will lose one of the operating constraints.

Distribution network reconfiguration (DNR) is an important technique for solving optimization network problem. Advanced researches have been carried out in the reconfiguration strategies to come out with new formulated method. Artificial intelligence algorithms are implemented in distribution network reconfiguration (DNR) to optimize the system. Artificial intelligence algorithms are arrangement computer science and formulated mathematical technique such as genetic programming, heuristics, pattern recognition, inference and data analytic. There are examples of the artificial intelligence algorithm such as Particle Swarm Optimization, Simulated Annealing and Genetic Algorithm [8, 9].

Particle Swamp Optimization (PSO) is 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 [8]. PSO is capable of solving large-scale problems arose in network reconfiguration as compared to the existing methods such as Artificial Bee Colony (ABC).

Simulated Annealing (SA) is well suited for solving combinatorial optimization problems because simulated annealing can prevent from local minima. Annealing process is the process of heating the solid in the hot liquid by increasing the liquid until the solid is melted with the liquid then the temperature is decreased slowly [9]. However, the use of simulated annealing is also responsible for an excessive computation time requirement.

Genetic algorithm (GA) which has becomes very popular for network optimization. In [10], GA combines solution evaluation with randomized, structured exchanges of information between solutions to obtain optimality. Genetic algorithms are considered to be robust methods because restrictions on solution space are not made during the process. The benefit of GA is the ability to access the historical information structure from the previous solution in order to develop the better future solution.

2.4 Distribution Generation

A power generation system is an industrial facility for the generation of electricity. It is a process of producing electric power that used other sources of main energy. Thus, power plant is located near the power source such as fuel sources for fuel power plant or dam for hydropower plant. Furthermore, power plant eventually located further from the customer due to environmental concern. A long distant of power transmission from generation system to distribution system has contributed to power losses. As stated in [10, 11], the main advantages of distribution generation are:

1. Reduced line losses
2. Voltage profile improvement
3. Reduced emissions of pollutants
4. Increased overall energy efficiency
5. Enhanced system reliability and security
6. Improved power quality and relieved transmission and distribution congestion
7. Reduced operation and maintenance costs of some DG technologies
8. Enhanced productivity
9. Reduced health care costs due to improved environment and
10. Reduced fuel costs due to increased overall efficiency

Distributed generation (DG) is an alternative electricity supply instead of the traditional centralized power supply. The power generated by distributed generation (DG) is sufficiently smaller than centralized power supply at any point in power system. The purpose is to cater back the power losses and at the same time fulfill the consumers' demand.

2.5 Genetic Algorithm (GA)

One of the methods that able to produced global optimal solution is genetic algorithm (GA). Genetic algorithm uses the principle of natural evolution and population genetics to search and attain at a high quality near global solution. A set of chromosomes known as initial solutions is used in GA. The group of chromosomes is named a population. The quality of a child produced is judged by the fitness function, which is derived from the objective function and is used in successive genetic operation. During each generation procedure, a new set of child with improved performance is generated using three GA operators which are selection, crossover and mutation.

Genetic algorithm (GA) first defines the chromosomes according to fitness function before going through selection process. The next stage of genetic algorithm (GA) would be crossover. Crossover is the process of selecting a random position in the parent's strings and exchanges the characters either left or right of this point with each other. This random position is called the crossover point. The last stage is the mutation process. Mutation is the process of random alteration of a child position by changing "0" to "1" or vice versa, with a small probability. This condition is repeated until it finds the best improvement of solutions.

2.6 Improved Genetic Algorithm (IGA)

Improved Genetic Algorithm (IGA) is the upgrade of the conventional genetic algorithm (GA) that can generate a better set of solution with faster computational time. Genetic algorithm (GA) is generally influenced by its operators. Therefore, a good improvement of genetic algorithm (IGA) can be found by varying selected stage either at selection, crossover or mutation operator [13].

A group of chromosome is ranked based on fitness size. In [14], chromosomes with the high fitness value have possibility to be selected as the parents. The fitness value represents the total power losses produced by individuals. Parents with highest fitness are selected in selection process. In this selection process, the improvement of genetic algorithm can be improved by arranging the chromosomes into a group from the best fitness to the least fitness. As for crossover process, a uniform crossover and multipoint crossover is the example of the types of crossover operator that can be used instead of the single point crossover in conventional genetic algorithm (GA). The child produced when some segment in both parents is exchange before proceed to the mutation process. Mutation takes place after the crossover is performed. The new offspring create by crossover is randomly changes based on the mathematical. For example, a few randomly chosen bits can be switch such as bits 1 to 0 or 0 to 1.

The radial topology of the network is maintained to alter the valid solution when using improved genetic algorithm (IGA). So, every stages of genetic operator process need to take a proper measurement to perform the radiality of the network.

2.7 Review of previous related research

Nowadays, metaheuristic techniques are used in the reconfiguration of the distribution network. The examples of the techniques are Artificial Bee Colony (ABC), Genetic Algorithm (GA) and Improved Genetic Algorithm (IGA) [15, 16, 17]. These techniques are applied to obtain the lowest power losses in a distribution system.

The distribution network reconfiguration is recognized by changing the status of sectionalizing switches to minimize power losses due to a few system constraints. The constraints are the network radiality voltage limits and feeder capability limits. The metaheuristic methods can be applied to solve the problem due to its complexity. One of the methods is artificial bee colony (ABC). Artificial bee colony (ABC) is proposed as a new population based metaheuristics approach inspired by intelligent foraging behavior of honeybee swarm. There are three groups of bees in the colony of artificial bees which is employed bees, onlookers and scouts as stated in [15]. Artificial bee colony (ABC) has its own advantage in obtaining the lowest power losses in distribution system. Artificial bee colony (ABC) does not require external parameter as genetic algorithm (GA). The external parameters are known as crossover rate and mutation rate. However, artificial bee colony (ABC) has slower convergence characteristic compare to genetic algorithm (GA) as discussed in [16].

Genetic algorithm (GA) is proposed to overcome the problem of artificial bee colony (ABC). Genetic algorithm (GA) allowed the reduction of the search space and making the application of the algorithm possible for large distribution system. GA is an effective parameter search techniques that considered when conventional techniques have not achieved the desired speed, accuracy or efficiency. However, there is a disadvantage of genetic algorithm. The performance of GA is mainly influenced by its operators. Thus, a good improvement of genetic algorithm (GA) can be found by altering the operators in genetic algorithm (GA). An improvement of genetic algorithm (IGA) is applied at the selection operator as stated in [17] where the processes of selection random population take place first before the re-ranked processes for second selection. Other than selection operator, there are another two operators in genetic algorithm (GA) that can be the altering which is crossover and mutation operator. There are many types of crossover operator such as single point crossover, double point crossover and uniform crossover [18]. Double point and uniform crossover is the improvement from the single point crossover used in conventional genetic algorithm (GA). The results of the improved genetic algorithm (IGA) show a better reduction in power losses compared to genetic algorithm (GA).

Another way of solving the optimization problem is the presence of distributed generation (DG) in distribution system. Optimum distributed generation (DG) placement and sizing is one of the present topics in restructured power system. Most of the authors have come out on with own optimum placement based on the power losses reduction concept. To simultaneously reconfigure and identify the optimal locations for installation of distributed generation (DG) units in a distribution network, a metaheuristic Harmony Search Algorithm (HSA) is used [19]. Sensitivity analysis is used in order to determine optimal locations for installation of distribution generation (DG) units. Different scenarios of distributed generation (DG) placement and reconfiguration of network are recognized to study the performance of the proposed method.

Besides Harmony Search Algorithm (HS), another method which is partial swarm optimization (PSO) is also introduced. In [20], partial swarm optimization (PSO) is able to achieve an optimum configuration in network distribution and at the same time produces the optimal size of distributed generation (DG) and reduce power loss.

2.8 Summary of previous related research

Recently, a variety of optimization algorithms are developed to solved the network optimization problem such as power flow analysis and distribution network reconfiguration. Among the algorithms presently used are Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), Harmony Search algorithm (HSA), Genetic Algorithm (GA) and Improved Genetic Algorithm (IGA). The solution obtained from each algorithms contrast from one application to another. The review of previous research proved that the heuristic search algorithm used in distribution network reconfiguration (DNR) is very beneficial in order to improve the reliability and reduce the power losses. Distributed generation (DG) also gives a good impact to the power losses in the distribution system.

Genetic algorithm (GA) is mostly used as the proposed methods based on the previous papers. However, previous studies also prove that by improving the genetic algorithm operator can lead to better solution. This project proposed improved genetic algorithm (IGA) method to solve the complex optimization problem and find the best route of network configuration which have the optimum power losses reduction. The implementation of improvement of genetic algorithm (IGA) for network reconfiguration has given an excessive effect to the applied buses system which is IEEE 33 and IEEE 69 buses network system.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Principles of the methods or techniques

3.1.1 Conventional GA

Genetic algorithm is the principles and mechanisms of natural evolution and genetics. The evolution usually starts from a population of randomly generated individuals and happens in generations. In each generation, the fitness of every individual in the population is evaluated, multiple individuals are stochastically selected from the current population (based on their fitness), and modified (recombined and possibly randomly mutated) to form a new population. The new population is then used in the next iteration of the algorithm. Commonly, the algorithm terminates when either a maximum number of generations has been produced, or a satisfactory fitness level has been reached for the population. If the algorithm has terminated due to a maximum number of generations, a satisfactory solution may or may not have been reached. Initially, the chromosomes are defined according to the fitness function and then undergo the selection according to the roulette wheel method. Finally, crossover and mutation take place and the best solution is obtained. The process of GA is illustrated below.

3.1.2 Single point crossover in conventional GA

Single point crossover is used in the Genetic Algorithm (GA). There is only one shifting point that is needed in this type of crossover. The shifting of genes happened when the shifting point is reached.

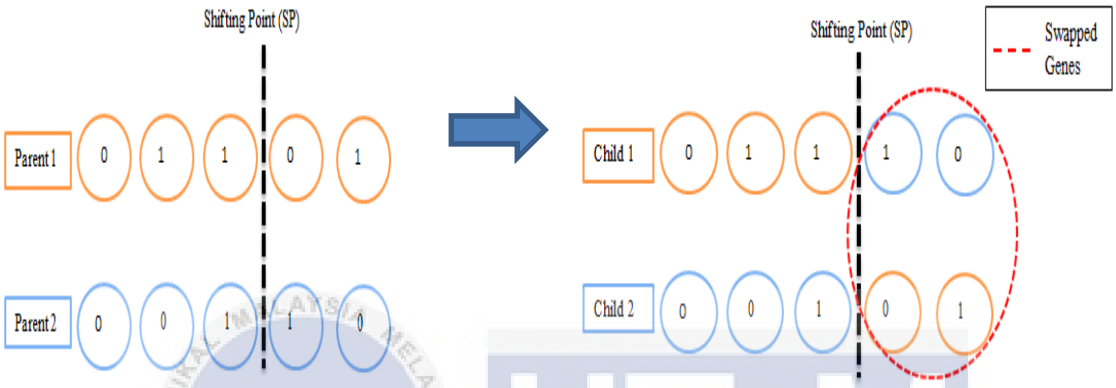

Figure 3.1: Process of Single point crossover

Figure 3.1 shows single point crossover where some genes in each parents are shifting or swapping with each other to produce new child. The crossover shifting point (S.P) is randomly chosen by the particular command in the algorithm. When the shifting point is reached, the genes for both parents are swapped with each other to form the new child which is Child 1 and Child 2. Child 1 inherits the genes of Parent 2 whereas Child 2 inherits the genes of Parent 1. As clearly shown in Figure 1, there are three non-swapped genes and two swapped genes existed.

3.1.3 Improved Genetic Algorithm (IGA)

Genetic algorithms are different from other methods in some ways. GA works on a population of possible solutions that make a most important difference compared to other methods that use a single solution in the iterations. The genetic algorithm used the fitness function, selection, crossover, and mutation.

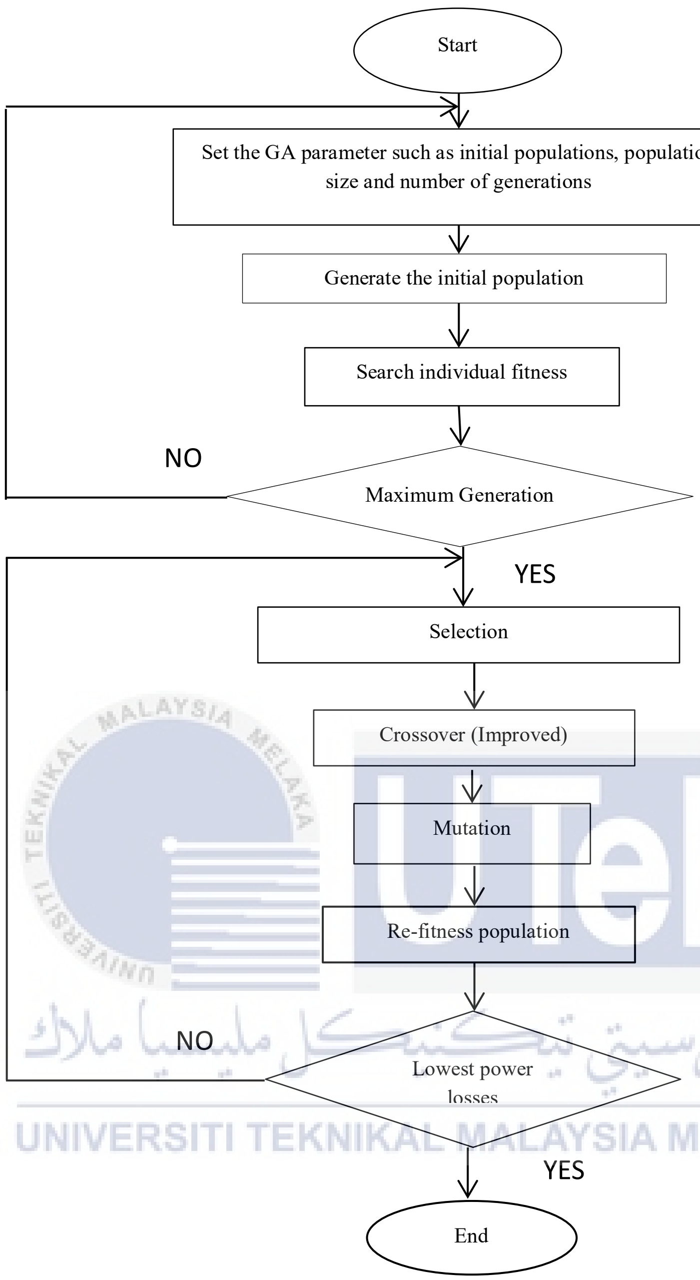

Figure 3.2: The flow of improved genetic algorithm

A. Fitness Function: A particular type of objective function that quantifies the optimality of a solution which is chromosome in a genetic algorithm is called as a fitness function. This particular chromosome may be ranked against all the other chromosomes. The fitness value represents the total power losses produced by individuals.

The evaluation process is conducted each time an individual is generated. The fitness is calculated using Newton Raphson method. Newton-Raphson Method equation at any given bus of i and j is as follow:

$$P_i = \sum_{j=1}^{n} |Y_i|\,|V_j||V_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) \neq i \quad (3.1)$$

$$Q_i = -\sum_{j=1}^{n} |Y_i|\,|V_j||V_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) \neq i \quad (3.2)$$

Where:

Vi,: Voltage magnitude of bus i and j respectively
δi,: Voltage angle of bus i and j respectively

The equation to define the difference in real power (Pi) and reactive power (Qi) is as follow:

$$Pi = Psch - Pi \quad (3.3)$$

$$Qi = Qsch - Qi \quad (3.4)$$

Where:
Pi and Qi are the specified real and reactive power at bus i respectively

The equation to define the power losses is as follow:

$$P_{loss} = \sum_{i=1}^{n}\sum_{i=1}^{n} A_{ij}\,(P_iP_j + Q_iQ_j) + B_{ij}(Q_iP_j - P_iQ_j) \quad (3.5)$$

$$Aij = \frac{\text{Rijcos}(\delta i - \delta j)}{ViVj} \quad (3.6)$$

$$Bij = \frac{\text{Rijcos}(\delta i - \delta j)}{ViVj} \quad (3.7)$$

Where:

Pi, : Real and reactive power at bus i respectively
Pj, : Real and reactive power at bus j respectively
Rij : Line resistance of bus i and j
Vi, : Voltage magnitude of bus i and j respectively
δi, : Voltage angle of bus i and j respectively

B. Selection: Parents are selected according to the fitness. The chances to be chosen are higher if the chromosomes are much better. In selection process, GA can be improved by arranging the chromosomes into a group from the best fitness to the least fitness.

C. Crossover: The genes from the parent chromosomes are selected through crossover. This creates a new child. The child is produced when some segment in both parents is exchange before proceed to the next step. A uniform crossover (UC), single point crossover or double point crossover can be used in order to make some improvement in GA. Example of crossover process is shows below:

$A_1 = 0\ 1\ 1\ 0 \mid 1$

$A_2 = 0\ 0\ 1\ 1 \mid 0$

The resulting crossover will be:

$B_1 = 0\ 1\ 1\ 0 \mid 0$

$B_2 = 0\ 0\ 1\ 1 \mid 1$

Where B_1 and B_2 are the new offspring formed.

The equation 3.8 and 3.9 are the cross of parents vector formula used in GA system.

child1 [j] = parent1 [i, rnd1], parent2 [rnd1, no. switch)] (3.8)

child2 [j] = parent2 [i, rnd1], parent1 [rnd1, no. switch)] (3.9)

D. Mutation: Mutation takes place after a Crossover is performed. Mutation changes randomly the new child. For binary encoding, a few randomly chosen bits can be switch such as bits 1 to 0 or 0 to 1.

Original Offspring 1	1	1	0	1	1	1	1	0
Original Offspring 2	1	1	0	1	1	0	0	1
Mutated Offspring 1	1	1	0	0	1	1	1	0
Mutated Offspring 2	1	1	0	1	1	0	1	1

Figure 3.3: Mutation process [12]

3.1.4 Multi-point crossover

For improved genetic algorithm (IGA), Multi point crossover is selected because it has more number of shifting point compared with single point crossover used in genetic algorithm (GA). The higher the number of shifting point led to better results of power losses reduction acquired. There are three shifting points that are in fixed position named as S.P1, S.P2, and S.P3. The steps of Multi point crossover are shown below.

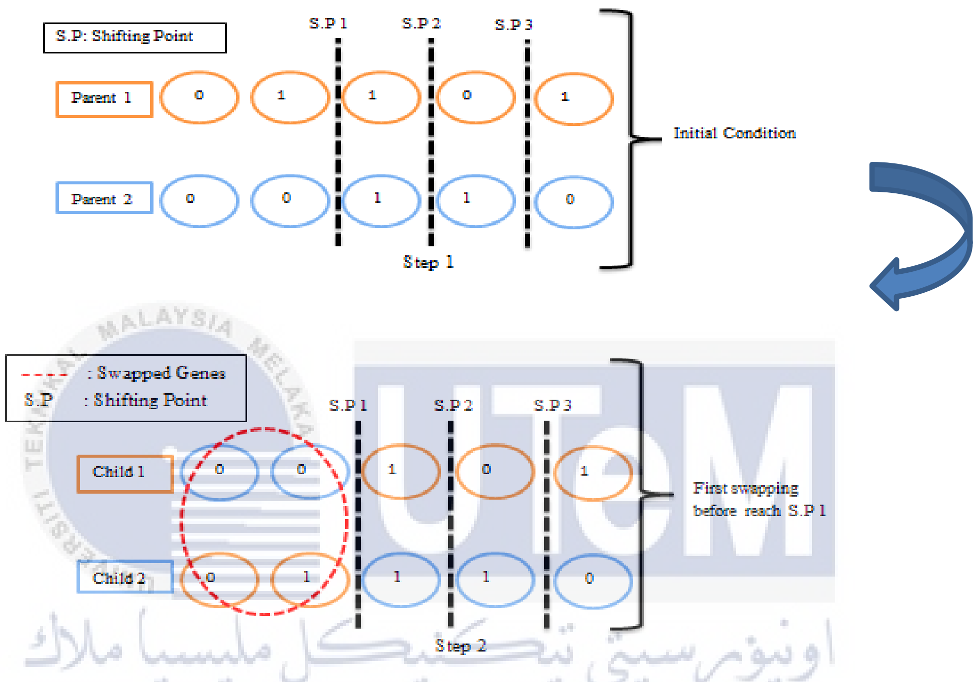

Figure 3.4: Step 1 and Step 2 of Multi-point crossover

Figure 3.4 shows the process of the multi-point crossover implemented in improved genetic algorithm (IGA). Step 1 shows the initial condition before the process of swapping of gene happen. In Step 2, the genes in the first area of Parent 1 and Parent 2 are swapped with each other. Thus, Child 1 inherits the genes of Parent 2 while Child 2 inherits the genes of Parent 1.

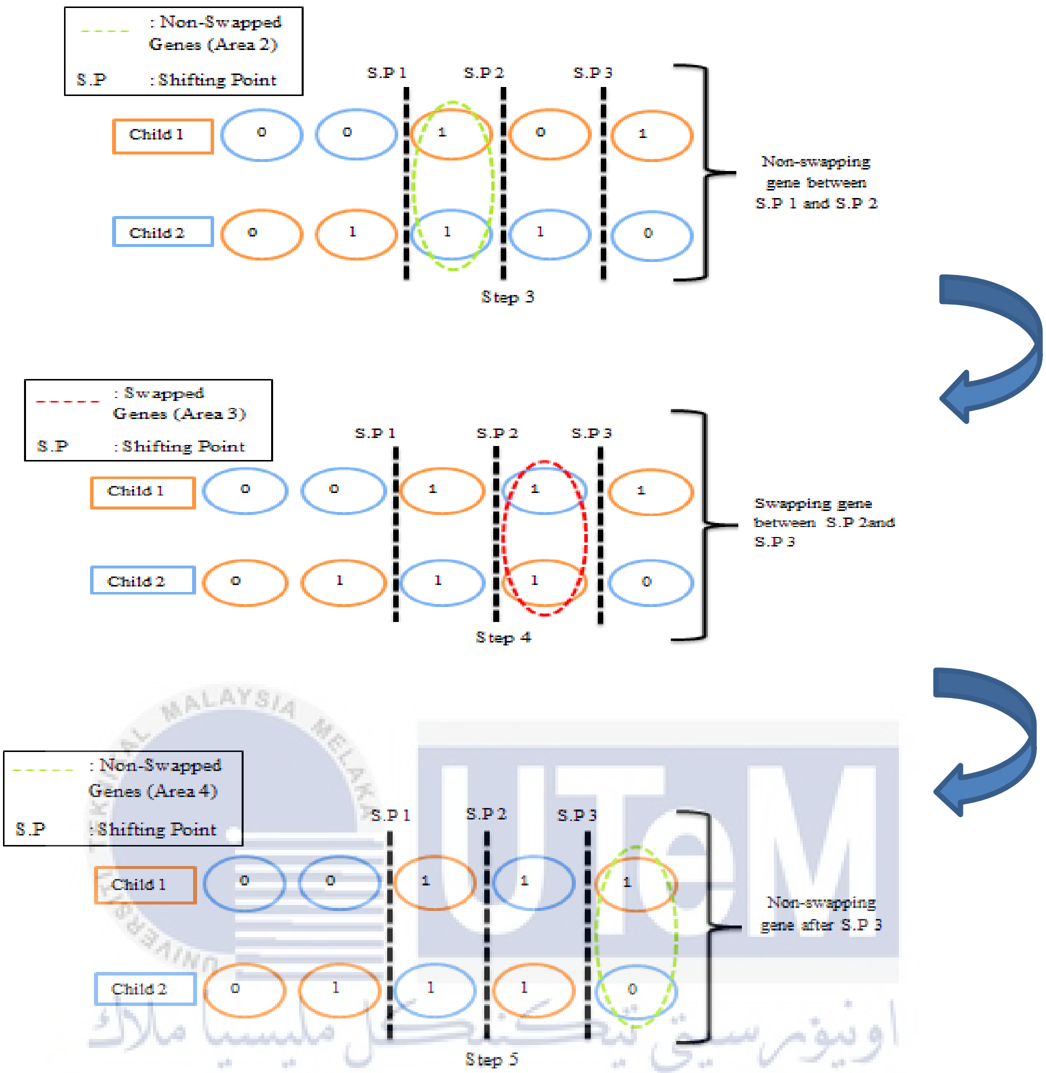

Figure 3.5: Step 3, Step 4 and Step 5 of Multi point crossover

After S.P 1 is reached as stated in Step 3, no swapping of gene occurs in area 2 for both parents. Hence, Child 1 and Child 2 copied the gene of its own parents respectively. According to Step 4, the gene of Parent 1 and Parent 2 in third area is swapping with each other when S.P 2 is reached and produced new Child 1 and Child 2. Child 1 inherited the gene of Parent 2 and Child 2 inherited the gene of Parent 1. Finally, the gene after S.P 3 is remaining the same gene since there is no swapping of gene occurs in last area. From the overall process of multi point crossover, there is some information that is remaining the same and some of the information is being changed. This is to maintain the genes' characteristics.

3.2 Implementation of Distribution Generation (DG)

DG is integrated in distribution network to provide reliable and uninterrupted power supply and also to achieve economic benefits such as minimum power loss and energy efficiency. However, higher power losses occur if the installations of DG are made at inappropriate locations and the size of the DG is incorrect. Therefore, it is very important to make sure that the location and the size of DG is appropriate to gain the optimum reduction of power losses. The power flow during the initial configuration is determined and set as a reference point. This reference point is act as a reference in determining the DG size. The changing of network power flow and voltage during the switching process is compared with the reference point. The sizing process for the combination of DG and GA program is repeated several times depending on the iteration setting. The best size of DG value within the limit of specific range with few parameter constraints applied is determined at the end of the combination of DG and GA program.

The implementation of DG in GA is prolonging the simulation to another stage which is DG sizing process. DG size is estimated or randomly chosen in the network before the calculation of optimal solution which is power losses is executed. For the implementation of improved genetic algorithm (IGA), the DG location is fixed to three buses which have the lower voltage profile. The DG sizing is randomly selected from the range of 1 MW to 4MW [10].

Besides that, the process and the flow of computation for IGA with implementation of DG are similar as GA with DG. The differences between both methods are at crossover operator. Multi-point crossover is used in IGA. Hence, the power losses reduction of the network is better than conventional GA.

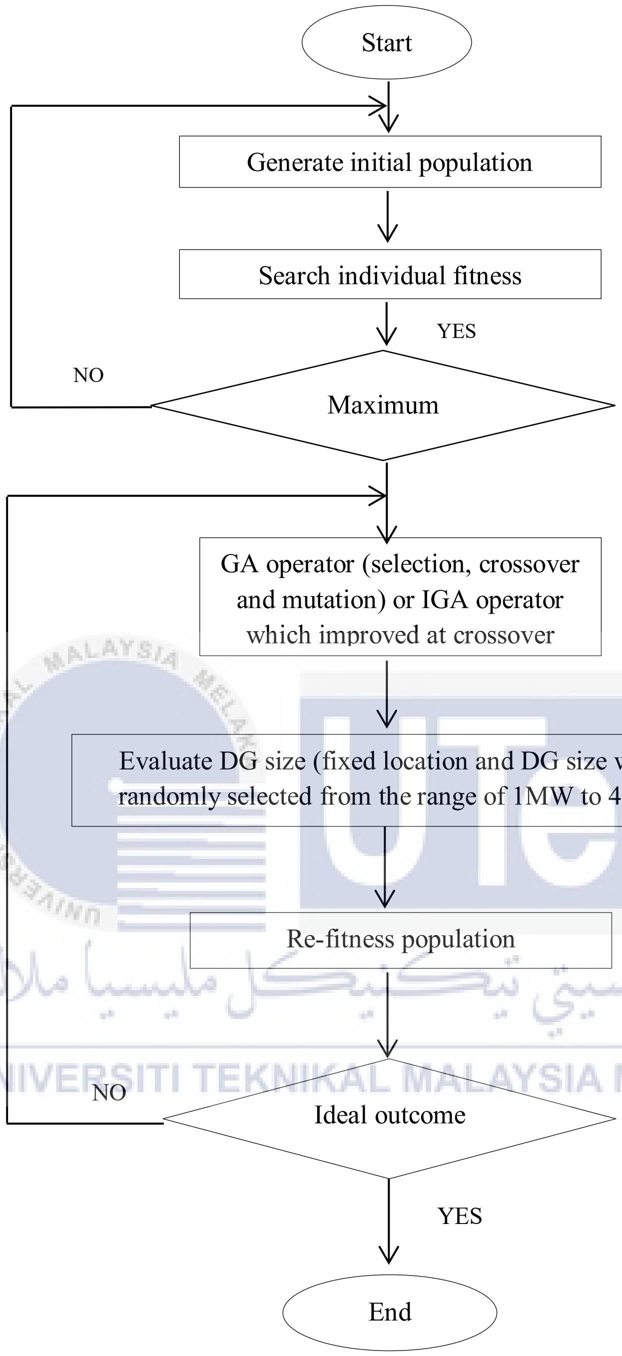

Figure 3.6: Flowchart of GA and IGA with consideration of DG

The parameter of DG is stated as below:

$$\sum_{i=1}^{N_{dg}} P_{dgi} < \sum_{i=1}^{N_L} P_{load\ i} \qquad (3.10)$$

Where:

$Pdgi$: Real power of DG capacity at bus location i

$Ploadi$: Load real power at bus i

Ndg : The total number of implemented DG units

NL : The total number of loads in the system

The total of DG capacity should be less than the system total loads as stated in (3.9). However, in real situation the DG capacity will naturally limited to its location energy resources as stated in (3.10) somehow make the first constraints is always within limit.

$$Pdg_i \le Pdg_{max}; \quad Pdg_{max} = 5MW \tag{3.11}$$

$$Pdg_i \ge Pdg_{min}; \quad Pdg_{min} = 25\% \, [Pdgi] \tag{3.12}$$

Where:

$Pdgi$: Real power of DG capacity at bus location i

Pdg_{max} : Maximum DG capacity

Pdg_{min} : Minimum DG capacity

The DG will supply power at least 25% of its location load for the minimum constraints [11]. The voltage can increase happen due to reverse flow of DG power after the implementation of DG. The increase in voltage preserved within standard limits at each bus. This voltage constraint is subjected to both cases condition that is DNR without DG and DNR with DG.

$$V_i \le V_{max}; \quad V_{max} = 1.0pu \tag{3.13}$$

$$V_i \le V_{min}; \quad V_{min} = 0.95pu \tag{3.14}$$

Where:

Vi : Voltage magnitude of bus i

$Vmax$: Maximum bus voltage in per-unit

$Vmin$: Minimum bus voltage in per-unit

DG is usually located at buses with low voltage profile so that the power generates is not only used at that bus but it can be transferred to other buses. The suitable feeder to place a DG in IEEE 33 buses is at bus number 16, 21 and 30 whereas the suitable feeder to place a DG in IEEE 69 buses is at bus number 61, 11 and 21.

3.3 Tested System

3.3.1 IEEE 33 buses system and IEEE 69 buses system

There are two algorithms named as genetic algorithm (GA) and improved genetic algorithm (IGA) executed on IEEE 33 buses system and also IEEE 69 buses system. IEEE 33 buses system consists of 32 sectionalizing switches whereas IEEE 69 buses system is designed with 68 sectionalizing switches. Both buses systems comprise of 5 tie-switches. The tie-switches are set to be opened while the sectionalizing switches are in closed condition for the initial configuration of the system. When distribution network reconfiguration (DNR) is performed, the normally tie-switches are closed to transfer the supply from one feeder to another. Meanwhile, the normally sectionalizing switches are opened to maintain the radiality of the configuration. Thus, it very important to make sure that the number of open branches must always equal to the number of close tie-switches. The best combination switches with lowest power losses can be determined throughout the reconfiguration process. Bus data and line data for both systems are attached in Appendix A and Appendix B. There are two conditions to be considered during the implementation of network reconfiguration. The conditions are DNR without DG and also DNR with the presence of DG in the system.

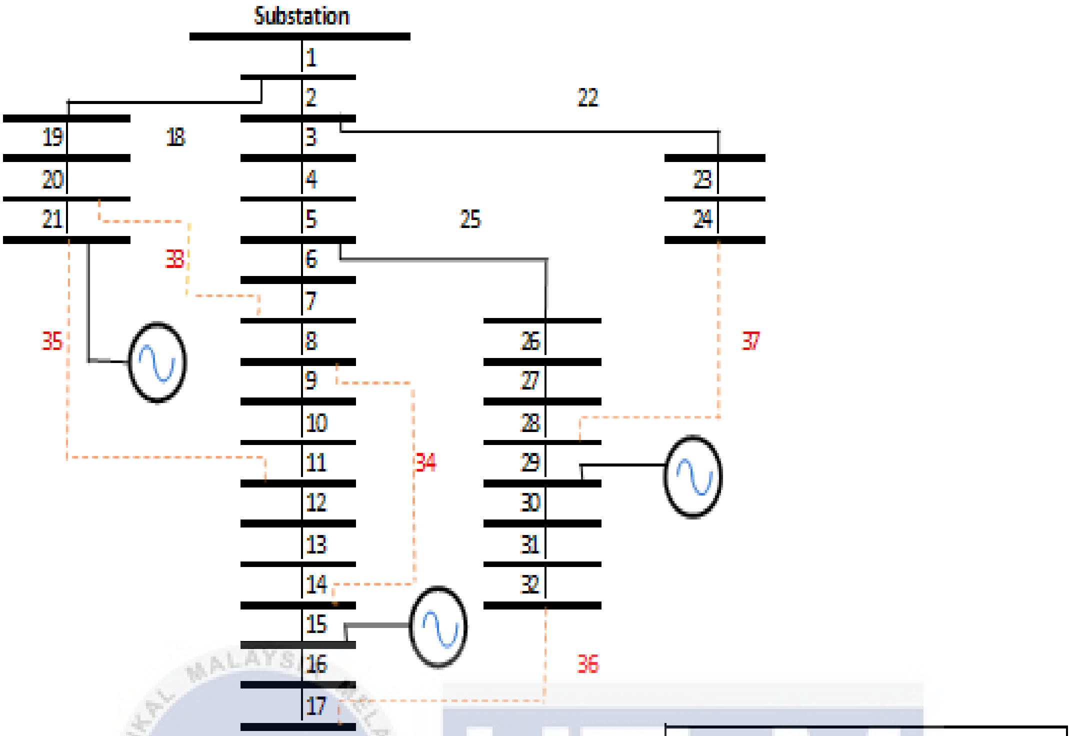

Figure 3.7: Initial configuration of IEEE 33 bus system with DG

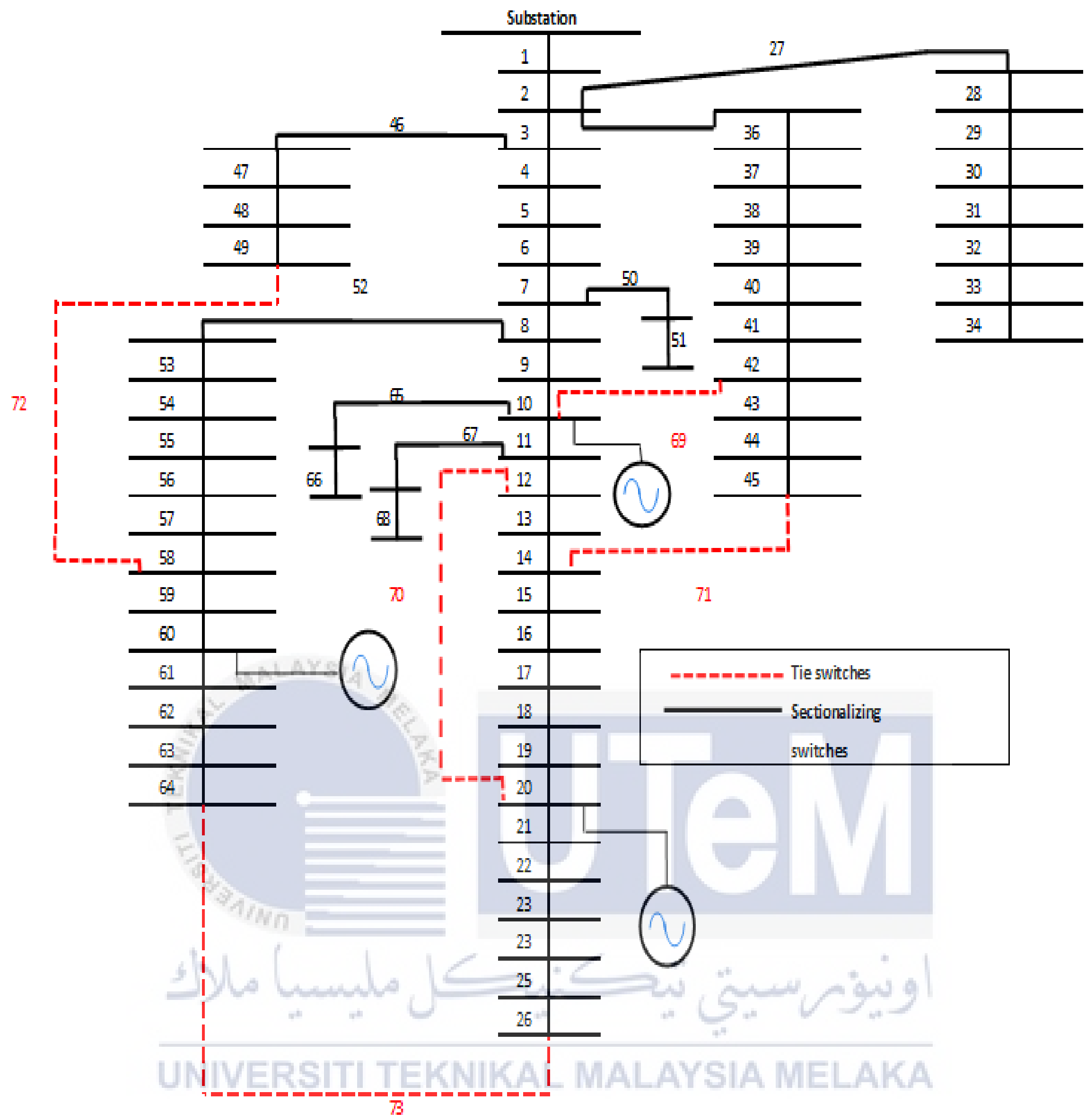

Figure 3.8: Initial configuration of IEEE 69 buses system with DG

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The objective of this research is to minimize the power losses in IEEE 33 and IEEE 69 bus system using distribution network reconfiguration (DNR) method. Improved Genetic Algorithm (IGA) is applied to solve for DNR problem and also determining the size of distributed generator (DG). The distribution network is tested by simulating into MATLAB software. The aim is to find the best route of distribution network that have the lowest power losses.

The IEEE 69 buses system consists of 5 tie switches and 68 sectionalized switches while IEEE 33 buses system contain 5 tie-switches and 32 sectionalized switches. When conducting DNR, the status of normally open (tie) and normally closed (sectionalized) switches is changed based on solution proposed by improved genetic algorithm while at the same time maintained the system radiality. The improvement in crossover operator helps faster the searching process with better result. As a result, the best route with lowest power losses is produced. Besides that, the results achieved by using IGA are compared with conventional GA. The results are shown as follows:

4.2 Initial configuration and DG positions

Table 4.1: Total power losses for initial configuration

Tested Network	No of switches	Total power loss (kW)	DG location
IEEE 33	33,34,35,36,37	162.0	16,30,22
IEEE 69	69,70,71,72,73	88.9	11,21,61

The result in Table 4.1 is achieved from the simulation of power flow analysis using the Newton-Raphson method. The tie-switches in initial configuration for IEEE 33 buses system are 33, 34, 35, 36 and 37 respectively. The power losses for IEEE 33 buses system is 162.0kW and the DG locations are at 16, 30 and 32. For IEEE 69 buses system, the open switches are at 69,70,71,72 and 73 respectively. The power loss for IEEE 69 is 88.9kW and the DG locations are at 11, 21 and 61. Both network power losses reduction after the DNR process is compared with this initial value.

4.3 The DNR without DG

The DNR without DG is the first condition that has been tested for both networks. In this particular condition, there are two methods that have been taken in order to find the five open switches that will give the lowest total power losses. There are 30 numbers of populations and the crossover probability is at 0.5. For each method, the best result is chosen based on the total power losses reduction and the DG sizing.

Table 4.2: DNR without DG for IEEE 33 buses

DNR without DG		
Bus	IEEE 33	
Algorithm	GA IEEE 33	IGA (crossover) IEEE 33
No of switch selection	5	5
No of switches	14, 28, 7, 17, 8	32, 10, 27, 14, 7
Total power losses (kW)	124.7	120.8
Total power losses reduction (kW)	37.4	41.2
Percentage of reduction	23%	25%

According to Table 4.2, the best combination of five tie-switches when using the conventional GA for IEEE 33 network is 14,28,7,17,8. The total power losses are 124.7kW and the percentage reduction of power losses is 23%. After the implementation of IGA, there is a decrement in total power losses achieved compared with the total power losses in genetic algorithm. The percentage reduction of power losses by using IGA is increased with value of 25%.

From the analysis, the implementation of IGA at crossover increases the reduction of total power losses better than conventional GA due to the multi-point crossover technique. The multi-point crossover technique provides better exchange in genes between both parents and increase the probability of getting lower power losses. Thus, multi-point crossover has more shifting points compared to the conventional genetic algorithm. Moreover, the multi-point crossover increases the power losses reduction about 3.8kW from conventional GA.

Table 4.3: DNR without DG for IEEE 69 buses

	DNR without DG	
Bus	IEEE 69	
Algorithm	GA IEEE 69	IGA (crossover) IEEE 69
No of switch selection	5	5
No of switches	12, 13, 57, 61, 10	59, 58, 20, 35, 69
Total power losses (kW)	51.6	48.8
Total power losses reduction (kW)	37.4	40.1
Percentage of reduction	42%	45%

For GA IEEE 69 buses, the total percentage reduction of power losses is 42% and total power losses of 51.6kW. The percentage reduction of power losses increase after the application of IGA at crossover with value of 45%. There is also a decrement in total power losses after IGA is implemented with the value of 48.8kW compared to the value achieved in genetic algorithm. This is because of the multi-point crossover used in IGA that has more shifting points compared to the conventional genetic algorithm. For instance, proposed algorithm proved that the larger the network the higher total power losses reduction that can be seen from the IEEE 33 and IEEE 69 buses system.

Table 4.4: Computational time for particular simulation

Network	Type of Algorithm	Computational time (s)
IEEE 33	GA	37.79
	IGA(crossover)	29.78
IEEE 69	GA	58.92
	IGA(crossover)	49.53

The computational time is the length of time required to perform a computational process. From the Table 4.4, IEEE 33 using GA and IGA completed the simulation with 37.79 and 29.78s respectively. For IEEE 69 buses system computational time, the GA method required 58.92s and the IGA method required 49.53s to complete the simulation. Based on the result, the bigger the network the longer the time required to compute the simulation. IGA method proposed faster computational time the conventional GA.

4.4 DNR with DG

In this part, the distribution network reconfiguration (DNR) is tested with the presence of distributed generation (DG). There are three fixed positions of distributed generation (DG) placed in the network. With the application of distributed generation (DG), the results achieved produced lowest total power losses compared to the distribution network reconfiguration (DNR) without distributed generation (DG).

Table 4.5: DNR with DG

DNR with DG		
Bus	IEEE 33	
Algorithm	GA IEEE 33	IGA (crossover) IEEE 33
No of switch selection	5	5
No of switches	14, 10,27,17,6	18,12,24,13,2
Total power losses (kW)	112	105.1
Total power losses reduction (kW)	50	56.9
Percentage of reduction	30.9%	35.1%
DG place	16,30,22	16,30,22
DG size (MW)	0.4225 1.425 1.0631	1.1713 0.6168 1.0761
Total DG capacity (MW)	2.6287	2.8642

From Table 4.5, the position of the DG for IEEE 33 buses in both techniques is same due to the lowest voltage profile at the bus [11].The finest tie-switches configuration in IEEE 33 buses obtained by GA is 14, 10, 27, 17 and 6 with total power losses of 112kW.

The DG capacity is set to values 0.4225MW, 1.425MW and 1.0631MW for DG units at bus 16, 30 and 32 respectively. For the multi-point crossover implemented in IGA, the best configuration is 18, 12, 24, 13 and 2 with total power losses 105.1kW. This technique suggest DG capacity setting of 1.1713MW for DG at bus 16, 0.6168MW for DG at bus 30 and 1.0761MW for DG at bus 32. From the observation, the DNR with DG offer better of reduction in power losses due to the decrease of the current in the lines with the presence of DG units. Thus, the line current contribute to the power losses due to the heavy load and by considering the DG at the particular buses help to reduce the power losses

Table 4.6: DNR with DG for IEEE 69 buses

DNR with DG		
Bus	IEEE 69	
Algorithm	GA IEEE 69	IGA (crossover) IEEE 69
No of switch selection	5	5
No of switches	20,63,56,17,8	36,57,13,46,5
Total power losses (kW)	43	41.4
Total power losses reduction (kW)	45.9	47.5
Percentage of reduction	51.6%	53%
DG place	11,21,61	11,21,61
DG size (MW)	1.4223 0.5329 1.1687	0.6189 1.7588 0.5675
Total DG capacity (MW)	3.1239	2.9449

In Table 4.6, the DG for both methods in IEEE 69 buses is consider three units DG fixed at bus numbers 61, 11 and 21.For IEEE 69 buses using GA, the best configuration achieved created total power losses of 43kW with tie switches 20, 63, 56, 17 and 8. This method proposed DG capacity of 1.4223MW, 0.5329MW and 1.1687MW for DG unit at bus 11, 21 and 61 respectively. Finally, the lowest power losses configuration is obtained by crossover IGA with total power losses of 47.5kW.

The opened switches are 36,57,13,46 and 5 the DG capacity suggested is 1.4223MW, 0.5329MW and 1.1687MW for DG unit at bus 11, 21 and 61 respectively. It is obvious that more reduction of power losses after an implementation of DG in the network. From the analysis, the reduction power losses after DG consideration are at increased state due to location and sizing of the DG in the network. Therefore, the DG location is placed at three buses that have high voltage drop and optimal size of the DG sizing is randomly selected.

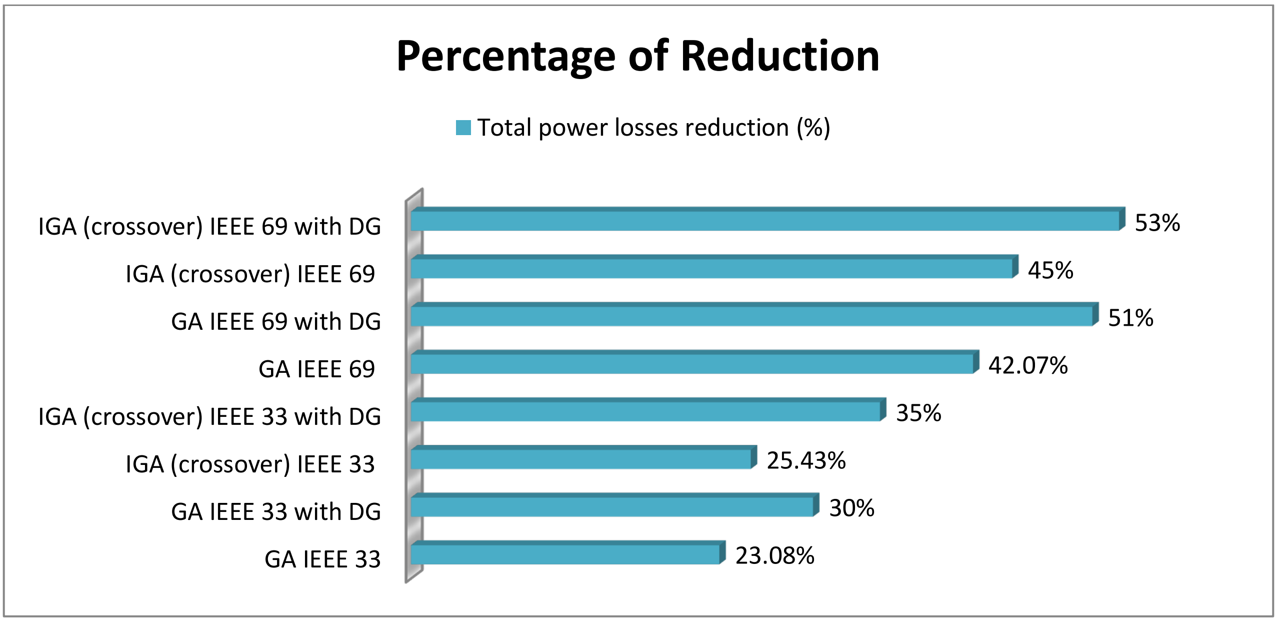

Figure 4.1: Comparison of the result for DNR with DG

The lowest percentage of total power losses reduction is obtained at GA IEEE 33 .The percentage of the reduction is about 23% from the initial power losses and followed with IGA (crossover) IEEE 33 that is 25% from the initial power losses.

For GA IEEE 69 tested network, the power losses reduction is about 42% and where increases after using IGA at 45% from the initial power losses. From the bar chart above, the increment about 2-3% of reduction after the crossover improvement related to both networks.

The implementations of DG into both tested network have shown a good enhancement in percentage of power losses reduction. According to Figure 4.1, the lowest reduction is acquired by GA IEEE 33 with 30.09% followed by IGA (crossover) IEEE 33 and GA IEEE 69 with reduction of 35.1% and 51.6% respectively.

The highest percentage of total power losses reduction is produced IGA (crossover) IEEE 69 that is 53%. From both tested condition; with and without DG, the crossover IGA method is proven as the most suitable method to be applied for DNR process. This is because of the multi-point crossover used in IGA that has more shifting points compared to the conventional genetic algorithm. The multi-point crossover technique provides greater interchange in genes between both chromosomes and increase the probability of receiving lower power losses.

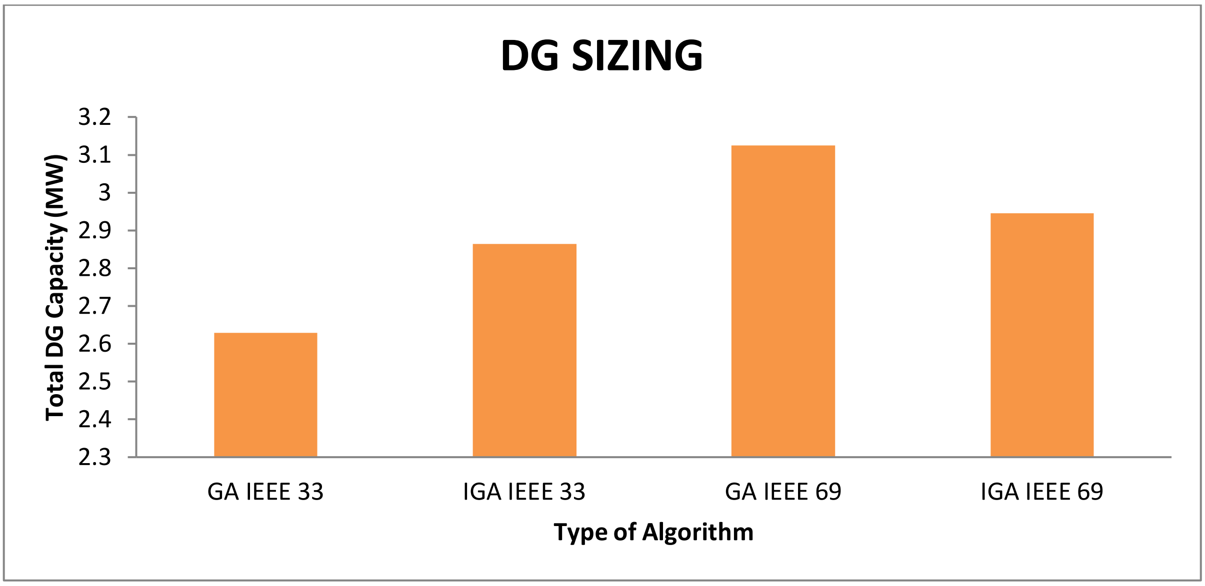

Figure 4.2: Total DG sizing

Figure 4.2 shows the total DG sizing achieved from all methods. The lowest DG capacity is achieved by GA IEEE 33 method with capacity of 2.6287MW. IGA IEEE 33 buses and GA IEEE 69 buses give a total of DG capacity which is 2.8642MW and 3.1239MW respectively. The highest DG capacity is acquired from IGA IEEE 69 buses which is 2.9449MW. If the DG capacity is very small, then the buses that are being supplied from the main source caused the power loss to increase due to the increment of current. Therefore the capacity of DG should be optimal. From the analysis, although the DG capacity for IGA IEEE 69 buses is not the highest compared to other methods but this particular method achieved the highest power losses. The analysis shows that the optimum total DG size of tested network is 2.9449MW achieved from IGA IEEE 69 buses. According to the area of network that is being supplied whereby the larger the area of network, the highest amount of the DG capacity usage.

Table 4.7: Computational time for particular simulation

Network	Type of Algorithm	Computational time (s)
IEEE 33	GA	38.69
	IGA(crossover)	32.74
IEEE 69	GA	62.13
	IGA(crossover)	54.64

The result in Table 4.7 shows the computational time for all methods. For IEEE 33 buses system, the computational time for GA method is 38.69s while for IGA method is 32.74s. Meanwhile, for IEEE 69 buses system, the computational time for GA method is 62.135s whereas for IGA method is 56.64s. The GA IEEE 69 method has the longest computational time that is 62.13s. So, it clearly shows that the computational time for IGA is faster than GA method. This due to the improvement implemented at crossover operator. Besides that, IEEE 33 buses system start to compute faster than IEEE 69 buses system. This is because of the smaller buses system has a smaller load. Therefore, it computes faster than larger buses system.

4.5 Numerical Study

Numerical study is conducted to ensure the effectiveness of the results achieved. Both algorithms which are genetic algorithm (GA) and improved genetic algorithm (IGA) for tested system are verified their convergence of the total power losses. Furthermore, the study also is being applied to network that considered the DG placement and without the DG placement. The convergence of the total power losses is simulated through 100 iterations for every method.

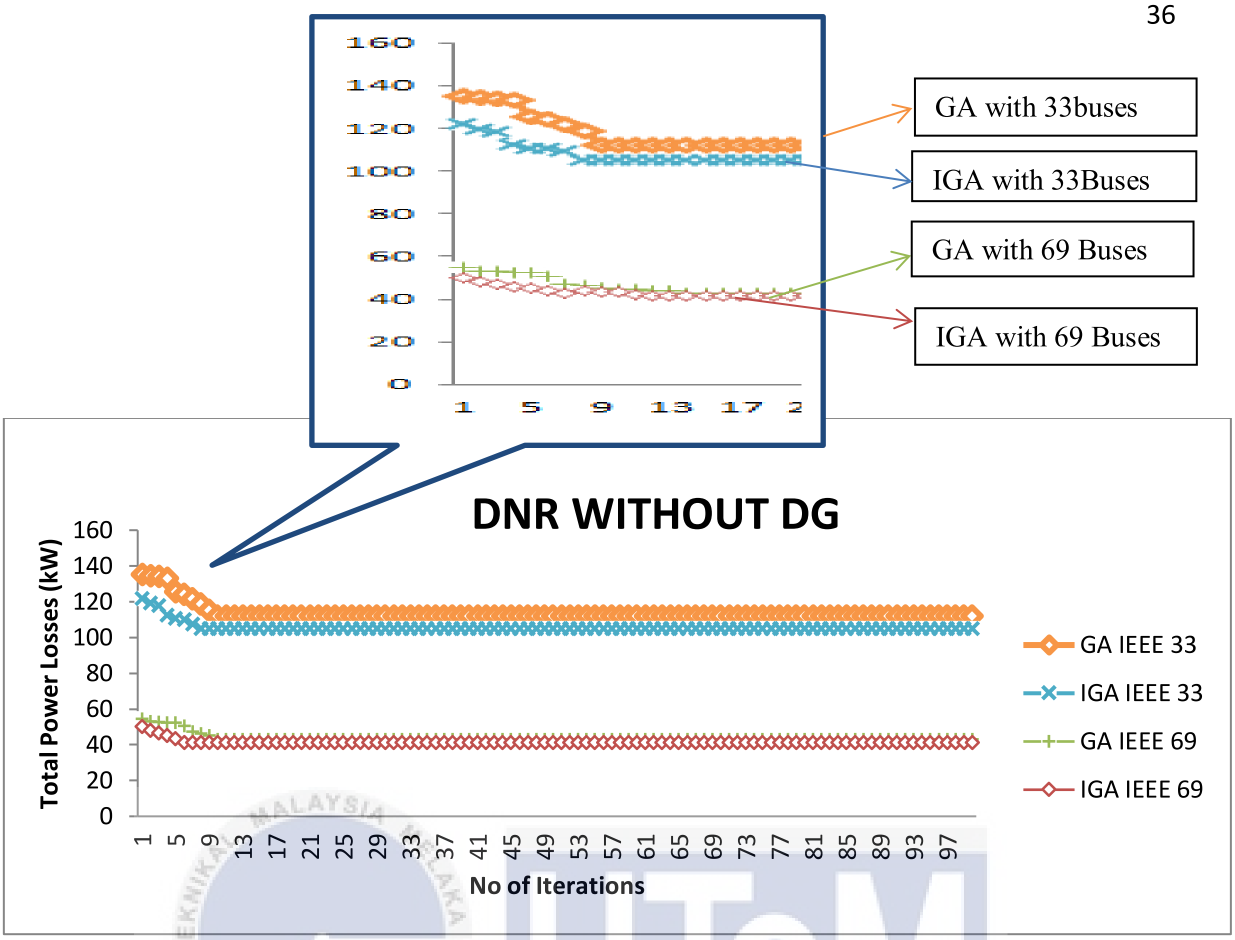

Figure 4.3: The convergence of the total power losses for DNR without DG

In Figure 4.3, the convergence of IGA IEEE 33 buses is at 8th iteration that gives the lowest number of iterations. Then, the slower convergence created from GA IEEE 33 and IGA IEEE 69 buses system which is at 9th and 12th iteration respectively. The higher iteration is achieved when using GA IEEE 69 buses method that gives 15th iteration. From the analysis, the convergence of the total power losses is considered to be fastest when the smaller network is tested and an improvement of GA is implemented. The convergence of the network affect the computational time. The faster the system starts to converge, the faster is the computational time.

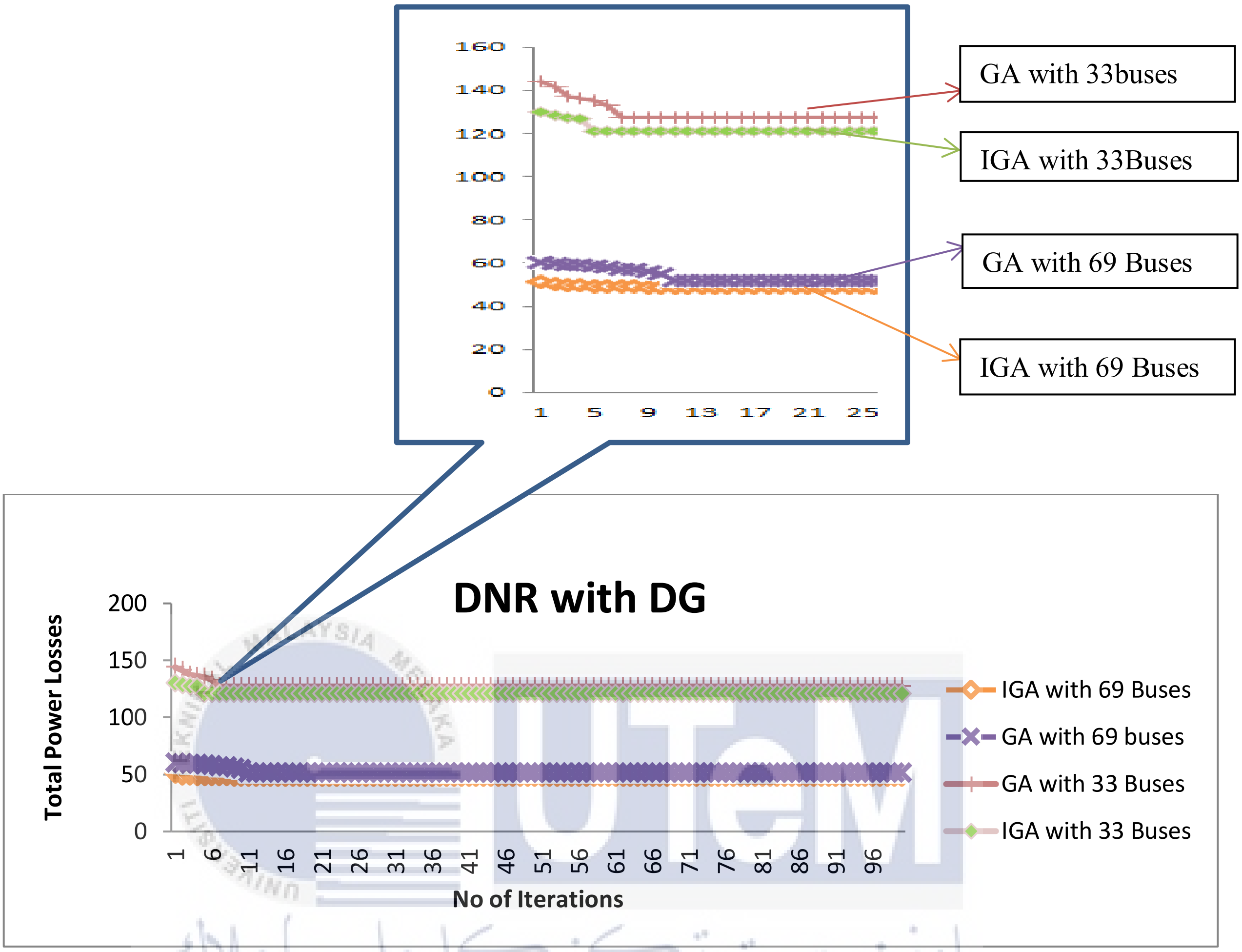

Figure 4.4: The convergence of the total power losses for DNR with DG

According to Figure 4.4, the IGA with IEEE 33 buses start to converge at 5th iteration. The convergence starts to iterate slowly after GA with IEEE 33 buses and IGA with IEEE 69 buses are used, which is at 7th iteration and 9th iteration respectively. From the result, the comparison of Figure 4.3 and Figure 4.4 can be concluded that the implementation of the DNR with DG cause the faster convergence of total power losses than the DNR without DG.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

Conclusively, distribution network reconfiguration (DNR) is the appropriate technique that improves the efficiency of distribution network in term of total power losses reduction and shortest computational time. The optimum radial structure of tie-switches and sectionalizing switches is achieved when the DNR is conducted.

Improved Genetic Algorithm (IGA) is the upgrade of the conventional genetic algorithm (GA) that can generate a better set of solution with faster computational time. These two methods are tested at IEEE 33 and 69 buses system. The result of both networks is compared in terms of power losses and computational time. From the results achieved, it illustrated that IGA is more effective compared to GA.

Another way of solving the optimization problem is the presence of distributed generation (DG) in distribution system. Optimum distributed generation (DG) placement and sizing is one of the present topics in restructured power system. The results show that implementation of DNR with DG technique able to produce lower percentage of total power losses better than DNR without DG. The DG capacity is directly proportional to the area of the network whereby the larger the area of the network, the higher the amount of DG capacity achieved.

5.2 RECOMMENDATION

For recommendation, the improvements at two genetic operators shall be considered. Hence, the improvements at two operators will result in better exchanging of the information between genes and the greater possibilities to configure radial topology. Moreover, the reduction of power losses also will be increased due to the improvement at two genetic operators and led to faster computational time. The improvement could be done at crossover, selection or mutation operators. The implementation of uniform crossover with selection operator or uniform crossover with mutation operator shall be done to give optimum solution. Selection operator can be improved by improving Roulette wheel selection or rank selection. Meanwhile mutation operator can be improved by using multi-point mutation instead of the normal mutation.

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APPENDIX A

IEEE 33 Buses System

Bus Data

Bus		Voltage		Load	
No	Code	Magnitude	Angle, X_o	MW	MVAR
1	1	1	0	0	0
2	0	1	0	1	0.6
3	0	1	0	0.9	0.4
4	0	1	0	1.2	0.8
5	0	1	0	0.6	0.3
6	0	1	0	0.6	0.2
7	0	1	0	2	1
8	0	1	0	2	1
9	0	1	0	0.6	0.2
10	0	1	0	0.6	0.2
11	0	1	0	0.45	0.3
12	0	1	0	0.6	0.35
13	0	1	0	0.6	0.35
14	0	1	0	1.2	0.8
15	0	1	0	0.6	0.1
16	0	1	0	0.6	0.2
17	0	1	0	0.6	0.2
18	0	1	0	0.9	0.4
19	0	1	0	0.9	0.4
20	0	1	0	0.9	0.4
21	0	1	0	0.9	0.4
22	0	1	0	0.9	0.4

23	0	1	0	0.9	0.5
24	0	1	0	4.2	2
25	0	1	0	4.2	2
26	0	1	0	0.6	0.25
27	0	1	0	0.6	0.25
28	0	1	0	0.6	0.2
29	0	1	0	1.2	0.7
30	0	1	0	2	6
31	0	1	0	1.5	0.7
32	0	1	0	2.1	1
33	0	1	0	0.6	0.4

Line Data

Start Bus	End Bus	R (p.u)	X (p.u)
1	2	0.000529155	0.000356061
2	3	0.002829431	0.00190303
3	4	0.002101125	0.001412121
4	5	0.002187213	0.001470455
5	6	0.004700413	0.005356061
6	7	0.00107438	0.004687879
7	8	0.004083448	0.001781061
8	9	0.005910813	0.005606061
9	10	0.005991736	0.005606061
10	11	0.001128903	0.000493182
11	12	0.00214876	0.000983333
12	13	0.008425161	0.008749242
13	14	0.003108356	0.005400758
14	15	0.003391299	0.003984848
15	16	0.004282599	0.00030303

16	17	0.007397268	0.013037879
17	18	0.004201102	0.004347727
2	19	0.00094123	0.001185606
19	20	0.00863292	0.010268939
20	21	0.002350207	0.003624242
21	22	0.004068526	0.007100758
3	23	0.002589532	0.002336364
23	24	0.005153811	0.00537197
24	25	0.005141758	0.005356818
6	26	0.001165634	0.000783333
26	27	0.001631084	0.001096212
27	28	0.00607725	0.007074242
28	29	0.004616047	0.005307576
29	30	0.002912075	0.001958333
30	31	0.00559286	0.007294697
31	32	0.001782025	0.002741667
32	33	0.001957645	0.004016667
8	21	0.01148	0.01148
9	15	0.01148	0.01148
12	22	0.01148	0.01148
18	33	0.0028696	0.0028696
25	29	0.0028696	0.0028696

APPENDIX B

IEEE 69 Buses System

Bus Data

Bus		Voltage		Load	
No	Code	Magnitude	Angle, (Xo)	MW	MVAR
1	1	1	0	0	0
2	0	1	0	0	0
3	0	1	0	0	0
4	0	1	0	0	0
5	0	1	0	0	0
6	0	1	0	0.026	0.022
7	0	1	0	0.404	0.300
8	0	1	0	0.750	0.540
9	0	1	0	0.300	0.220
10	0	1	0	0.280	0.190
11	0	1	0	1.450	1.040
12	0	1	0	1.450	1.040
13	0	1	0	0.080	0.055
14	0	1	0	0.080	0.055
15	0	1	0	0	0
16	0	1	0	0.455	0.300
17	0	1	0	0.600	0.350
18	0	1	0	0.600	0.350
19	0	1	0	0	0
20	0	1	0	0.010	0.006
21	0	1	0	1.140	0.810
22	0	1	0	0.053	0.035
23	0	1	0	0	0
24	0	1	0	0.280	0.200

25	0	1	0	0	0
26	0	1	0	0.140	0.100
27	0	1	0	0.140	0.100
28	0	1	0	0.260	0.185
29	0	1	0	0.260	0.185
30	0	1	0	0	0
31	0	1	0	0	0
32	0	1	0	0	0
33	0	1	0	0.140	0.100
34	0	1	0	0.195	0.140
35	0	1	0	0.060	0.040
36	0	1	0	0.260	0.186
37	0	1	0	0.260	0.186
38	0	1	0	0	0
39	0	1	0	0.240	0.170
40	0	1	0	0.240	0.170
41	0	1	0	0.012	0.010
42	0	1	0	0	0
43	0	1	0	0.060	0.043
44	0	1	0	0	0
45	0	1	0	0.392	0.263
46	0	1	0	0.392	0.263
47	0	1	0	0	0
48	0	1	0	0.790	0.564
49	0	1	0	3.847	2.745
50	0	1	0	3.847	2.745
51	0	1	0	0.405	0.283
52	0	1	0	0.036	0.027
53	0	1	0	0.043	0.035
54	0	1	0	0.264	0.190
55	0	1	0	0.240	0.172
56	0	1	0	0	0
57	0	1	0	0	0

58	0	1	0	0	0
59	0	1	0	1.000	0.720
60	0	1	0	0	0
61	0	1	0	1.244	8.880
62	0	1	0	0.320	0.230
63	0	1	0	0	0
64	0	1	0	2.270	1.620
65	0	1	0	0.590	0.420
66	0	1	0	0.180	0.130
67	0	1	0	0.190	0.130
68	0	1	0	0.280	0.200
69	0	1	0	0.280	0.200

Line Data

Start Bus	End Bus	R, (p.u)	X, (p.u)
1	2	2.2.8691E-06	6.8870E-06
2	3	2.2.8691E-06	6.8870E-06
3	4	8.60882E-06	2.06112E-05
4	5	0.000144054	0.000168733
5	6	0.002100551	0.001069789
6	7	0.002187213	0.001113981
7	8	0.000529155	0.000269743
8	9	0.000282943	0.000144054
9	10	0.004700413	0.001553604
10	11	0.001074380	0.000355257
11	12	0.004082874	0.001349288
12	13	0.005911387	0.001951331
13	14	0.005991736	0.001980028
14	15	0.006072084	0.002006428
15	16	0.001128329	0.000373049
16	17	0.002148760	0.000710514
17	18	2.69743E-05	9.18274E-06

18	19	0.001880165	0.000621556
19	20	0.001208678	0.000396006
20	21	0.001960514	0.000647957
21	22	8.03489E-05	2.64004E-05
22	23	0.000913108	0.000301882
23	24	0.001987489	0.000657140
24	25	0.004297521	0.001420455
25	26	0.001772842	0.000585973
26	27	0.000994031	0.000328283
3	28	2.52525E-05	6.19835E-05
28	29	0.000367309	0.000898186
29	30	0.002283058	0.000754706
30	31	0.000402893	0.000133150
31	32	0.002014463	0.000665748
32	33	0.004815197	0.001616162
33	34	0.009802571	0.003240358
34	35	0.008459596	0.002796717
3	36	2.52525E-05	6.19835E-05
36	37	0.000367309	0.000898186
37	38	0.000604339	0.000705923
38	39	0.000174472	0.000203742
39	40	1.03306E-05	1.20523E-05
40	41	0.004179867	0.004883494
41	42	0.001779155	0.002079316
42	43	0.000235308	0.000274334
43	44	5.28007E-05	6.65748E-05
44	45	0.000625000	0.000787994
45	46	5.16529E-06	6.88705E-06
4	47	1.95133E-05	4.82094E-05
47	48	0.000488407	0.001195478
48	49	0.001663223	0.004069674
49	50	0.000471763	0.001154155
8	51	0.000532599	0.000271465

51	52	0.001904844	0.000639348
9	53	0.000998623	0.000508494
53	54	0.001165060	0.000593434
54	55	0.001631084	0.000830464
55	56	0.001614440	0.000822429
56	57	0.009125344	0.003063017
57	58	0.004497819	0.001509412
58	59	0.001745868	0.000577365
59	60	0.002215909	0.000672635
60	61	0.002912649	0.001483586
61	62	0.000558999	0.000284665
62	63	0.000832185	0.000423554
63	64	0.004077709	0.002077020
64	65	0.005974518	0.003042929
11	66	0.001154729	0.000350666
66	67	2.69743E-05	8.03489E-06
12	68	0.004243572	0.001402663
68	69	2.69743E-05	9.18274E-06
11	43	0.002869605	0.002869605
13	21	0.002869605	0.002869605
15	46	0.005739210	0.002869605
50	59	0.011478421	0.005739210
27	65	0.005739210	0.002869605