Doctoral Dissertation

Shibaura Institute of Technology

Distribution Network Loss Minimization via Artificial Immune Bee Colony

2014/SEPTEMBER

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DISTRIBUTION NETWORK LOSS MINIMIZATION VIA ARTIFICIAL IMMUNE BEE COLONY

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Engineering

Shibaura Institute of Technology

SEPTEMBER 2014

Specially dedicated to my beloved family:

Muhtazaruddin, Rismawaty,Zaredah, Mohd Hadri, Husna Asila, Husna Najiha,

Husna Nabiha, Muhammad Zahin, Husna Kamilah, Muhammad Luqman Hakim,

Danish Hakim, Muhammad Naufal, Marissa Elyna

You are both my strengths and inspirations.

And my supervisor

Prof. Dr. Goro Fujita

ACKNOWLEDGEMENTS

In the name of Allah, most Gracious and Merciful. I am very grateful with his permission; I was able to accomplish my Doctoral thesis.

A special thanks to my supervisor, Prof. Dr. Goro Fujita from Department of Electrical Engineering, Shibaura Institute of Technology. His insightful comments, guidance and all the useful discussion are very much appreciated. Without his encouragement and persistent help, this thesis would not have been possible. Not forgetting my defense committee members: Prof. Dr. Satoshi Matsumoto, Prof. Dr. Harukazu Igarashi, Prof. Dr. Hiroshi Takami and Prof. Dr. Yoshikazu Fukuyama. Thank you for your attention, advices and constructive feedback.

Very special thanks to Shibaura Institute of Technology and Universiti Teknologi Malaysia for giving me opportunity to carry out doctoral program for their scholarship support and also to all my friends; Dr. Jasrul, Ariff, Dan vu, Dr. Tuyen and those who supported me during the completion of the thesis. Thank you so much.

I would also like to express gratitude to my parents and the rest of my families for unconditional love and constant support. I am truly thanks to my loved wife, Zaredah, who always been at my side when I was depressed and supporting me spiritually. Not forgetting to both of my children, Muhammad Naufal and Marissa Elyna that always invigorate my life.

ABSTRACT

Transformation of distribution network into the direction of more intelligent and efficient system suffers with many difficulties. One of most challenges task for the engineers is to achieve more economic distribution network. Introduction of Distributed Generation (DG) in the system promise a good solution by means of reduce dependency on centralized generation and has the capability to reduce power losses that exists in the distribution system. Another approach to reduce power losses is network reconfiguration. This approach works by controlling the tie and sectionalizes switches in order to change the original topology of the system. Nevertheless, coordination of the approaches are still an issue needs to be solved by the utility. Many researchers have suggested various tools to compute optimally the DG coordination (output power and location) and network reconfiguration (opened/closed switches). Among the methods that preferred by the researchers is meta-heuristic due to robustness and easy to implement. In this thesis, a new hybrid optimization technique based on Artificial Bee Colony (ABC) and Artificial Immune System (AIS) algorithm is proposed. To see the effectiveness of the proposed method, a comparative study is conducted between the AIBC and the ABC in solving the DG coordination to minimize total power losses in the distribution system. In addition, a solution to harmonize between DG coordination with network reconfiguration is also examined. The analysis shows that the performance of the proposed method is improved than the original ABC in solving the DG coordination. Furthermore, determination between two approaches simultaneously gives better results, particularly in reduction of power losses compared than analysis if using one of approaches either DG coordination or network reconfiguration.

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LIST OF SYMBOLS

FV	-	Fitness Value
$Ob.\ Func$	-	Objective Function
x_{ij}^{new}	-	New value of variable
x_{ij}^{old}	-	Old value of variable
x_{kj}	-	Neighbour value that is selected randomly
$range(0,1)$	-	Random value between 0 and 1
$prob_i$	-	Probability value
N	-	Total number of employed bees
x_1	-	DG output power
x_2	-	DG location
nbr	-	Number of lines
I	-	Current
i	-	Line number
R	-	resistance
n	-	Bus number
$P_{DG,min}$	-	Lower bound of DG output power
$P_{DG,max}$	-	Upper bound of DG output power
P_{DG}	-	DG output power
$V_{n,min}$	-	Minimum allowable voltage
$V_{n,max}$	-	Maximum allowable voltage
V_n	-	Voltage at each bus
tdg	-	Total number of DG
tl	-	Total number of load
P_{load}	-	total amount of load consume at each bus
$P_{substation}$	-	Power from substation
W	-	Unit for real power

LIST OF ABBREVIATIONS

ABC	-	Artificial Bees Colony
ACO	-	Ant Colony Optimization
AIS	-	Artificial Immune System
AIBC	-	Artificial Immune Bee Colony
ANN	-	Artificial Neural Network
ACSA	-	Ant Colony Search Algorithm
BPSO	-	Binary Particle Swarm Optimization
C-VSI	-	Combined-Voltage Stability Index
DDG	-	Dispatchable Distributed Generation
DE	-	Differential Evolution
DG	-	Distributed Generation
EP	-	Evolutionary Programming
EP-ACO		Evolutionary Programming-Ant Colony Optimization
FA	-	Firefly Algorithm
GA	-	Genetic Algorithm
GA-PSO	-	Hybrid Genetic Algorithm - Particle Swarm Optimization
HDE	-	Hybrid Differential Evolution
HSA	-	Harmony Search Algorithm
NDDG	-	Non-Dispatchable Distributed Generation
PQ	-	Power-Reactive
PSO	-	Particle Swarm Optimization
PV	-	Power-Voltage
QIEP	-	Quantum-Inspired Evolutionary Programming
RPF	-	Reverse Power Flow
SA		Simulated Annealing
SPSO	-	Selective Particle Swarm Optimization

TS	-	Tabu Search
TS-SA	-	Tabu Seacrh-Simulated Annealing
X/R	-	Reactance/Resistor

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The classic power system model consists of three important components, namely generation, transmission line and distribution system. The components are interdependent to ensure the generated power can be transmitted from the generation to the distribution system/demand via the transmission line. In addition, the power system is designed to works with unidirectional power flow due to lack of power source except in the generation component only. However, as the demands are expected to escalate in the future, one of the possible solutions could be done is to ameliorate the entire power system performance [1]. Concerning to this solution, it will require intensive planning to all the components; thus, increasing the overall cost of the power system. On the contrary, introduction of micro grid concept [2] offers an interesting solution to integrate small capacity of Distributed Generation (DG) in the distribution system instead of rely solely on centralized generation schemes, thereby reducing the necessary improvements made in the generation and the transmission lines.

Introduction of the DG has changed the basic nature of operation in the power systems, particularly the distribution networks where the status has changed from passive to active network [3]. This means that the DG can actively participate in the distribution system in order to provide additional support to the main grid in fulfil load demands. In addition, there are numerous benefits that have been identified by other researchers, for instances enhance voltage profile, improve reliability and also reduce power loss [4, 5].The reduction of power losses is an important task that can be done to maintain the efficiency of the distribution system. There several approaches which are commonly proposed by researchers to reduce the power losses; either network reconfiguration or installing capacitors or installing DGs. However, the advantage of these approaches can be achieved if they are carefully coordinated in the distribution system.

There are several groups which have been used to solve coordination problems such as analytical, heuristic and meta-heuristic technique, where each of the groups has its own advantages and shortcomings [6].Among these groups, the meta-heuristic are more prominent in solving the coordination problems due to robustness and simple to implement [6]. There are several of methods that have been introduced under the meta-heuristic group such as Simulated Annealing (SA) [7], Genetic Algorithm (GA) [8], Particle Swarm Optimization (PSO) [9], Ant Colony Optimization (ACO) [10] and Artificial Bee Colony (ABC) [11]. Additionally, some authors have also proposed hybridized optimization methods by combining two optimization techniques to cancel out the discrepancies of each for achieving better solutions. Almost all of these methods were inspired by natural life [12].

Recently, some studies have been done by a number of researchers to harmonize between the two approaches as an example to solve coordination between the DG and the capacitors, simultaneously. Means, the location and size of the DG and the capacitor are determined simultaneously by using one approach. One significant advantage when combining this approach is the reduction of the power loss can be obtained more than if executed separately. Nevertheless, the proper method needed to solve the problem of combination of the two approaches so that a better solution can be obtained. Therefore, investigation of optimal coordination between the DG with network reconfiguration should be carried out to achieve better performance in distribution system.

1.2 Research Questions

The reliability and sustainability of the power distribution system are important issues that many engineers and researches have studies and proposed various solutions for increase its efficiency. This matter is important in order to fulfil load demands, which increase significantly year by year. However, the progress in enhancing the efficiency of the system is hindered by one major factor that is the existence of high real power losses. Furthermore, the current trend of electrical energy tariff is showing signs of increment and it is expected to escalate in the future; hence, increasing the significance of power reduction. Consequently, many researchers have devoted their effort to find the possible solution to minimize the power losses whilst retaining the stability and security of the system.

There are several approaches suggested by researches to deal with the reduction of power losses such as determining optimal DG coordination (output power and location), capacitor coordination (size and location) and network reconfiguration. However, the incorrect use of these approaches might deteriorate the system's performance and appear operational and planning problems of the distribution system. The aim of this research is to find a solution that can harmonize the network reconfiguration with DG coordination in order to further reduce the power loss in the distribution network.

Several research questions that will arise when analyzing the effect of combining the approaches on the distribution system are listed below:

i. What is the appropriate method that can be applied to solve the coordination problems?

ii. Which combination gives the best impact to the distribution system?

iii. What happens to the performance of voltage profile and stability index when the coordination is performed on the system?

All the questions raised will be analysed and discussed later.

1.3 Problem Statement

Transformation of distribution network into the direction of more intelligent and efficient system suffers with many difficulties. One of the most difficult challenges faced by engineers is to achieve a more economical distribution network through reduction of power loss. In addition, basic nature of the distribution network itself that has a low X/R ratio lead the distribution system have more impact on the power loss and voltage profile compared with the transmission line [3, 13].

As previously discussed, there are several approaches have been done to solve the problem. Generally, these solutions are done separately, which means power losses reduction is achieved either by using network reconfiguration or via DGs coordination or via capacitors coordination. Thus, the solution might be trapped in a local optimum (meaning that there is a better solution - the global optimum) since the solution to determine one approach (for example: DG coordination) is not based from another approach (for example: network reconfiguration), and vice versa.

Latterly, some researchers have proposed a solution to harmonize any of the two approaches into single solution so that it can provide better results than the separate analysis. However, this solution consists of many variables and wrong coordination can inflict negative effects on the system especially in power losses, voltage deviation as well as stability index.

As a result, this research will focus on a new hybrid optimization to handle on simultaneous approach and at the same time to alleviate such problems.

1.4 Research Objectives

The objectives of this research are as follows:

i. To improve the performance of ABC by combining with Artificial Immune System (AIS) in order to solve specific high dimensional problem.

ii. To investigate the effectiveness of the simultaneous approach analysis compared with the separate analysis.

iii. To investigate the effectiveness of network reconfiguration with DG coordination which gives better results in term of power losses, voltage profile as well as stability index.

1.5 Scope of Work

The scopes of the research are listed below:

i. The total output of the DG unit must be less than the summation of total load and power losses in the test system, in order to avoid reverse power flow to the main grid.

ii. The maximum amounts of the DGs are only three units.

iii. The objective function for all case studies only focuses on single objective which is total power losses.

iv. All the results obtained in this thesis is in the context of operational planning division only, except the results obtained for DG coordination is a suggestion to construction planning division for their references.

1.6 Significance of the Research

The main motivation of this research is to determine the optimal network reconfiguration with DG coordination, in order to enhance distribution system performance in terms of total power loss reduction, voltage profile improvement as well as increase the stability.

Installation of the DG in the distribution has helped to improve the overall system efficiency especially reduction of power losses. Another approach that can be used to increase system performance is to install the capacitors or reconfigure the network by controlling tie and sectionalize switches. In addition, further improvements in the system can be obtained by combining any of these approaches rather than solve using single approach.

Simultaneously, determining of combination between two approaches involved high dimension problem in the power system analysis. For example, three units of DG are used with five tie switches (for network reconfiguration process) in the test network. Hence, the total variables involved are 11, X_i= [$Location_1$ $Location_2$ $Location_3$ DG $Output_1$ DG $Output_2$ DG $Output_3$ $Switch_1$ $Switch_2$ $Switch_3$ $Switch_4$ $Switch_5$]. Thus, hybridization between the ABC and the AIS is proposed to solve the problem and subsequently give minimum total power losses.

Overall, the analysis simultaneously provides a positive impact on distribution system especially for the reduction of the power loss. Furthermore, the use of optimization method assists and facilitates utilities in the planning division to provide optimal coordination.

1.7 Thesis Organization

This thesis is organized in six chapters. The first chapter begins with an overview of the research background and problem statement. It includes the most important aspects for overall research including the objectives and scopes. Chapter two presents a collection of literature from previous research work to tackle the problems in coordination. Next, in the chapter three describes a new hybrid optimization methods based on the ABC and the AIS algorithm.

Chapter four focuses on comparison between the ABC and the proposed method in solving DG coordination. In addition, the proposed method will be compared with a separate analysis that use single DG placement algorithm to determine the location and using the AIBC to determine the output of the DG. Chapter five discusses the effectiveness of simultaneous approach by combining the DG coordination with network reconfiguration. Furthermore, a comparison with other optimization methods will be performed.

Chapter six concludes of this research. Additionally, several ideas for future works are also proposed.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In the first chapter, the overview of research background and other important aspects to define this research have been touched. As previously discussed, there are various approaches that have been used to reduce overall total power losses in the distribution system. Hence, in this chapter, previous related research works on network reconfiguration and DG coordination will be discussed.

2.2 Network Reconfiguration

Network reconfiguration is a common practice that performed by the utility to change the topology of the distribution system. This process is done by closing and opening the switches that exist in each branch. However, searching process for optimal combination of opened/closed switches is a complicated task that needs to be done properly.

As an alternative of loss reduction, the network reconfiguration also offers other advantages that can be leveraged by the distribution system. In ref. [14-16], they have listed several advantages of network reconfiguration in the distribution system, as listed below:

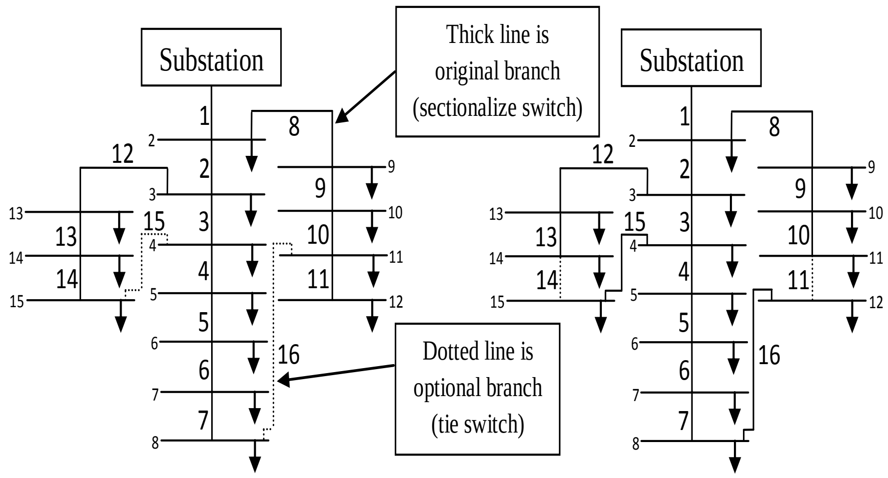
i. Improve reliability of the distribution network.

ii. Restrain the distribution line from being overloaded.

iii. Improve the voltage profile at all network buses.

iv. Help to restore supply to the demands when fault occurred.

Figure 2.1 illustrates an example of the basic concept of network reconfiguration process by controlling sectionalize and tie switches to change the topology of the distribution system.



(a) Before reconfiguration process (b) After reconfiguration process

Fig. 2.1. An example of network reconfiguration process

Besides network reconfiguration, another different approach to reduce power loss is by installing the DG. In the next section, the importance of installation the DG will be discussed.

2.3 Installation of Distributed Generation in Distribution System

As the power system become more complex and challenging, the need for advanced technology on the system become a priority for electrical utilities in order to ensure power is supplied to the demands without any interruption. Furthermore, with more concern to achieve high reliability and efficiency of distribution network, introduction of the DG concept seems as an interesting solution by integrating small scale of generator in the distribution system. Followed by the expected increase in energy consumption in the near future, the importance of DG installations has attracted the attention of many parties, especially electrical utilities.

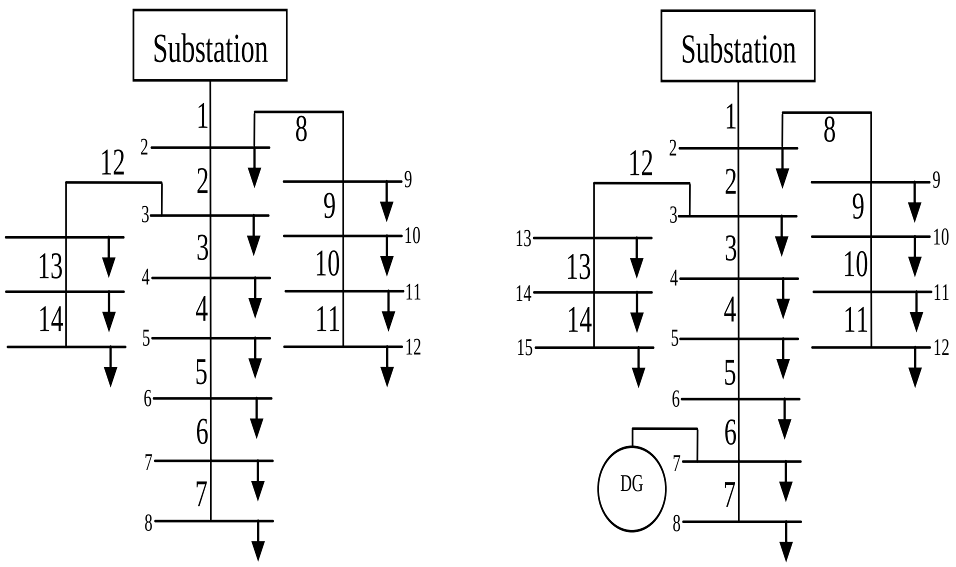
A recent report conducted by Synapse Energy Economics, Inc. comprised of several organizations comprised of several organizations estimate that DG capacity in 2013 will increase by 191% at the end of 2021 in several states in New England, United State of America [17]. Meanwhile, another report released by the California public utilities commission on the 18th of March, 2013 stated that the state was targeting a total DG capacity of 12 GW to be installed by 2020 [18]. Based on these reports indicate that the installation of DG is indispensable in the future.

There are numerous definitions to describe the DG and until now there are still long arguments to justify the meaning. Not only that, term and rating of the DG also have various understanding depending on the region and the institutes [13]. Although there are different interpretations exist, the purpose of this small capacity of DG is still same. It will act as an additional power support to the system instead of depending solely on centralized generation; hence, power sharing between them can benefit the entire power system. In refs. [5, 19-22], they explain in detail the impact of the DG when connected to the network. Based from these studies, they pointed out that installation of the DG offer many benefits, especially to the distribution network. Some of the advantages as mentioned earlier are as follows:

i. Minimize total power losses at the distribution network.
ii. Enhance performance on voltage profile.
iii. Improve stability index and security of the distribution system.
iv. Help in improving the efficiency and reliability of the system.
v. Help in saving costs due to less expansion plan on generation and transmission lines.
vi. Increase power quality in the distribution system.
vii. Relieve the transmission line due to peak shaving.

According to a report issued by the International Energy Agency in 2012, the percentage of power losses that occur in the transmission lines and distribution system was 8.78% from the total power supplied [23]. Therefore, in accordance with one of the advantages that previously mentioned, the installation of DG can contribute in reducing the amount of losses that occur in the power system. However, the advantage can only be obtained if the DG properly coordinated in the system. Furthermore, one of the issues still faced by utilities is uncertainty in determining the output power and location of the DG. Figure 2.2 shows an example of installation of single DG in the distribution system at the specified bus.

Improper coordination of the DG can deteriorate the distribution system performance. Several studies have been conducted by researchers to see the impact on the system when the location and power output wrongly selected [24-26]. Based on their findings, different locations and sizes of the DG can affect the total power losses as well as voltage profiles. Hence, proper methods are needed to address the problems in determining the location and output power of the DG optimally.



(a) Before installation of DG (b) After installation of DG

Fig. 2.2. An example installation of DG

2.4 Previous Research Works on Distributed Generation Coordination

The power loss is one of the constraints to achieve a more reliable and economic distribution system. This problem exists due to the nature of the system which only depends on the generation that located far away to transmit power supply. In addition, characteristic of the distribution system in which has a low X/R ratio makes further increment of power losses. One of available solution is by install the DG in the existing problem where it is close to the load to help reduce dependence on the generation; hence, minimize the power losses. The presence of DG in the system without a proper sizing and location will actually worsen the problem. Therefore, many researchers have studied the effects of optimizing the location and size of the DG.

There are many methods published in the literature to determine location and size of DG, which can be categorized into several groups namely analytical, numerical, heuristic and meta-heuristic [6, 27]. Each of these groups has its own advantages and disadvantages. In ref. [6], the author has briefly discussed the comparison of each group in solving the DG coordination problem. Based on their findings, they concluded that meta-heuristic and heuristic methods are more robust and easier to implement in solving the complex problems.

Previously, calculations of location and size of DG are treated independently, which means different method is applied to each of them. Candidate of DG location can be determined either by using voltage sensitivity factor [28-30] or loss sensitivity factor [31, 32] or analytical method [33-35] or suggested by the authors [36]. Basically, the voltage and the loss sensitivity factor are operate by placing a DG at each node in the test system and choose the node which has a high sensitivity on the changes of power losses. Meanwhile, computation of the DG size is using optimization approach. However, when the analysis is done separately, the objective function or goal of the study is not in best solution due to predetermined location and considered as fixed parameter when to optimize the size of DG. Thus, it could lead the solution trapped in local optimum.

In ref. [30], the authors have applied Evolution Programming (EP) method to determine optimal sizing of DG, whereas for the DG location based on loss sensitivity factor and voltage sensitivity index. From the simulation results, both of the sensitivity gives different optimal location for installing the DG. This shows that these two methods do not provide consistent results to determine the optimal location of the DG. In addition, there is no further explanation given by the authors which method should be preferred. In ref. [29] work has proposed a novel optimization method based on EP, which is known as Quantum-Inspired Evolutionary Programming (QIEP) to determine optimal size of DG. Conversely, determination of optimal location is not included in the QIEP, but based on the voltage sensitivity index. Based from the obtained result, proposed method showed better performance compared to the EP. However, the analysis had only focused a single mode of DG, which is PQ (Power-Reactive) mode. In ref. [34], the determination of the optimal location of DG is based on analytical approach which is known as single DG placement algorithm, whereas size of DG by using the PSO. The basic concepts of the algorithm is by insert a DG at each bus one by one and select the bus that give maximum value of power losses reduction as a candidate for best location. This process is repeated for the next DG. In another study proposed by ref.[35], the same concept in ref. [34] have been used to determine the location of DG, but using different optimization method which is ABC to calculate the size of DG. Although both of these references successfully provides better results compared to other analytical approach, but it does not guarantee to give the best solution due to the analysis in the DG coordination is done separately.

Recently, some authors have proposed a solution to determine both the location and size of the DG in simultaneous that means using one method to solve the DG coordination problem. Some of the aforementioned methods are Genetic Algorithm (GA) [37-39], Particle Swarm Optimization (PSO) [40, 41], Artificial Bee Colony (ABC) [42], Evolutionary Programming (EP) [43] and Firefly Algorithm (FA) [44].

The work done by ref. [41] applies PSO to deals with DG coordination problem. In this simulation analysis, the authors consider only one unit of DG to be optimized. Despite the reduction in power loss can be achieved, there is no comparison with other methods are done to show the effectiveness of the proposed method. Ref. [43] suggested EP to determine optimal location and size of single DG optimally. In this paper, the authors tested the effectiveness of the proposed method with the AIS. Based on the comparison, the EP method gives better results in term of power loss reduction, but the AIS method shows better voltage performance compared to the EP. In ref. [44], the authors propose to solve coordination of DG by using the FA. This method imitate behaviour of fireflies communicate with others through the brightness of flashing light. In this study, they tested the proposed method using two units of DG and compare with the GA method. From the analysis of the simulation results, they concluded that the proposed method gives similar results with the GA and shows that there is no improvement in the quality of solutions. Another ref. [42], they propose ABC for the coordination of DG. The authors consider two types of scenarios for the load conditions, which are normal load and increase the load up to 50% of the normal value. Furthermore, in the analysis, they optimize the power factor and consider the DG in the PQ mode. Nevertheless, based on the proposed method, only one variable is chosen during the "mutation" process and the selection is done at random (for example randomly selects either DG location or DG size). Hence, in case of high dimension problems, the ability of the ABC algorithm to search all possible solution area might be limited due to the aforementioned construction.

Some authors have also proposed hybridized optimization methods by combining two optimization methods to cancel out the discrepancies of each method for achieving global or near global optimal solutions [45, 46].In ref. [45], the authors propose a hybrid optimization method which combines the PSO and the GA. Each of these optimization methods has different functions where PSO and GA are used to determine optimal size and optimal location for DG, respectively. Although the proposed method succeeded in giving the best answer compared to the PSO and GA methods, but the solution is divided into two stages, and it is probable that the solution is trapped in local minimum due to the calculation of the location depends on the size determined by other method. Similarly, in ref. [46] the authors propose a combination between Fuzzy logic and ABC. The solution is divided into two phases where the focus on the first part is to solve the optimal location for DG by using Fuzzy logic, while in the second phase; the ABC method is used to solve the DG size. Based on the results obtained, it was found that the proposed method gives the same power loss reduction with PSO method for all case studies that have been conducted. In addition, the authors only consider the type of DG in PQ mode.

Despite there are various method that have been used to solve the DG coordination problem, there are several disadvantages that needs to be considered before selecting the appropriate methods. For example, the PSO consumes high number of iterations, easy to get trapped in local optimum when solving the complex problems [47] and weak at local search [48]. For the GA method, the basic operation is similar to PSO, but the GA has a filtering process (crossover and mutation), thus it makes the GA process a bit complicated than the PSO [49]. In addition, it stability depends on the crossover and mutation rates [47]. Unlike the PSO, the AIS shows a good performance to avoid the local optima [48], however, one of the disadvantages of AIS, it have many parameter to tune [47]. Another method which is known as ABC show better performance compared to other methods such as the PSO and the GA [50]. One of the clear advantages of the ABC, it only have two parameter that need to be tuned and thus make it easier to implement. However, one of drawbacks of ABC comes when solving problems with high dimensions. Therefore, in this thesis a new hybrid optimization based on ABC and AIS, known as Artificial Immune Bee Colony (AIBC) was introduced to improve the ABC method.

Overall, the coordination of DG can be divided into two groups of analysis, which are separate and simultaneous analysis. As previously discussed, the separate analysis is performed by determine location and size of DG separately. On the other hand, the simultaneous analysis is based on the location and size is determined simultaneously by using single calculation. The methodology for both analyzes is typically comprised of several groups of methods such as analytical, numerical, heuristic and meta-heuristic. However, most of recent work focused on meta-heuristic optimization either for single DG or multiple DG. In addition, simultaneous analysis preferred over the separate analysis because it provides an opportunity for the optimization method to search all possible solutions and thus quality of solution can be achieved. Moreover, to obtain more reliable results and consistency in the determination of DG coordination, some researchers have combine two types of optimization to produce better results than the original optimization.

2.5 Previous Research Works on Network Reconfiguration

As previously explained, the basic concept of network reconfiguration is to reconfigure the original architecture of distribution network by changing status of sectionalize (normally closed position) and tie switch (normally open position) to open and close positions respectively, whilst maintaining radiality of the system and network constraints. The appropriate protection scheme for over current relays demands the radial topology of the system.

There are several methods that have been used to solve the problem of network reconfiguration. Same as the coordination of the DG approach, these methods can be divided into several groups such as mathematics, heuristic, optimal flow pattern and meta-heuristic [14, 15].Based on ref.[51], most of the methods chosen by the researches to solve the network reconfiguration are heuristic and meta-heuristic.

One of the early researchers who worked on network reconfiguration is in ref. [52]. They proposed a simple formula to estimate the loss reduction when transmitting a cluster of load from one feeder to another feeder. It is further followed by the authors of the study [53] who introduced approximation of power flow based on concept presented by the study [52]. In addition, the authors also take into account the load balancing in their analysis. There are researchers that were based on the paper [52] and published the studies in ref. [54-56]. All of these solutions are known as heuristic algorithm.

Recently, modern optimization methods have been applied to network reconfiguration by many authors. Ref. [57] implements GA to solve the reconfiguration problem. Later on in ref. [58], they proposed Artificial Neural Network (ANN) to solve network reconfiguration problem. In the analysis, the authors use seven ANNs, which have a different topology for each of them. However, this method has a problem because it depends on the size of the system. If the size used is large then the amount of time taken to train the ANN takes time. To solve the problem, the authors in ref. [59] determine the amount of ANN based on number of sensitive switches where only four ANNs involved for the same test system. Therefore, the amount of time needed to train the ANN can be greatly reduced. Further investigation on implementation of ANN in network reconfiguration has been done in ref. [60]. They use clustering technique to divide the loads based on load level, which is used as inputs to the ANN. Furthermore, the training set used does not depend on the size of the test system and only one ANN is applied to solve the problem.

In ref. [61], the authors suggest a combination of methods between the SA and Tabu Search (TS). Based on the results obtained, the hybrid method shows similar performance in terms of loss reduction and minimum voltage, but faster in computation time when compare with SA and TS, separately. Besides that, the authors in ref. [62] consider Hybrid Differential Evolution (HDE) to solve the network reconfiguration. One of the advantages of the proposed method compared with Differential Evolution (DE) is be able to reduce the amount of population; thereby reducing the computational time. To test the effectiveness of the proposed method, they make a comparison with SA method and based on the results obtained it was found that their method gives faster results. In another research work done by the authors in ref. [63] has used Ant Colony Search Algorithm (ACSA). The proposed method is inspired from the ants through the process of finding food. In the study, they were compared with the GA and SA. Based on their findings, the proposed method provides more consistent results compared with other methods when the simulation is repeated 100 times.

In ref. [64], the authors have proposed method that combines between the EP and Ant Colony Optimization (ACO). In the analysis, they take into account the impact of changes in load on the network reconfiguration. The authors have divided each day into several slots, where each slot comprises a maximum load current. Therefore, information on the number of switch conversions that occur for each slot can be obtained. Another ref. [65], Selective Particle Swarm Optimization (SPSO) is proposed to solve the network reconfiguration problem. The proposed method is a result of some modifications in the updating (mutation) process on Binary Particle Swarm Optimization (BPSO) that enables it to search in selected space. Furthermore, to facilitate the conversion process in finding the appropriate switches, they close all the switches (tie and sectionalize) on the test system and as a result several loops are formed. During the process of searching, only switches that are in these loops will be considered for network reconfiguration process.

Overall, apart from using the DG approach to reduce power loss in the distribution system, the network reconfiguration is another approach to help in enhancing the performance of the system. This method works by controlling the switches located on the branches and indirectly alter the original topology of the system. Therefore, the solution by considering two approaches together maybe can give positive impact, especially in terms of power loss reduction when compared to the solution that performed separately (DG coordination or network reconfiguration).

2.6 Previous Research Works on Network Reconfiguration with DG Coordination

Ref. [66] is among the earliest researchers examined the impact of DG on the network reconfiguration. In the study, they used TS method to determine the appropriate configuration when DG included in the test system. In addition, they also investigate the effect of Reverse Power Flow (RPF) caused by the DG due to amounts of power generated exceeds the load requirements. Later on in ref. [67], they suggest PSO to solve distribution feeder reconfiguration with DG. In this paper, the authors make a comparison between Dispatchable Distributed Generation (DDG) and Non-Dispatchable Distributed Generation (NDDG). Based on the results obtained, they concluded that DDG gives better results in terms of reduced power loss compared to NDDG. Furthermore, it also managed to reduce conversion process between switches.

In ref. [68], they propose a heuristic method that is based on sensitivity and branch exchange to determine the best configuration of the test system. In this paper, they consider four DGs unit with various capacities. Based on their analysis, it was found that the reconfiguration of the network in the presence of DG can help to reduce power loss almost half from the initial power losses. In another study carried out by the ref. [69], they apply ACO method to determine optimal network reconfiguration includes several DG units with different capacities and power factor. Aside from the reduction of power loss, the authors also consider load balancing in their analysis. In the meantime, the authors in ref. [70] also used ACO to resolve network reconfiguration with DG. In addition, they also study the ability of network reconfiguration to ensure that all the loads can be supplied by the DG when test system is disconnected with main substation (islanding).

According to the refs. [66-70], determination of the location and size of DG is determined either randomly or based on assumptions or considered as fixed at particular location by the author. Nevertheless, those solution obtained in the aforementioned references can be considered not the best solution due to the result for network reconfiguration is not based from optimal coordination of DG. If the all locations in the distribution system assumed eligible for the installation of the DG, thus, harmonization between DG coordination and network reconfiguration can provide opportunity to find a better solution.

In ref. [71], the authors attempted to solve optimal DG coordination with network reconfiguration. Nevertheless, the solution proposed by them is not carried out simultaneously due to the location of DG is determined first by using sensitivity factor. Based on acquired location, they only optimize the size of the DG and the reconfiguration of the system by using Harmony Search Algorithm (HSA). Therefore, there is a possibility that the proposed solution fails in finding better results because the search process for DG size and network reconfiguration depending on the particular location (fixed location).

Overall, previous studies as described in sections 2.4 and 2.5 are only focusing on one approach (either DG coordination or network reconfiguration) to reduce power loss in the distribution network. This will cause the main objective of which is to further reducing power loss become limited. To solve the problem, several studies as explained in refs. [66-71] have been conducted by combining two approaches, but still do not provide the best solution due to not solve both approaches, simultaneously. Since, there are no research works solve the coordinate between DG coordination and network reconfiguration, in this thesis, the effectiveness of combination of both approaches will be examined so that the results obtained are better than the approach conducted separately. In addition, due to combination between DG coordination with network reconfiguration involve with high dimension problem (high number of variables), the AIBC is chosen to solve the problem.

2.7 Conclusion

In this chapter, previous studies conducted by other researchers in order to reduce power loss in distribution system have been discussed briefly. There are two approaches covered in this chapter, namely coordination of DG and network reconfiguration. Based on the literature review, both of these approaches have been proven to enhance the performance of distribution system, especially in power loss reduction. In addition, the reduction can be further reduced by combining the two approaches. Therefore, to ensure that these approaches can be implemented, hybrid optimization known as the AIBC will be described in the next chapter.

CHAPTER 3

ARTIFICIAL IMMUNE BEE COLONY

3.1 Introduction

In the previous chapter, the significance of the DG and the network reconfiguration to minimize the power loss was discussed briefly. The power loss is one of important aspects need to be considered by the utilities during planning stage. This matter is essential in order to achieve high efficiency of distribution system. Nevertheless, one of the issues still faced by them is uncertainty to determine the best coordination. Improper coordinate the approaches can deteriorate the system performance. Therefore, many researchers have suggested various tools to alleviate such problem.

At the beginning of this chapter, some discussions related to meta-heuristic methods will be discussed. Thereafter, the Artificial Bee Colony (ABC) algorithm will be discussed. Finally, the proposed method which is hybridization of ABC and Artificial Immune System (AIS) will be explained in details.

3.2 Overview of Meta-Heuristic Method

There are numerous methods that have been introduced by researchers to solve various engineering problems. Among the methods that are widely used in solving the problem is mathematical, heuristic and meta-heuristic algorithm. Since, engineering problems are very complex and difficult to be solved, thus, using meta-heuristic is the best decision, due to simplicity of the algorithm in solving complex system [72].

According to the Oxford dictionary, the word “meta” is referring to the “beyond”, while the definition of the heuristic refer to engage in the process of learning something for themselves. In some sense, meta-heuristic is a refinement from heuristic algorithm in searching of near-optimal solutions [47]. In general, meta-heuristic can be categorized into two types which are trajectory-based and population-based. The difference between these types can be seen in the initial solution where for the trajectory starts with single point and replaced with another point (the best solution so far) during the iterative process, whereas the population-based have multiple point during the initial solution [47].

Under the population-based, there are two classes of algorithm which are evolutionary and swarm intelligence [50]. Among the examples for the population-based optimization that has extensively used in wide range of engineering problems are Genetic Algorithm (GA) [8], Particle Swarm Optimization (PSO) [9], Firefly Algorithm (FA) [73], Ant Colony Optimization (ACO) [10], Artificial Immune System (AIS) [74], Harmony Search Algorithm (HSA) [75] and Artificial Bee Colony (ABC) [11].

In ref. [47], the authors have made brief overview on related to several meta-heuristic methods. In addition, they also make a comparison for each method and list all the advantages and disadvantages. Based from their observations, they conclude that none of these methods can solve all engineering successfully. This conclusion is known as “No Free Lunch Theorem” [76] which means that for certain types of engineering problem, the optimization approaches may not gives similar results from each others. Therefore, some improvement or modification must be made to the original method for solving specific problem.

In the literature review, there are various recommendations that have been suggested by researchers to improve performance of the original method in solving a specific problem. Typically, this is done through some modifications on the original formula or by integrating (hybrid) two methods to become a new method. Some examples available in the literature review are QIEP [29], GA-PSO [45], Hybrid TS-SA [61], HDE[62], EP-ACO [64], and SPSO [65].

In ref. [50], a comparative study between the ABC with other methods has been carried out. They make comparisons with various kinds of numeric test functions and simulation results showed that the ABC method gives better performance compared with other methods. Therefore, in the thesis, Artificial Bee Colony (ABC) will be the main focus of the study. Overview of theory for ABC and mathematical formulation will be covered in the next section.

3.3 Artificial Bee Colony

Artificial Bee Colony or simply known as ABC optimization was proposed by ref. [11] in 2005. The effectiveness of ABC algorithm had been tested at various engineering applications and better performance compared to other algorithms [77-82]. Basic principle of this method describes the replicating activities swarm of bees in searching for food source around hive [50, 77] as depicted in Fig. 3.1.

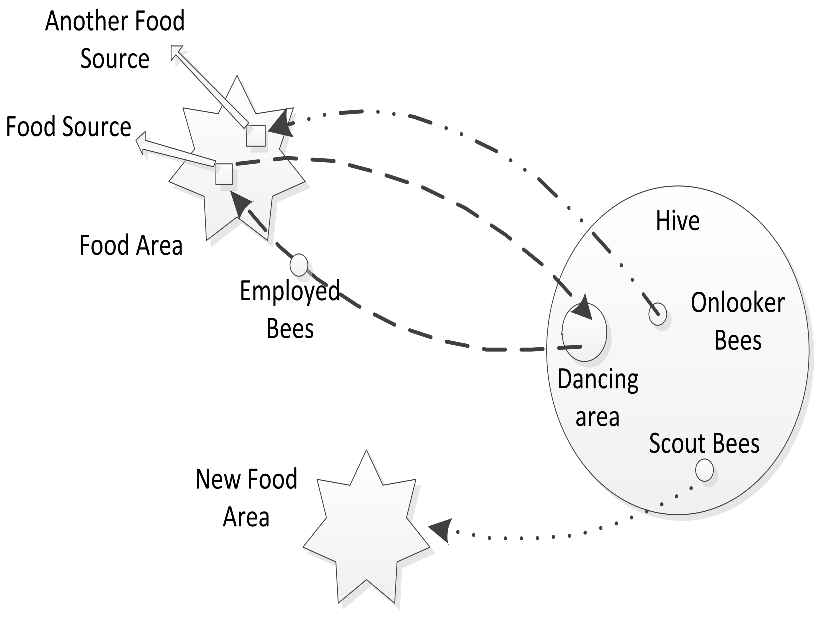


Fig. 3.1. Behavior of bees finding the food sources [77]

In general, the ABC consists of three types of bees, which are employed, onlooker and scout, where each type of bees represents different phases and task. This algorithm can be divided into four phase which are initialization phase, employed phase, onlookers phase and scout phase as shown in Fig. 3.2. There are two important parameters involved to tune the ABC optimization which are size of colony and limit. The size of colony is defined as total number of onlooker bees and employed bees, whereas; for the limit is total numbers of onlooker's bees multiply by size of dimensional parameter to be optimized [11].

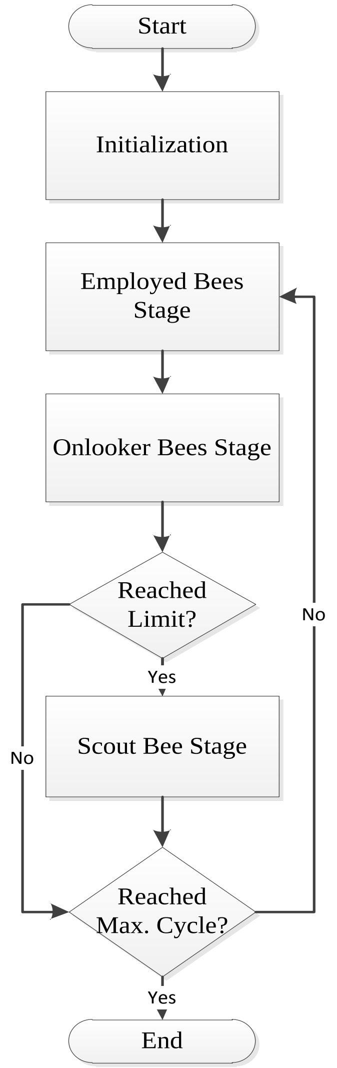


Fig. 3.2. Basic flow chart of ABC

The analysis is started by the scout bees; they are deployed out randomly in the possible search solution area to find the food source. After the acquisition of food sources, there will be an information exchange between scout bees and employed bees, according to Eq. 1. Specifically, the employed bees will find new food sources that are positioned near to the location given by previous scout bees by using Eq. 2. Based from this new location, they calculate the new fitness to be compared with the old fitness (obtained during the initialization phase) by using greedy selection. In the greedy selection process, only the higher of fitness value will be memorized by the bees and used in the onlooker bee phase.

$$FV_i = \frac{1}{(1 + Ob.Func_i)} \tag{1}$$

where FV_i is the fitness value and $Ob.Func_i$ is the objective formula of the study's problem.

$$x_{ij}^{new} = x_{ij}^{old} + range(0,1) \times \left(x_{ij}^{old} - x_{kj}\right) \tag{2}$$

where x_{ij}^{new} and x_{ij}^{old} are the new and previous value of variable, respectively. x_{kj} is a neighbor value that is selected randomly from j^{th} dimension and *range*(0,1) is a random value between 0 and 1.

The obtained information about the amount of food will be share with the onlooker via dancing area. However, the possibility for the onlooker bees to be chosen for extracting the food at the area where given by the employed bees is dependent on the amount of nectar available as in Eq. 3. If the food in the area is exhausted, the onlooker will be change to scout bees and search for new food source locations. The process is repeated until the maximum cycle that has been set by the user is reached. However, if the fitness value didn't improve for a specified number of times (until it reaches a certain predetermined limit), they will abandon the food source and assign a scout bee to explore new food source location randomly. Figure 3.3 shows an overall process of bees finding the foods.

$$prob_i = \frac{FV_i}{\sum_{i=1}^{N} FV_i} \tag{3}$$

where $prob_i$ is probability value and N is the total number of employed bees.

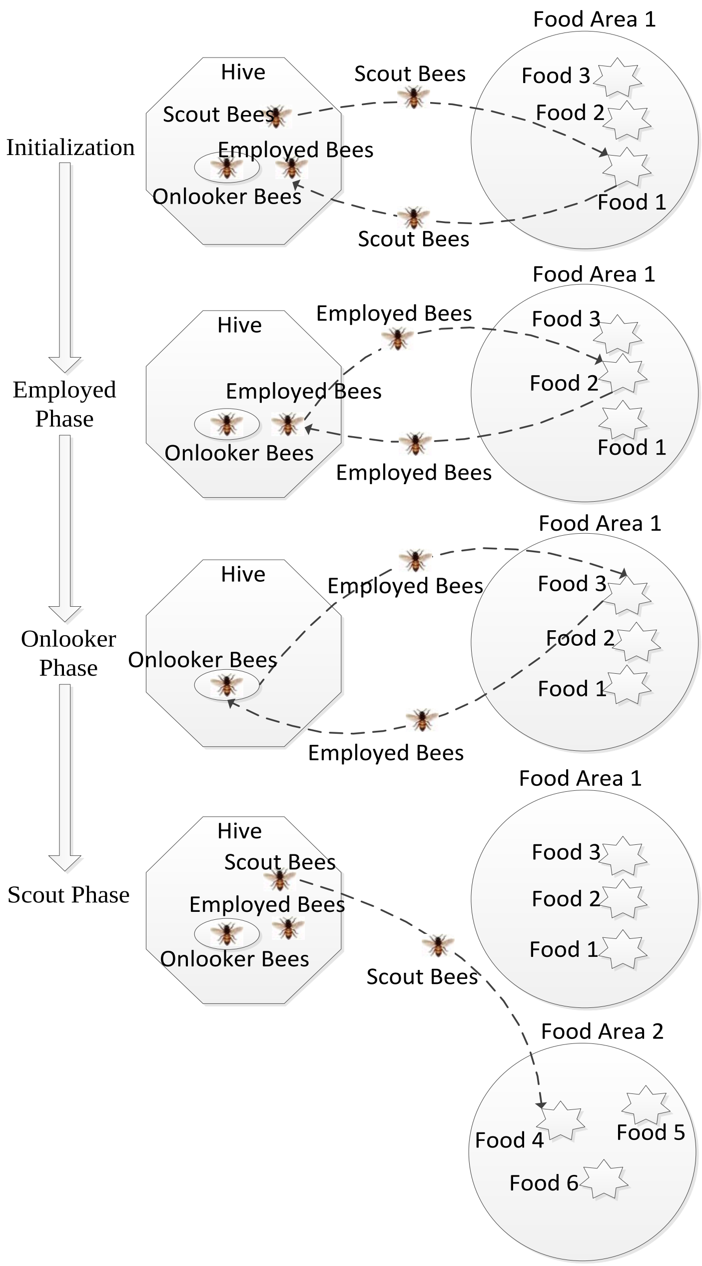


Fig. 3.3. Example of bees finding the foods

3.4 Artificial Immune Bee Colony Optimization

In original ABC, mutations process (Eq. 2) for new value of variables are determined randomly for one variable at one time (for example either location or output power of DG) for each cycle. However, for a problem that involved with many variables, hence, the ability of the ABC algorithm to search all possible solution area might be limited due to the aforementioned construction. Therefore, some modifications are done to the original ABC algorithm. The Artificial Immune Bee Colony Optimization, which is a combination of ABC and AIS, is introduced for solving the specific high dimensional problem. An example of comparison for mutation process between ABC and AIBC is explained in Appendix A.

The AIS is an algorithm that imitates the behavior of the immune system (human particularly), a natural defense mechanism to protect the human body from foreign substances [74]. Fig. 3.4 shows the general flow chart of AIS in searching optimal solution. Based from that figure, it can be observed that the AIS method involves several processes which are the initialization process, the duplication process, the mutation process, the sorting process and the selection process. The incorporation of the AIS method (duplicate, sort and selection) to the ABC algorithm implies that the hybrid optimization can gives reliable results than the original ABC algorithm. The basic flow chart of AIBC algorithm is depicted in Fig. 3.5. The main difference between AIBC and ABC is searching process, according to the comparison of the Fig. 3.2 and the Fig. 3.5.

Therefore, by implementing the AIS concept, the initial group of ABC will be duplicated based on group of variable (DG location, DG output and open/close switch) in the analysis. For example, if there are three groups of variable, the initial group will be duplicated three times. After that, each variable group is updated to a new value as described in Eq. 2. It can be seen that, after completing the updating process, at least three variables (DG location, DG output and Configuration) have been changed in each cycle but in the original ABC, only one variable (Either DG location, DG output or Configuration) is updated. Furthermore, after completing the "greedy selection" process, the results of three different variable groups are combined and will be sorted based on their fitness value. Only the high potential solution will be chosen (selection process) to be used for the next cycle, while the other values will be deleted. By using this approach, all variable groups will have the possibility to be updated in the analysis and the process to search all possible solutions can be achieved.

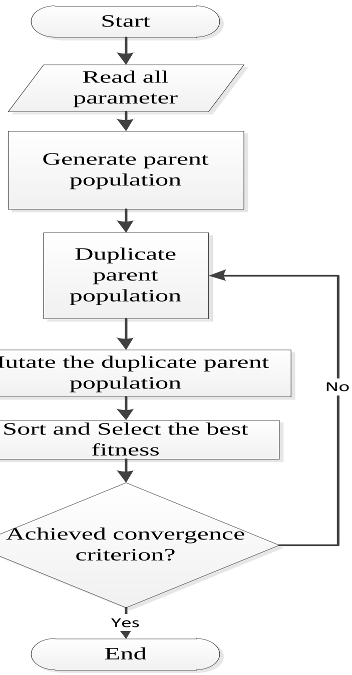


Fig. 3.4. Basic flow chart of AIS

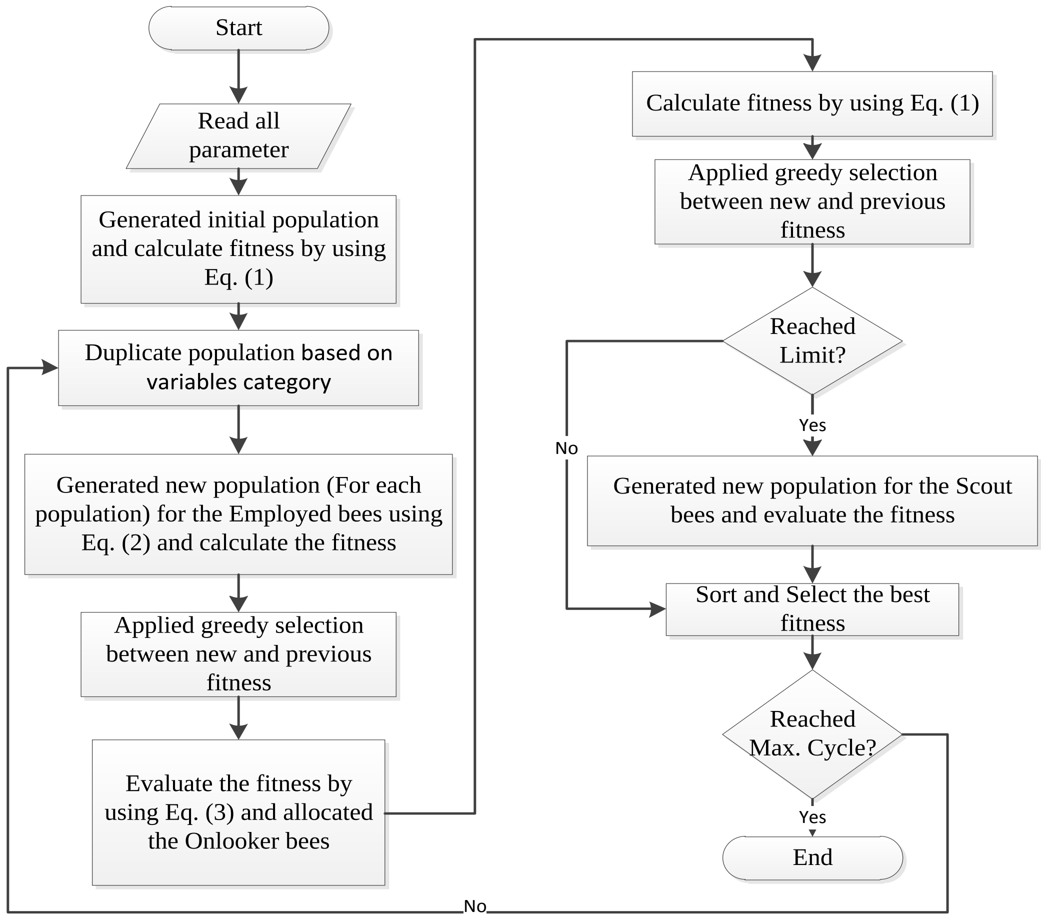


Fig. 3.5. Basic flow chart of AIBC

Table 3.1 shows comparison of pseudo code for each algorithm. It can be observed that the differences between the ABC and the AIBC are on duplication, sorting and selection process taken from the AIS algorithm.

Table 3.1: Comparison of pseudo code for each algorithm

ABC	AIS	AIBC
1) Initialize population 2) Place employed bees 3) Place onlookers bees 4) Check the Limit *if* the Limit reached *then* send scout bees 5) Memorize the best results 6) Check the maximum cycle *if* YES *then* STOP *else* Repeat steps 2 to 6	1) Initialize population 2) **Duplicate population** 3) Mutation process 4) **Sorting the results** 5) **Selection the best results** 6) Check stopping criteria *if* fulfill all requirements *then* STOP *else* Repeat steps 2 to 6	1) Initialize population 2) **Duplicate population** 3) Place employed bees 4) Place onlookers bees 5) Check the Limit *if* the Limit reached *then* send scout bees *else* 6) **Sorting the results** 7) **Selection the best results** 8) Memorize the best results 9) Check the maximum cycle *if* YES *then* STOP *else* Repeat steps 2 to 9

3.5 Conclusion

In this chapter, an overview of various methods under meta-heuristic that is widely used to solve engineering problems have been discussed. In addition, the ABC method which also the main focus of this study is discussed briefly. This method is the replication of foraging activity of bees around the hive. To improve the performance of this method, some modifications were made to the ABC by incorporating with the AIS. In the next chapter, the proposed method will be used to determine the coordination of DG in the distribution network.

CHAPTER 4

DETERMINATION OF OPTIMAL OUTPUT POWER AND LOCATION OF DG BY USING AIBC

4.1 Introduction

In this chapter, the advantages of the proposed method will be tested to determine the DG coordination on the designated test systems. The analysis will be divided into two parts. For the first part, the proposed method will be compared with the ABC in solving the location and output power of the DG, simultaneously. This comparison will be done on two test systems that have different sizes which are 33-bus and 69-bus. Multiple units of DG will be imposed on that system in order to investigate at various dimensional problems. In the next section, a comparison between the simultaneous analysis (same as proposed method in the first part) and separate analysis will be done. The separate analysis is a combination between single DG placement algorithm and Artificial Bee Colony (ABC).

4.2 Problem Formulation to Minimize Power Losses

Power flows in the test system are calculated by using Newton-Raphson approach. For example, let assumed the test system as shown in the Fig. 4.1. The current enter to bus i is given as in Eq. 4.

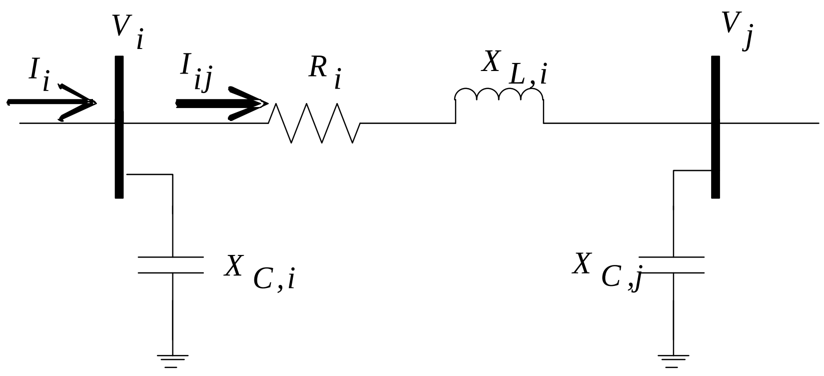


Fig. 4.1. Simple Test System

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \tag{4}$$

where Y_{ij} is the nodal admittance and V_j is bus voltage at bus *j*.

Transform the Eq. 4 into polar form and thus the new equation can be expressed as follows:

$$I_i = \sum_{j=1}^{n} |Y_{ij}||V_j| \angle \theta_{ij} + \delta_j \tag{5}$$

where θ_{ij} is the angle of nodal admittance, whereas δ_j is voltage angle at bus *j*.

The complex power at the bus *i* can be compute as in Eq. 6 and substitute the equation into the Eq. 4. The complex power at bus *i* can be expressed as below:

$$P_i - jQ_i = |V_i| \angle -\delta_i \sum_{j=1}^{n} |Y_{ij}||V_j| \angle \theta_{ij} + \delta_j \tag{6}$$

Separating the real and imaginary and the equations can be expressed as follows,

$$P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \tag{7}$$

$$Q_i = -\sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \tag{8}$$

After the Eqs. 7 and 8 are computed; the values of voltage and phase angle can be determined by using formula below.

$$\left|V_i^{(k+1)}\right| = \left|V_i^{(k)}\right| + \Delta\left|V_i^{(k)}\right| \tag{9}$$

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \tag{10}$$

where $\Delta V_i^{(k)}$ and $\Delta \delta_i^{(k)}$ can be calculated from Jacobian matrix as shown in Eq. 11.

$$\begin{bmatrix} \Delta P_i \\ \Delta Q_i \end{bmatrix} = \begin{bmatrix} J1 & J2 \\ J3 & J4 \end{bmatrix} \begin{bmatrix} \Delta\delta_i \\ \Delta|V| \end{bmatrix} \tag{11}$$

The power losses at each line and total power losses can be determined as in Eqs. 12 and 13, respectively.

$$Plineloss_{ij} = \left|I_{ij}\right|^2 \times R_{ij} \tag{12}$$

$$PTotalloss_{ij} = \sum_{i=1}^{nbr} |I_i|^2 \times R_i \tag{13}$$

where *nbr* is total number of line/branch.

Figure 4.2 shows the test system with DG. Similar as calculation of power losses without the DG, the line losses and total power losses can formulated as below:

$$Plineloss_{ij} = \left|I_{ij}'\right|^2 \times R_{ij} \tag{14}$$

$$PTotalloss_{ij} = \sum_{i=1}^{nbr} |I_i'|^2 \times R_i \tag{15}$$

where I_{ij}' and I_i' are the new current flow at line between two buses after DG is connected.

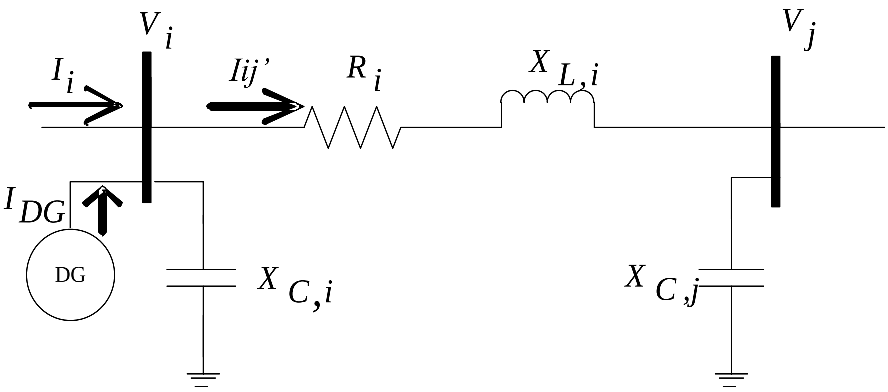


Fig. 4.2. Simple Test System with DG

For the optimization process, coordination of DG can be formulated as a mixed-integer nonlinear optimization which is involved with continuous state variable (DG output power) and discrete state variable (DG location). Since, the aim of this study is to reduce the total line losses in the distribution system, while maintaining all constraints within permissible limit. Therefore, objective function of the problem formulation can be expressed in Eq. 16

$$\min f(x_1, x_2) = \sum_{i=1}^{nbr} |I_i|^2 \times R_i \tag{16}$$

where,

x_1	continuous variables (DG output power),
x_2	discrete variables (DG location),
nbr	number of lines,
I_i	current at line, i of distribution system.
R_i	resistance at line, i of distribution system.

Four constraints are considered in the optimization process to ensure all parameters in the distribution network are within allowable limit. The lists of constraints are shown below:

a) DG operation constraint (continuous variable):

$$P_{DG,\min} \le P_{DG} \le P_{DG,\max} \tag{17}$$

All DG units must operate within the tolerable value where $P_{DG,min}$ and $P_{DG,max}$ are minimum and maximum limit of DG output power. In this study, all DGs are assumed to have the same minimum and maximum output.

b) Bus voltage constraint

$$V_{n,\min} \le V_n \le V_{n,\max} \tag{18}$$

The voltage value for all buses in the network must be within the acceptable limit where $V_{n,min}$ and $V_{n,max}$ are minimum and maximum allowable voltage at bus n.

c) Total power injection constraint

$$\sum_{k=1}^{tdg} P_{DG,k} < \sum_{n=1}^{tl} P_{load,n} + \sum_{i=1}^{nbr} \left| I_i \right|^2 \times R_i \tag{19}$$

The total power output from all DG units in the system must less than the total load and total power loss in the test system. Therefore, the reverse power flow to the main can be avoided with this constraint. The *tdg* and *tl* are total number of DG and total number of load, respectively. P_{DG} is size of DG and P_{load} is total amount of load consume at bus n.

d) Power balance constraint

$$\sum_{k=1}^{tdg} P_{DG,k} + P_{substation} = \sum_{n=1}^{tl} P_{load,n} + \sum_{i=1}^{nbr} \left| I_i \right|^2 \times R_i \tag{20}$$

The total power injected into the system which is from the DG unit and main substation, $P_{substation}$ must be same with total load and the total power loss (power equilibrium concept).

In order to solve this problem, DG power output and DG location are selected as variable x_1 and x_2, respectively. Total power losses of the system are selected as objective function, $Ob.Func_i$, whereas, the fitness value, FV_i can be obtained from the $Ob.Func_i$ by using the relation as in Eq. 1. At the first step of solution process, initial population, x_i, is randomly generated that consists of DG output power and location with the size of the population is N number. Based from this initial population, the fitness value is calculated. After that, the population will be duplicated based on the number of categories involved (For example DG location and DG output power) and new population will be generated by using Eq. 2 and then new fitness is calculated. Since, x_2 is considered as a discrete value, so the results obtained from the Eq. 2 will be rounded off to the nearest real number. In this "mutation" process, only variable that belong to each category will be modified by using Eq. 2, whereas other variable retained at previous value.

Next, the new and old fitness will be compared with greedy selection method where only high fitness is selected. From this selected value, the probability value will be calculated by using Eq. 3 for selection in onlooker phase. This selection is using the roulette wheel selection process that normally used in original ABC. Each of the fitness value will be normalized to 1.0 and will be randomly selected by the onlooker bees. After that, new population is obtained and new fitness value is calculated. Again, greedy selection will be used to obtain best fitness value. However, if the fitness value is not improved for a certain numbers (limit) during iteration process, the current variables will be abandoned and replaced with the new value that is selected randomly (scout bee phase). All fitness values for each population will be combined together and next, sorting and selection process will be done. This process is repeated until maximum cycle is reached. The proposed of DG coordination by using AIBC is summarized as follows:

Step 1: Randomly generated initial population, x_i consisting of DG output power and location with size of N number of Employed bees.

Step 2: Calculate fitness value, FV_i by using Eq. 1 for each solution of x_i.

Step 3: Duplicate the population based on number of category (DG output power and DG location).

Step 4: Compute new value of DG output and DG location by using Eq. 2 on each population and calculate the new FV_i.

Step 5: Apply greedy selection (Only higher FV_i is saved) between old and new FV_i.

Step 6: Calculate probability, $Prob_i$ value by using (3) and assigned the onlooker bees.

Step 7: Calculate new FV_i for the new population.

Step 8: Apply greedy selection and save the best fitness value.

Step 9: If the number of trial (limit) had been exceeded, one scout bee is assigned by randomly generate new value of both parameters and replace the solution, x_i with the new ones.

Step 10: Sort all population and select only N number of best fitness

Step 11: Memorize the best results so far.

Step 12: Repeat the process from step 3 to 11 until maximum cycle.

Figure 4.3 shows flow chart for AIBC to determine the optimal DG location and DG output power in the distribution system whilst as a comparison, Fig. 4.4 shows flowchart for ABC in solving the problem.

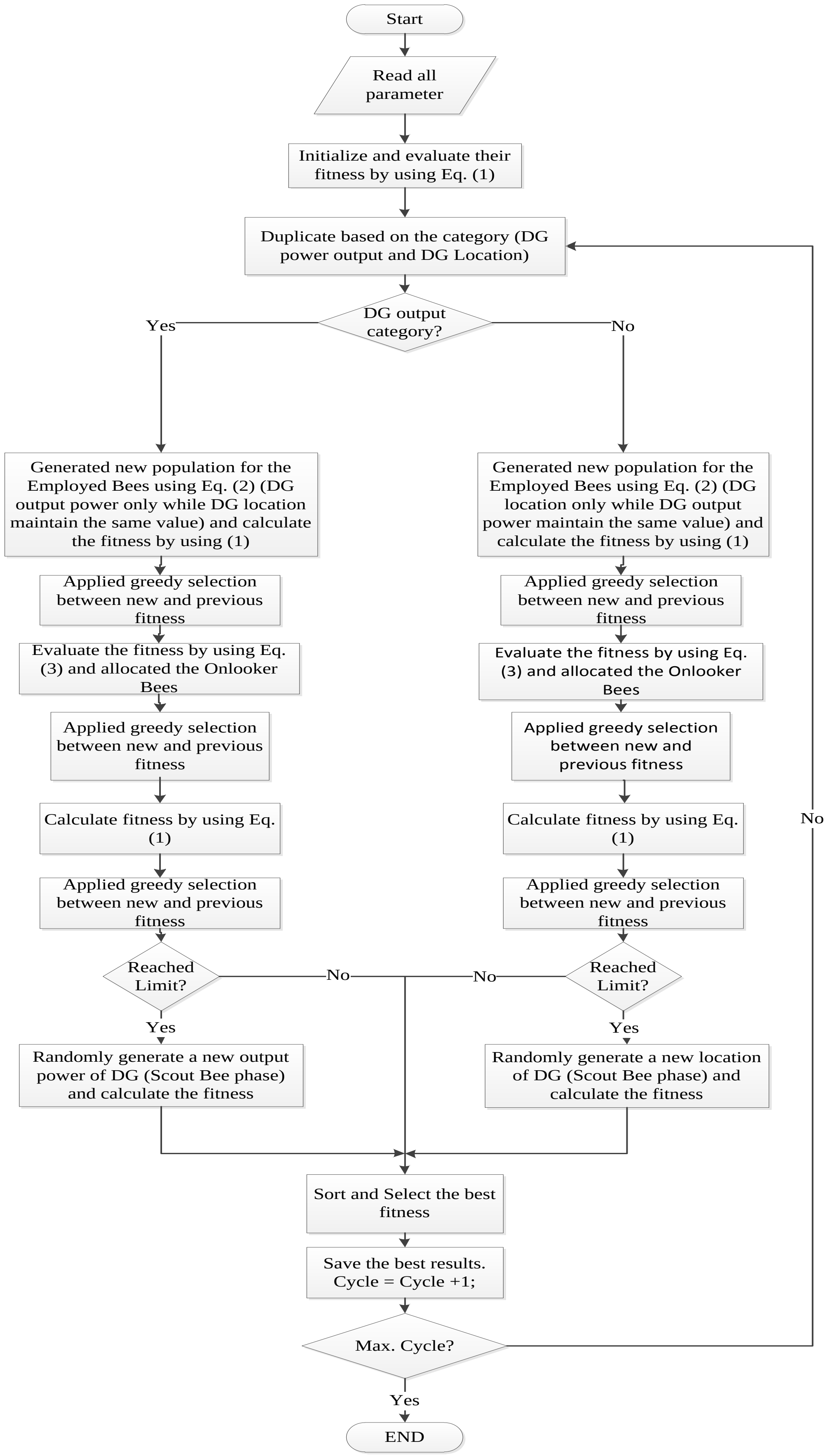


Fig. 4.3. Flow chart of AIBC to determine optimal DG coordination

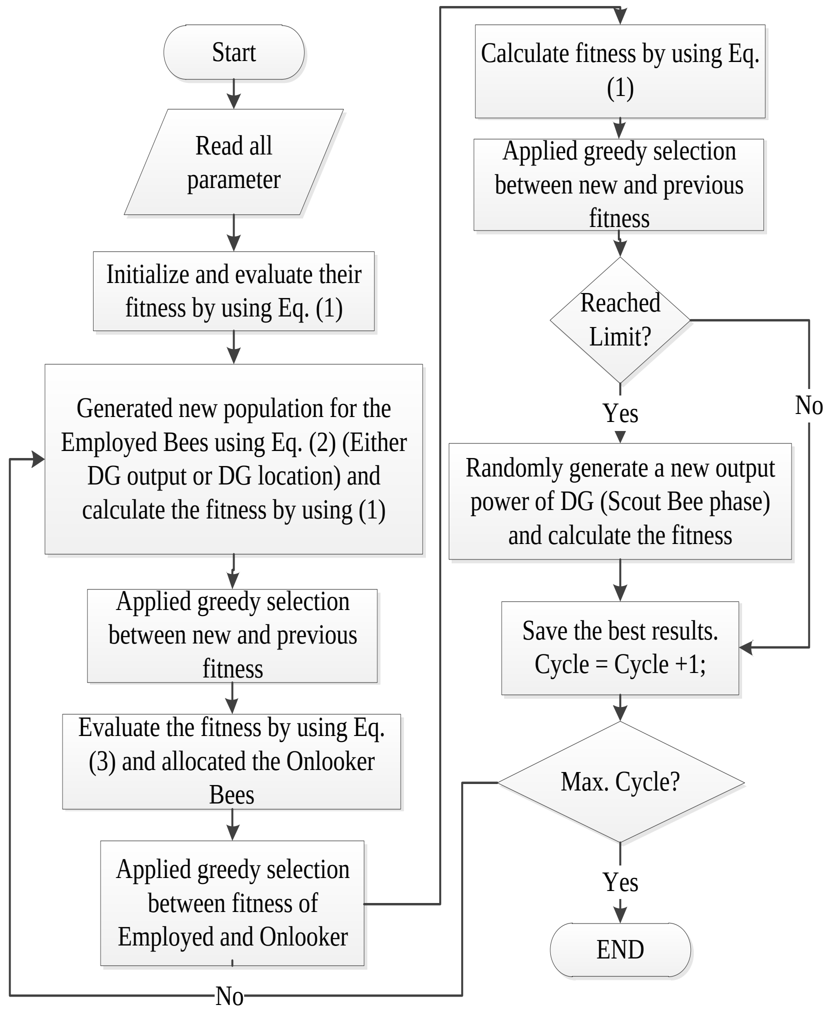


Fig. 4.4. Flow chart of ABC to determine optimal DG coordination

4.3 Related Data for 33-bus and 69-bus Test System for DG Coordination

All the case studies are applied to the 33-bus and 69-bus test system as shown in Fig. 4.5 and Fig. 4.6, respectively. The 33-bus system consists of 33 buses and 32 branches, whereas for the 69-bus system have 69 buses with 68 branches. Both of the test system connected to the main substation of 132/12.66 kV. All data related to the test systems can be obtained in Appendix B [83] and C [84]. The power and voltage base values are 100 MVA and 12.66 kV, respectively. In addition, all the DGs assumed to function in Power-Voltage (PV) mode whilst the loads are presumed to be power constant.

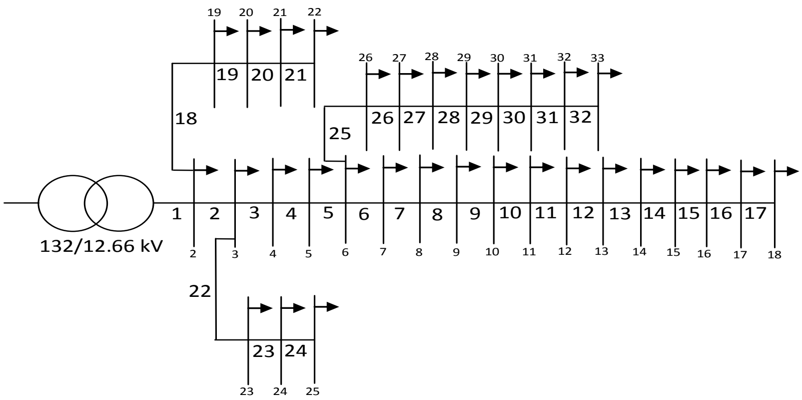


Fig. 4.5. 33-bus test system without DG

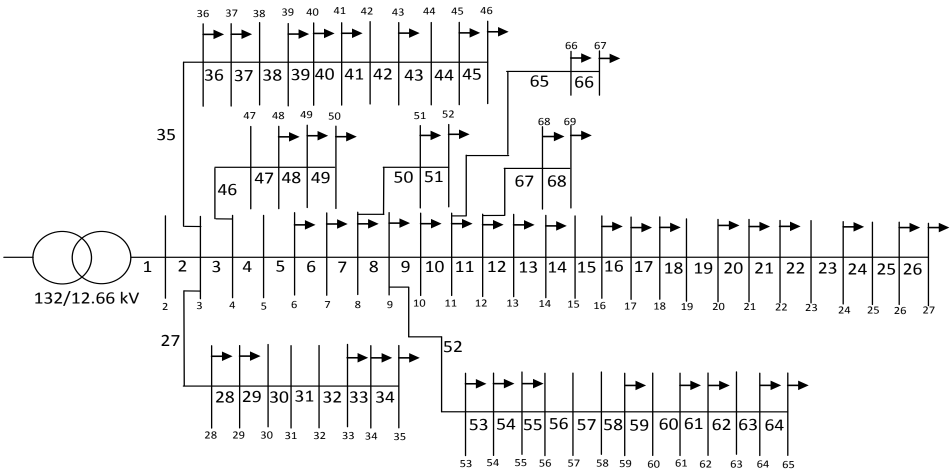


Fig. 4.6. 69-bus test system without DG

4.4 Comparison of Performance between AIBC and ABC

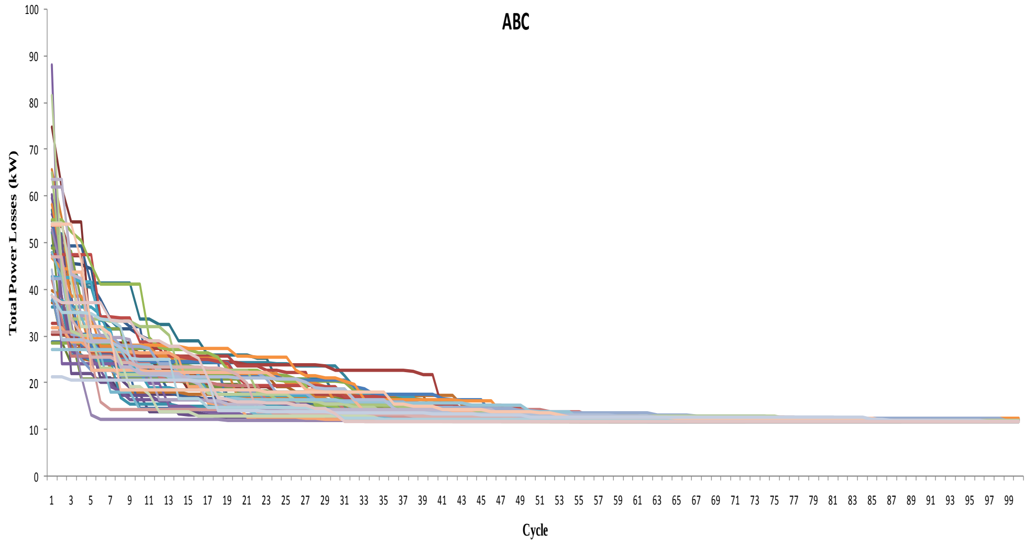
To test the effectiveness of proposed method at various dimensional problems, comparison with original ABC has been conducted for both the test system. In this comparison, both of techniques are runs independently for 50 times (100 cycles for each run) to determined output power and location for various number of DG.

Table 4.1 shows summary of the results between ABC and AIBC in solving coordination problems for multiple DG on 33-bus system. Based on the results obtained, both methods give similar results when the amount of DG installed on the test system is one and two, except the standard deviation of the AIBC is slightly higher than the ABC. The difference of the standard deviation values is contributed by the proposed method sometimes trapped at local optimum, but does not preclude the proposed method to obtain best results. When the number of the DG increased to three units, which means that the number of variables increases, it can be observed that the power losses reduction acquired by the AIBC is slightly better than the ABC at 11.6420 kW and 11.6433 kW, respectively. Even though this value is the same value when the number is rounded to two decimal places, but it showed that the ABC failed to obtain the same value as AIBC. Another significant difference that is expected is calculation time to solve the problem. The proposed method takes a longer time to solve the problem due to the AIBC have additional steps compared to the original ABC.

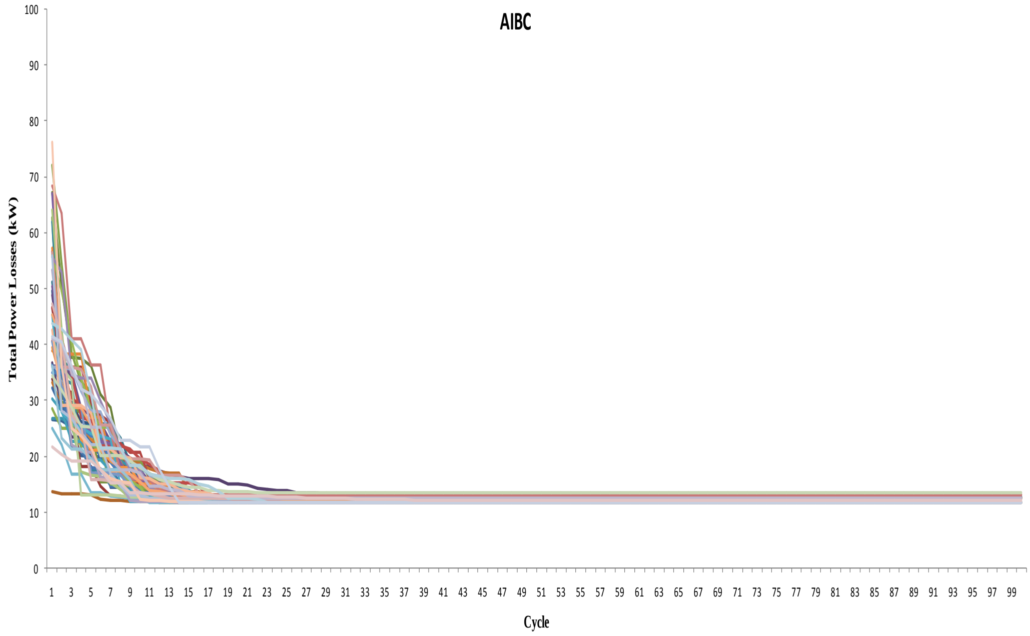
Table 4.1: Summary of Results between ABC and AIBC for 33-bus system

		Number of DG		
Method	**Descriptions**	**1**	**2**	**3**
ABC	Control Parameters (L=Limit NoB=Number of Bees)	L=40 NoB=40	L=140 NoB=70	L=300 NoB=100
	Optimal Location	6	13,30	14, 24, 30
	Optimal Output Power (MW)	2.4736	0.8381, 1.1194	0.7515, 1.0589, 1.0368
	Best (kW)	61.5481	28.5127	11.6433
	Mean (kW)	61.5482	28.5367	11.7215
	Worst (kW)	61.5488	28.6751	12.4054
	Standard Deviation (kW)	1.1861×10^{-4}	4.0536×10^{-2}	1.4531×10^{-1}
	Calculation Time (Seconds)	48.84	87.92	145.30
AIBC	Control Parameters (L=Limit NoB=Number of Bees)	L=40 NoB=40	L=140 NoB=70	L=300 NoB=100
	Optimal Location	6	13, 30	14, 24, 30
	Optimal Output Power (MW)	2.4736	0.8381, 1.1194	0.7496, 1.0644, 1.0375
	Best (kW)	61.5481	28.5127	11.6420
	Mean (kW)	61.5481	28.5734	11.9189
	Worst (kW)	61.5481	28.9612	13.3664
	Standard Deviation (kW)	5.1500×10^{-6}	1.0977×10^{-1}	4.4385×10^{-1}
	Calculation Time (Seconds)	57.30	97.17	170.35

Further analysis was conducted to compare the convergence curves for ABC and AIBC method in solving the problem. Figure 4.7 shows comparison of convergence characteristic (50 runs at different random seeds) for both methods to solve case for three DGs. It can be clearly seen that for all runs in the proposed method converge faster than the original ABC and this indicates that the AIBC is capable to find the optimal results at about half from total cycles compared to the ABC that requires more cycles to converge.



(a) Convergence characteristic of original ABC



(b) Convergence characteristic of AIBC

Fig. 4.7. Comparison of convergence curves between ABC and AIBC on 33-bus

Figure 4.8 illustrates voltage profiles based from the results for both methods. Voltage profile of the system without DG included for comparison and to investigate the impact of installed the DG on the test system. All the voltage values are normalized to 1.0 p.u (Per Unit) where the voltage that closer to 1.0 p.u is better. It can be observed that both voltage profiles show similar performance. Figure 4.9 shows the optimal location of all three units of DG on the 33-bus test system based on the results obtained by the ABC and the AIBC.

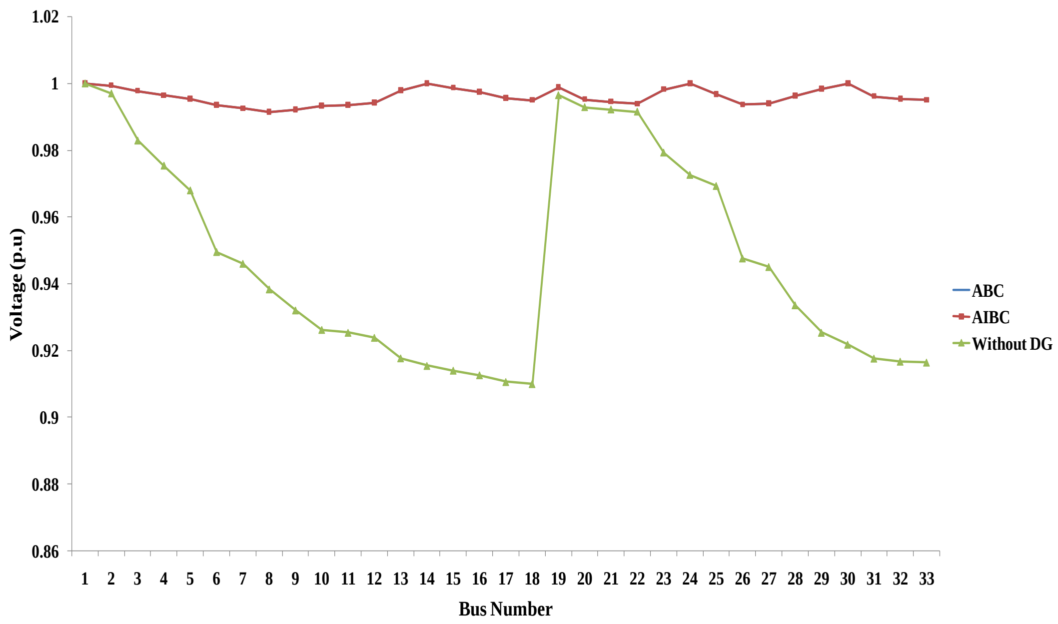


Fig. 4.8. Comparison of voltage profiles between ABC and AIBC on 33-bus system

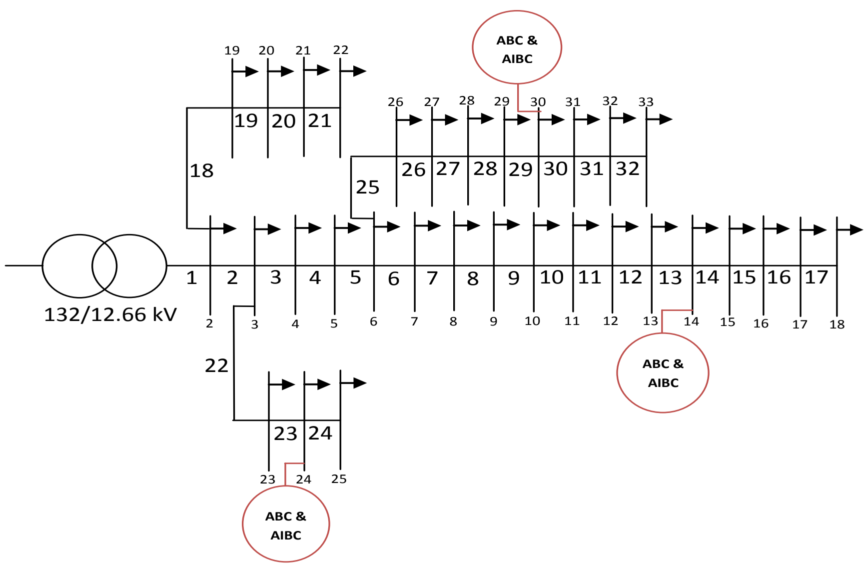


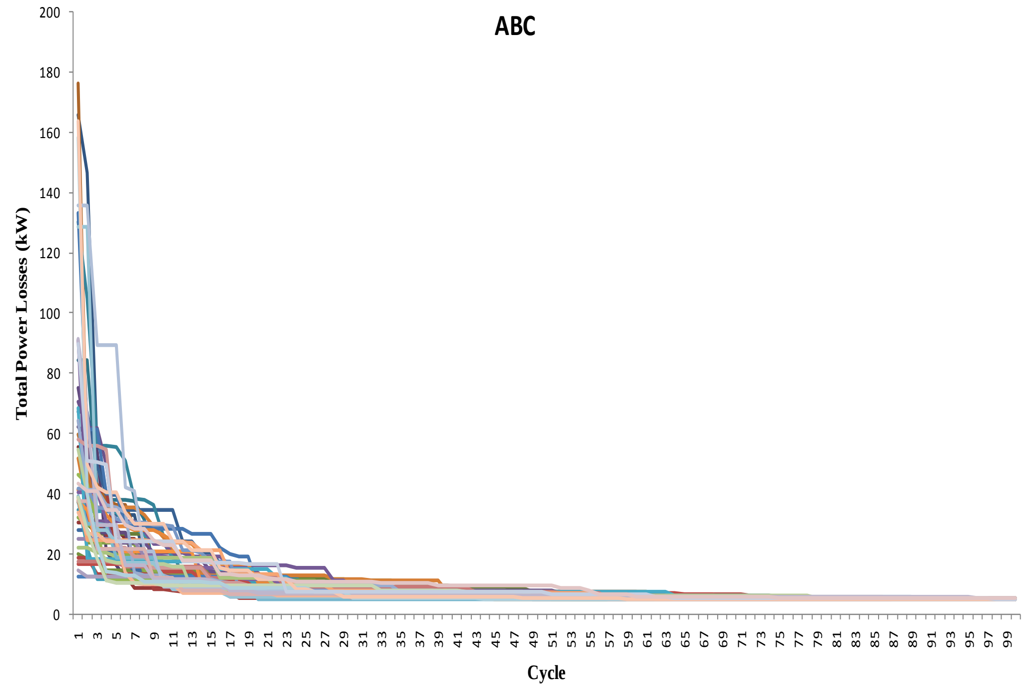
Fig. 4.9. Comparison of optimal location of DG between ABC and AIBC on 33-bus system

For the 69-bus system, the results obtained are shown in Table 4.2. It can be observed that AIBC gives better results than the ABC when the number of DG increased to three, where the best results provided by the AIBC is 4.2730 kW and the ABC is 4.9241 kW. In addition, the optimal locations for both methods are different too. This proves that when number of variables is huge, the ABC fails to search better results. Nevertheless, for the cases when the DG connected are one and two, the ABC and the AIBC gives similar total power loss reduction.

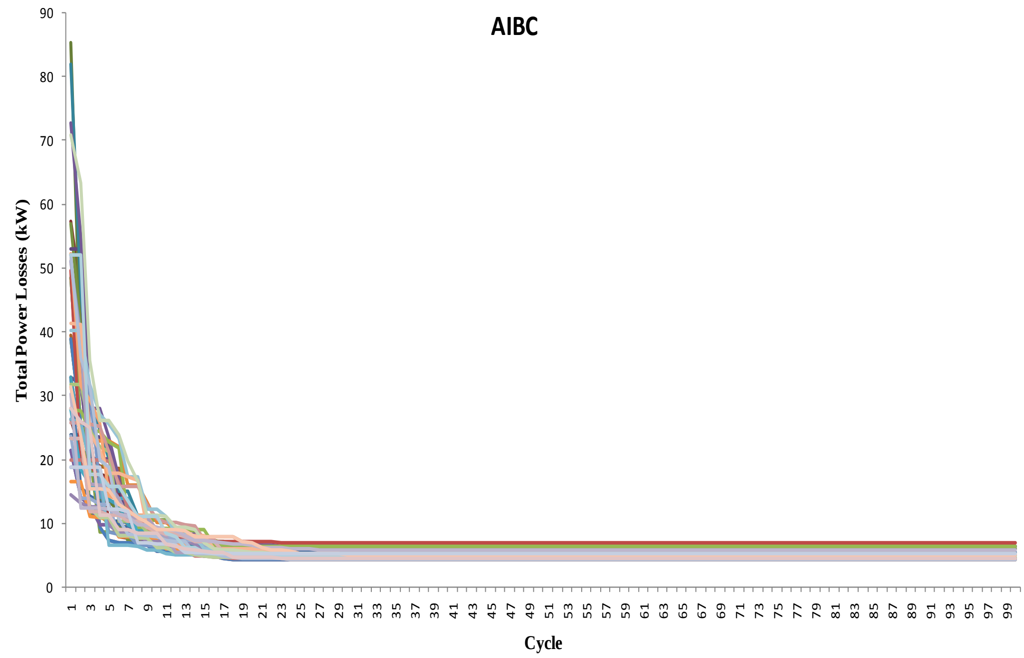
Table 4.2: Summary of Results between ABC and AIBC for 69-bus system

		Number of DG		
Method	**Descriptions**	**1**	**2**	**3**
ABC	Control Parameter (L=Limit NoB=Number of Bees)	L=40 NoB=40	L=140 NoB=70	L=450 NoB=150
	Optimal Location	61	17,61	17, 50, 61
	Optimal Output Power (MW)	1.8369	0.5284, 1.7392	0.5278, 0.7080, 1.7386
	Best (kW)	23.2151	7.2115	4.9241
	Mean (kW)	23.2151	7.2521	5.0192
	Worst (kW)	23.2151	7.4979	5.3361
	Standard Deviation (kW)	2.8368×10^{-6}	7.2504×10^{-2}	1.0446×10^{-1}
	Calculation Time (Seconds)	208.24	470.11	888.41
AIBC	Control Parameter (L=Limit NoB=Number of Bees)	L=40 NoB=40	L=140 NoB=70	L=450 NoB=150
	Optimal Location	61	17,61	11, 18, 61
	Optimal Output Power (MW)	1.8369	0.5284, 1.7388	0.5023, 0.3789, 1.6742
	Best (kW)	23.2151	7.2115	4.2730
	Mean (kW)	23.2151	7.2949	5.0317
	Worst (kW)	23.2151	8.5087	6.9156
	Standard Deviation (kW)	2.4472×10^{-6}	2.0906×10^{-1}	5.6626×10^{-1}
	Calculation Time (Seconds)	234.42	506.59	907.60

Comparison of convergence curves for the ABC and AIBC in solving coordination of two DG in 69-bus system is illustrated in Fig. 4.10. Based from that graphs, it can be observed that the AIBC converge more faster for all runs compared to ABC.



(a) Convergence characteristic of original ABC



(b) Convergence characteristic of AIBC

Fig. 4.10. Comparison of convergence curves between ABC and AIBC on 69-bus

Comparison of voltage profile for ABC and AIBC is depicted in Fig. 4.11. Both of these graphs show almost performance. Although there are several nodes that have low voltage compared to other nodes, but still in the allowed range and stable condition. This voltage differences is caused by two different locations of DG. Figure 4.12 shows the optimal locations proposed by both methods. All locations for DG is different except at node 61.

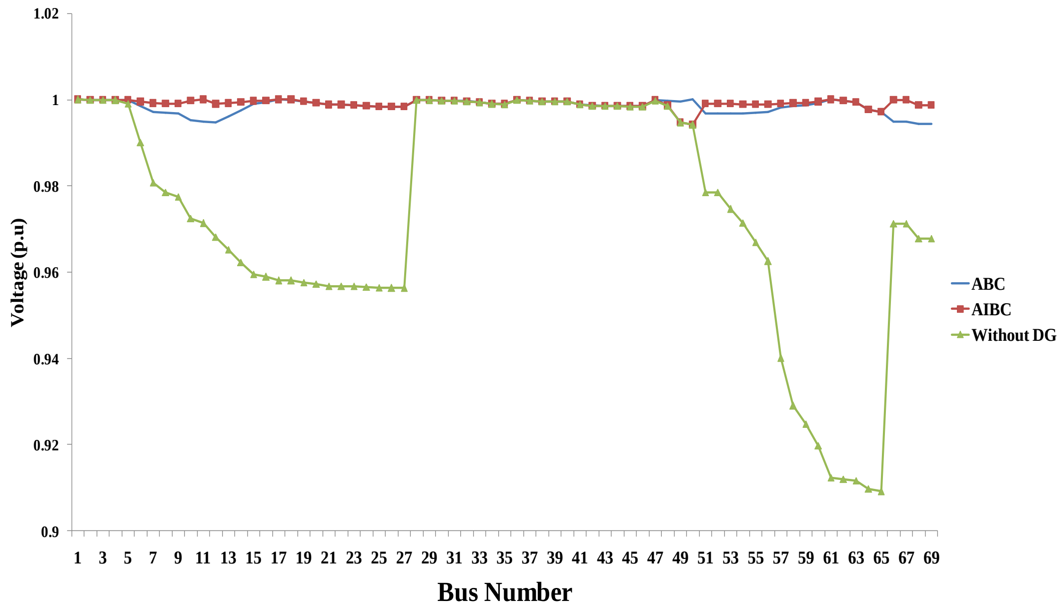


Fig. 4.11. Comparison of voltage profiles between ABC and AIBC on 69-bus system

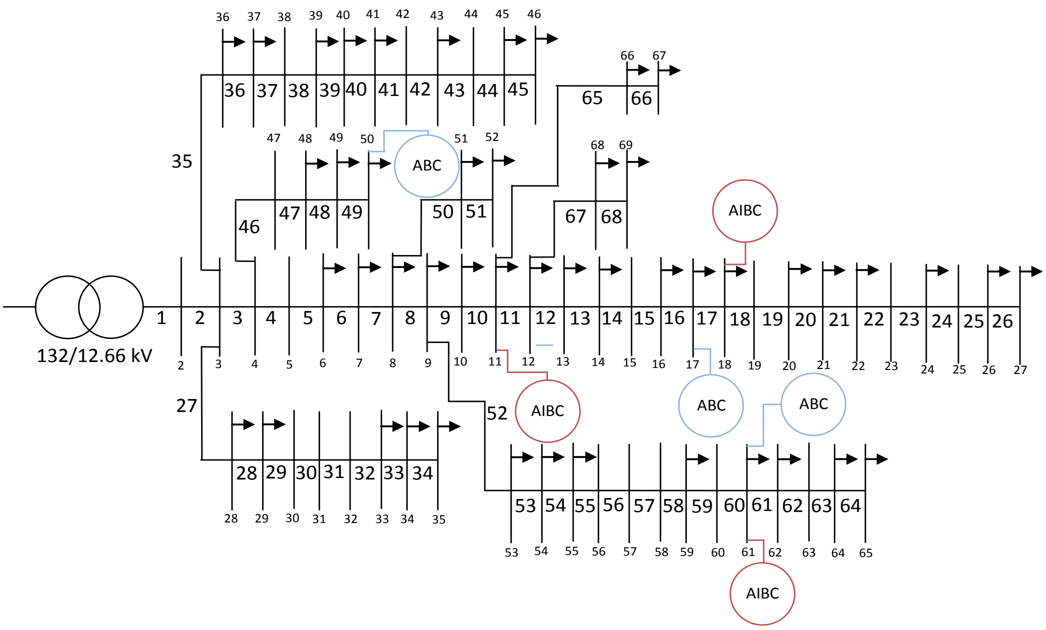


Fig. 4.12. Comparison of optimal location of DG between ABC and AIBC on 69-bus system

Based on all the results obtained from the comparison between ABC and AIBC, it can be concluded that the proposed method (AIBC) shows better results than ABC. Although both of these methods give the same results in determination of one and two units of DG, but when the number of DG is three, significant differences can be observed in the results for the location, output power of DG and total power loss. In next section, comparison between the coordination of DG performed simultaneously and separately will be conducted.

4.5 Comparison between Simultaneous and Separate Analysis in DG Coordination

As previously discussed in section 2.2, coordination of DG can be done either simultaneously or separately. For simultaneous analysis, determination of the location and the power output of the DG performed simultaneously where only one method is involved. On contrary, for separate analysis, the calculation of location and output power are done separately by using two different methods. Therefore, focus of this section is to investigate the quality of solution in solving DG coordination by using both analysis.

For separate analysis, combination between single DG algorithm [34] and AIBC will be utilized. The optimal location of the DG will be determined by using the single DG algorithm, whereas for optimal output power of DG is based on the AIBC optimization. In general, the basic concepts of single DG algorithm is operate by inserting single DG one by one at each bus in the system and choose the bus which gives the highest power lost reduction as a candidate of DG location, this process is repeated for next DG.

Three cases studies were conducted on both the test system (33-bus and 69-bus) as presented in Table 4.3. Case 1 is set as a reference (without any DG is installed) for comparison in term of total power losses and voltage profile with other two cases. In case 2, optimal DGs are determined by using AIBC optimization whereas for location of DGs, it is based from single DG placement algorithm. For last case, both of location and size of DGs are determined from AIBC algorithm simultaneously.

Table 4.3: Description for case studies in comparison of simultaneous and separate analysis

Case Studies	Description
1	This case is original network of test system without DG and set as a base case for comparison with other cases.
2	Locations are based on single DG placement algorithm, whereas optimal output of multiple DG by using AIBC.
3	Determine optimal output and location simultaneously for multiple DG by using AIBC.

Table 4.4 shows summary of results for all three cases in term of DG locations, outputs power and total power losses in the system. Without presence of DG in the system, an initial power loss is 203.19 kW. Further power losses reduction can be acquired when the DGs are consider in the system as shown in the results for case 2 and 3. A total of 83.63% of power losses reduction can be obtained for case 2 compared to case 1. However, more power losses reduction can be achieved when the DG location and size are determined simultaneously as shown in results of case 3. Based on this result, it indicates that the solution for case 2 trapped in a local minimum due to the chosen for the installation of DG is not the best location and in turn affects the selection of optimal output power. As a consequence, greater power loss reduction could not be achieved. Optimal locations of the DG that obtained by both case 2 and 3 are totally different as shown in Fig. 4.13. By using single DG placement algorithm, the optimal locations are at bus 6, 16 and 25, whereas by using the AIBC for the case 3 are at bus 14, 24 and 30.

Table 4.4: Summary of results of 33-bus system for comparison of simultaneous and separate analysis

Case	DG Locations (Bus number)	DG output power (MW)	Total Power Losses (kW)
1	-	-	203.19
2	6,16,25	1.71, 0.55, 0.77	33.26
3	14, 24,30	0.75, 1.06, 1.04	11.64

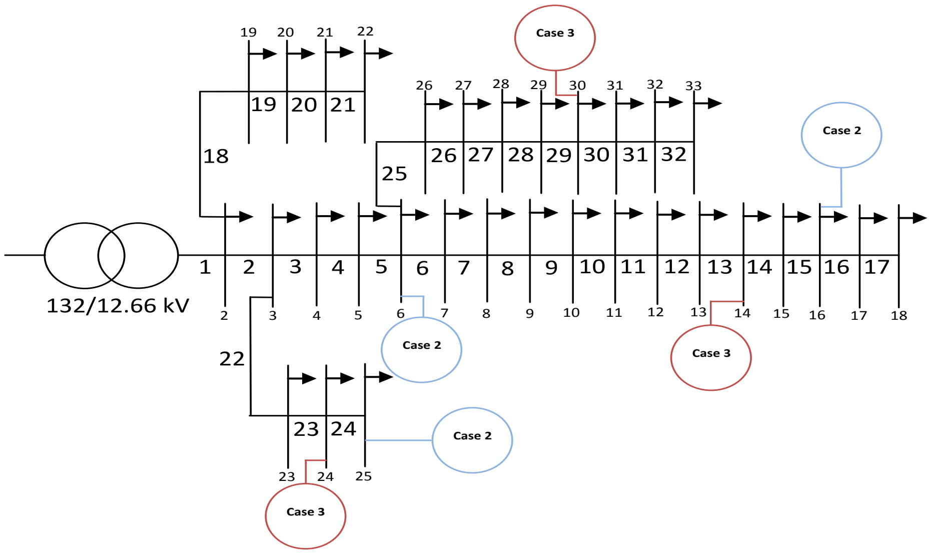


Fig. 4.13. Comparison of optimal location of DG between case 2 and case 3 on 33-bus system

Fig. 4.14 illustrates voltage profiles of the network for all cases. Based from the results obtained, voltages at each bus for case 2 are between 0.96 p.u and 1 p.u whereas for case 3, they vary from 0.99 p.u to 1.0 p.u. Although the performance of case 2 and case 3 increased significantly compared to the case 1, but there are still some buses showed a slight voltage reduction at 28, 29, 30 31, 32 and 33 as shown in case 2. Overall, the determination of the location and output power of DG simultaneously gives better voltage profile compared to the base case and case 2.

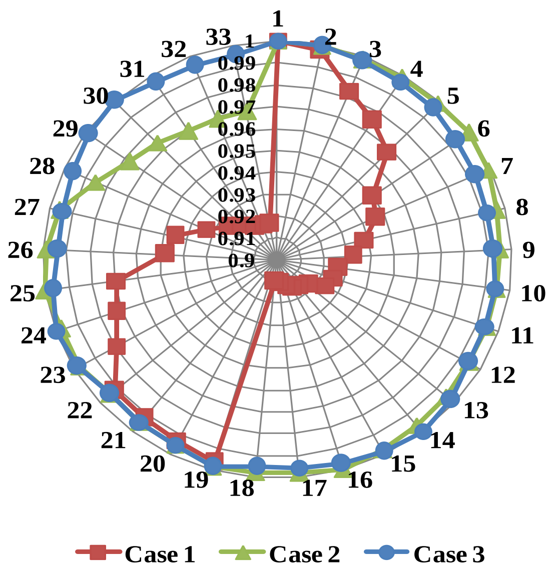
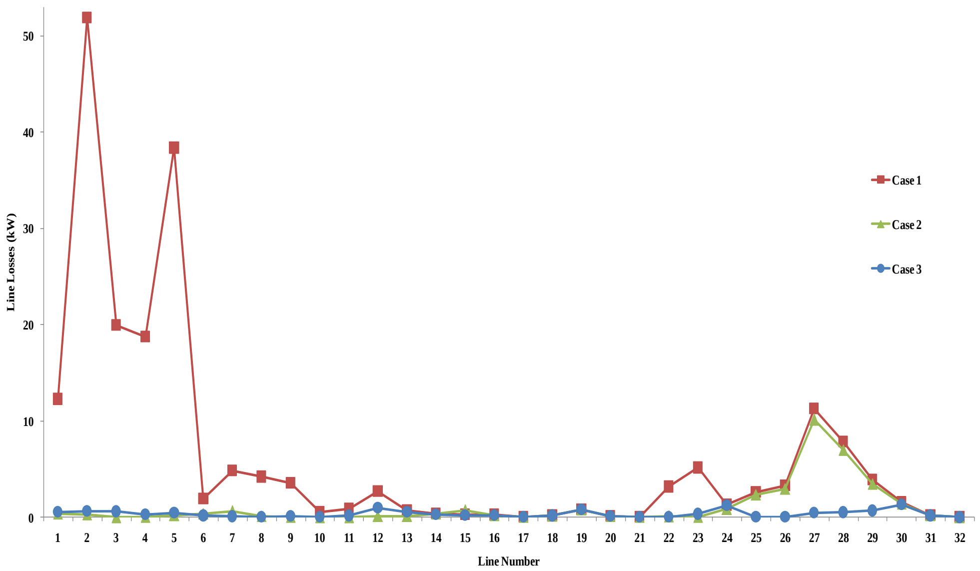
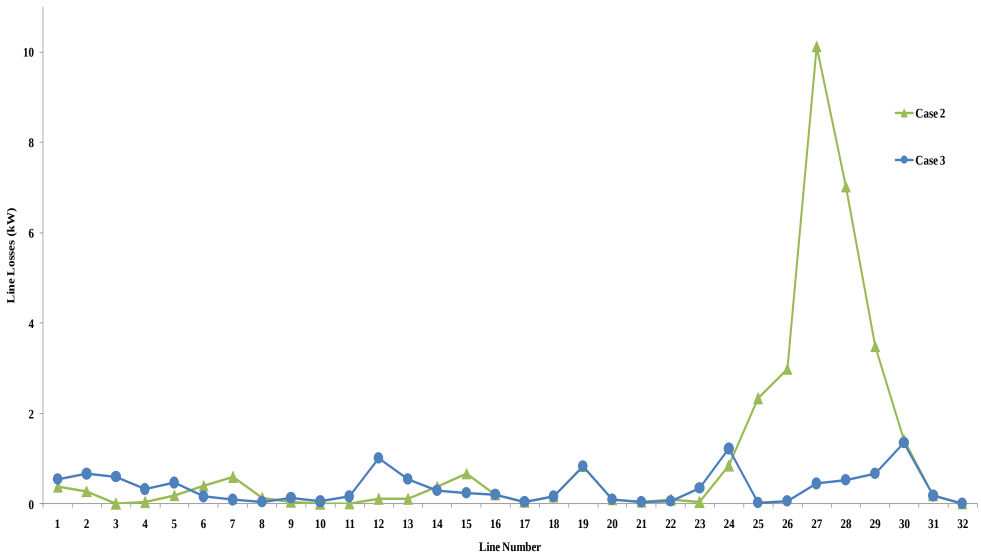


Fig. 4.14. Comparison of voltage profiles for all cases on 33-bus system

Figure 4.15 shows line loss at each branch for 33-bus system. The base case shows worst performance of line losses compared to other case studies, especially at branch number 2 and 5 which give high power loss as shown in Fig. 4.15(a). Nevertheless, it can be clearly seen that by applying simultaneous approach of DGs size and location, each branch gives lower power losses compared to the base case. Although case 2 also gives low power losses pattern same as in case 3, but several lines showed a significant increase of power losses which are at branch 25, 26, 27, 28 and 29 as illustrated in Fig. 4.15(b).



(a) Line losses for all cases



(b) Comparison line losses between case 2 and 3

Fig. 4.15. Line losses of 33-bus

Table 4.5 shows summary of results for 69-bus system. The initial power loss in the test system without DG is 225.06 kW. Based on the results obtained, the proposed method shows promising results in reducing the amount of power loss. A total of 98.10% power loss reduction was achieved when the optimal location for DG are 11, 18 and 61 with the optimal output power of 0.50, 0.38 MW and 1.67 MW, respectively. However, when a separate analysis is used to determine the coordination of DG, the percentage of reduction in power loss is at 97.81% where the total power losses increase at about 15.46% from the proposed method. In addition, the optimal location and output power of the DG obtained are quite different with the case 3 where the locations are 17, 50 and 61 with the corresponding output power of 0.53 MW, 0.72 MW and 1.74 MW, respectively. Figure 4.16 depicts comparison of optimal location of multiple DG for case 2 and case 3.

Table 4.5: Summary of results of 69-bus system for comparison of simultaneous and separate analysis

Case	DG Locations (Bus number)	DG output power (MW)	Total Power Losses (kW)
1	-	-	225.06
2	17,50,61	0.53, 0.72, 1.74	4.93
3	11, 18,61	0.50, 0.38, 1.67	4.27

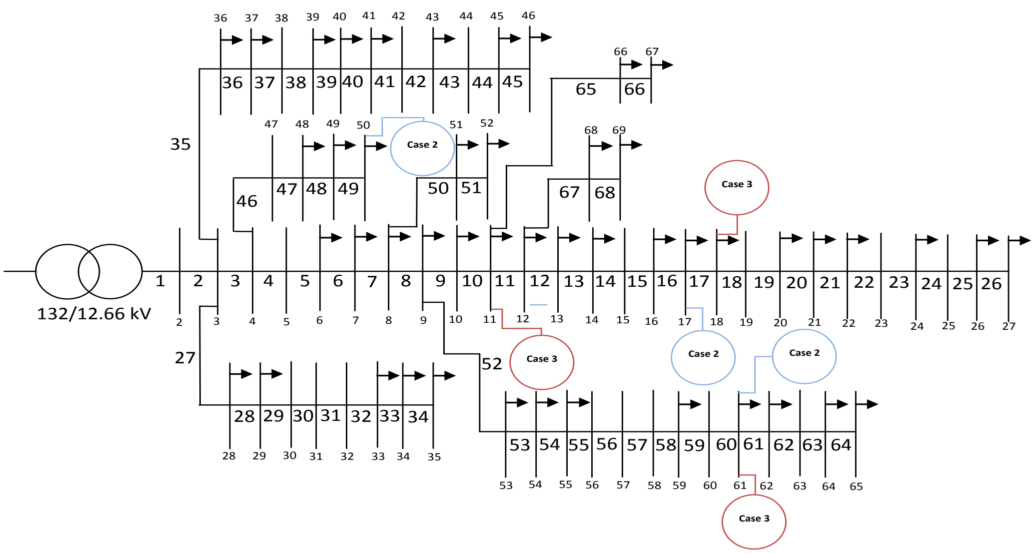


Fig. 4.16. Comparison of optimal location of DG between case 2 and case 3 on 69-bus system

Figure 4.17 shows a comparison of the voltage profiles of 69-bus system for all cases. It can be clearly seen that cases 2 and 3 shows significant voltage improvement compared to the case 1. Nevertheless, case 3 shows a better voltage improvement. This can be observed at bus 5 to 15, 51 to 56 and 66 to 69 in which the voltage increases slightly compared to the case 2. On the other hand, there are several buses which are not experiencing voltage increments such as bus number 49 and 50, due to no DG connected at a nearby location. This can be proved as in case 2 there is one DG connected at bus 50 and thereby improving the voltage. Overall, case 3 shows better improvements in voltage profile compared to other cases.

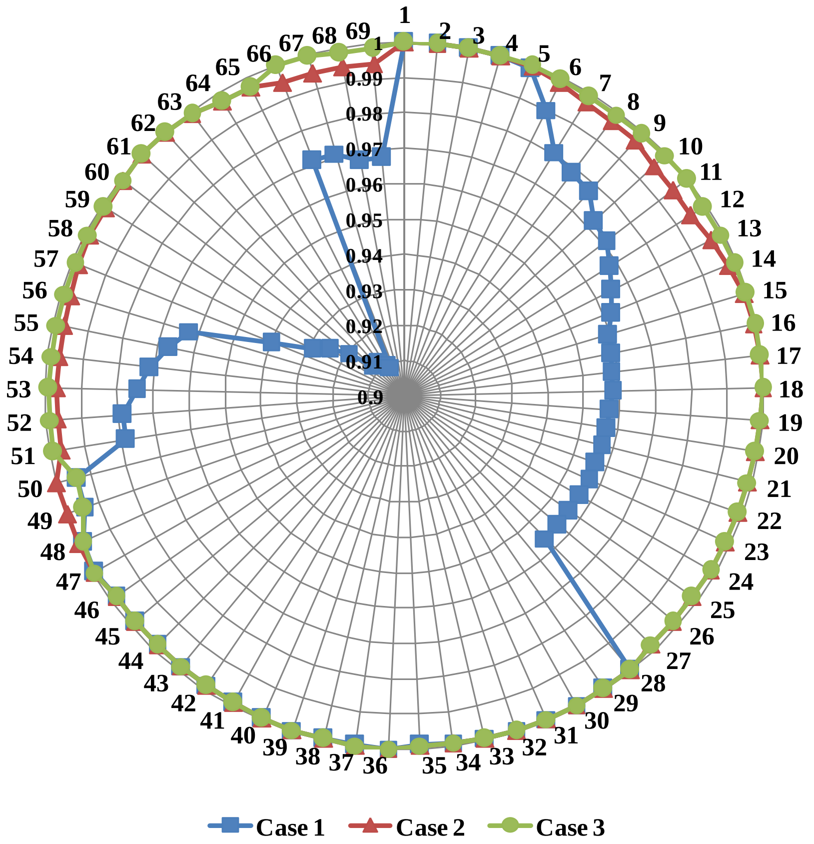


Fig. 4.17. Comparison of voltage profiles for all cases on 69-bus system

Figure 4.18 shows line losses in each line for case 2 and case 3. Based on the results obtained, it can be observed that all the lines losses are low. Although there is a line at 48 gives a relatively high (due to no DG connected at a nearby location) fro case 3, but overall simultaneous approach is better than in the case 2.

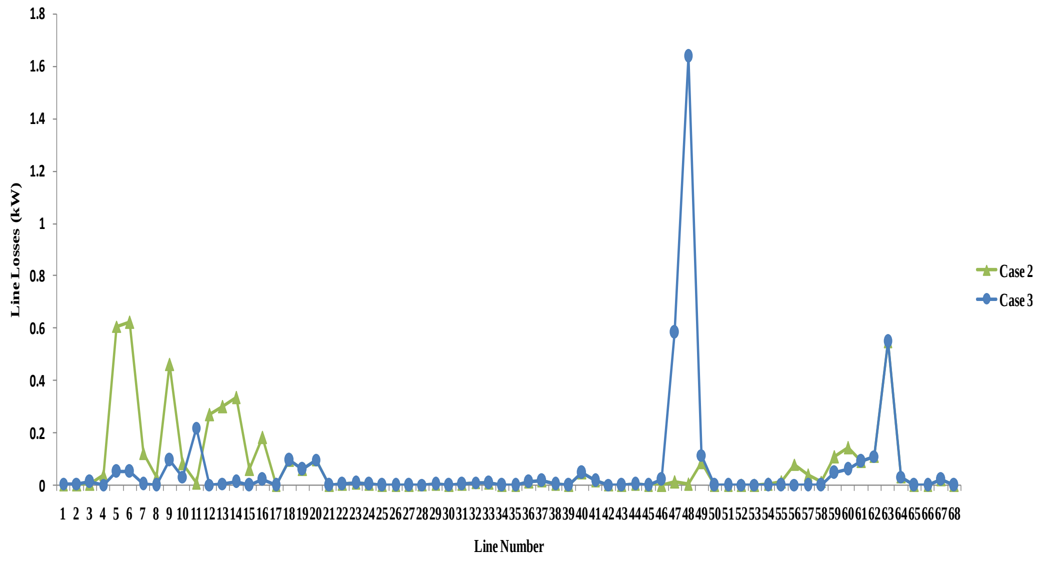


Fig. 4.18. Line losses of 69-bus

4.6 Comparison with other Methods

In order to show the effectiveness of the proposed method, several comparisons have been made with other references as presented in Table 4.6. Based on the results obtained, it shows that the proposed method gives better solutions in term of power losses reduction for both of test system. In the results of single DG case, the comparison between the proposed methods with other methods showed not too many difference in term of total power losses. This is due to the optimal location for all methods have same location, thus during the searching process (eg. PSO or GA or ABC) for DG output, the difference is not too significant. This can be observed through the results obtained. However, when the number of DG increased to two and three, differences on location plays a very significant role to reduce power losses.

Table 4.6: Comparison with Other Methods for 33-bus and 69-bus test system

Test System	Approach	DG Locations	DG Output (MW)	Total Power Losses (kW)
33-Bus	**Proposed**	**6**	**2.47**	**61.55**
	Analytical Approach [33]*	6**	2.49	61.56
	CSA [31]*	6**	2.28	63.26
	Proposed	**13,30**	**0.85,1.12**	**28.52**
	GA [32]*	6, 8**	1.72,0.84	55.67
	Proposed	**14,24,30**	**0.75,1.06,1.04**	**11.64**
	PSO[34]	6,15,25***	1.76,0.58,0.78	33.19
69-Bus	**Proposed**	**61**	**1.84**	**23.22**
	Analytical Approach [33]*	61**	1.81	23.39
	Proposed	**17,61**	**0.53,1.74**	**7.21**
	CSA [31]*	59,61**	0.37,1.47	23.37

*The result had been simulated again due to different mode of DG and power flow in original manuscript.

**Locations are based on sensitivity index.

***Locations are based on single DG placement via differential equation technique.

****Locations are based on loss sensitivity factor.

4.7 Conclusion

This section presented a solution to determine optimal output power and location of multiple DG simultaneously by using AIBC. The performance comparison in solving DG coordination has been made between the AIBC and the ABC. The results showed that the proposed method gives better results in term of power losses reduction and voltage profile for higher dimensions of the problem compared to the ABC method. In the second part, several case studies have been conducted to investigate the effectiveness of simultaneous approach in solving the DG coordination compared to separate analysis. Based on the results obtained, the proposed method gives better results in term of quality solutions. In addition, comparisons with other methods showed promising results. Therefore, at the next chapter, studied on the simultaneous network reconfiguration with DG coordination will be reviewed.

CHAPTER 5

LOSS MINIMIZATION VIA NETWORK RECONFIGURATION WITH DISTRIBUTED GENERATION COORDINATION

5.1 Introduction

In the previous chapter, the study of the coordination of DG has been discussed. Based on the results of this study, it was found that the location and output power by DG plays a very important role in reducing power loss. In addition, if the solution is done simultaneously, further reduction of power loss can be obtained. As discussed in chapter 2, another approach that can be used to reduce power loss is through network reconfiguration. Therefore, the main objective of this chapter is to determine the optimal network reconfiguration with DG coordination, simultaneously. The same method will be used as in chapter 4 (AIBC) to determine the coordination of the DG and network reconfiguration.

5.2 Problem Formulation for Minimal System Power losses

The optimal network reconfiguration with DG coordination problems can be formulated as a mixed-integer nonlinear optimization, which consists of continuous and discrete state variable. In addition, the main interest of this research is to find a solution that can harmonize both network reconfiguration and DG coordination solutions in order to further reduce total power loss in the test system. Hence, the objective function of this approach is similar as in chapter 4 and can be expressed as in Eq.16. For the constraint, six constraints are considered in the optimization process where four constraints are the same as in chapter 4 (Eq.17-20) and others constraints are listed below:

a) Radial configuration constraint:

The network must maintain the radial configuration for the whole duration of the optimization process. It means that, when a tie switch in the network is closed; one of the lines (sectionalizes switch).in the network must be opened.

b) Isolation constraint:

The configuration process must ensure that all nodes (load and lines) in the system are connected to the main supply (substation). In other words, there is no load or line disconnected from the system after the configuration process.

Method for solving this problem is the same as in solving the coordination for DG, except there are three categories of variables are involved, namely DG output power, DG location and list of switches for network reconfiguration, where it can be expressed as x_1, x_2 and x_3, respectively. To facilitate the search for closing/opening switches, the method in ref. [65] was used. In general, the search is performed by isolating certain number of switches in each group where the total group depends on the number of loops that exist when all tie switches are closed. In addition, only switches that are in the loop is included in the search space. Therefore, this will reduce the number of solutions that not feasible.

The proposed of DG coordination with network reconfiguration by using AIBC is summarized as follows:

Step 1: Randomly generated initial population, x_i consisting of DG output power, location and list of switches with size of N number of Employed bees.

Step 2: Calculate fitness value, FV_i by using Eq. 1 for each solution of x_i.

Step 3: Duplicate the population based on number of category (DG output power, DG location and switches).

Step 4: Compute new value of DG output, DG location and switches by using

Eq. 2 on each population and calculate the new FV_i.

Step 5: Apply greedy selection (Only higher FV_i is saved) between old and new FV_i.

Step 6: Calculate probability, $Prob_i$ value by using (3) and assigned the onlooker bees.

Step 7: Calculate new FV_i for the new population.

Step 8: Apply greedy selection and save the best fitness value.

Step 9: If the number of trial (limit) had been exceeded, one scout bee is assigned by randomly generate new value of both parameters and replace the solution, x_i with the new ones.

Step 10: Sort all population and select only N number of best fitness

Step 11: Memorize the best results so far.

Step 12: Repeat the process from step 3 to 11 until maximum cycle.

Figure 5.1 shows flow chart for AIBC to determine the optimal DG coordination with network reconfiguration in the distribution system.

5.3 Related Data for 33-bus Test System for DG Coordination with Network Reconfiguration.

The proposed approach (network reconfiguration with DG coordination) is applied to the 33-bus test system as shown in Fig. 5.2, which consists of 37 branches (sectionalize switches from branches 1 to 32), including optional 5 tie switches from branches 33 to 37 for network reconfiguration purpose. All data related to test system can be obtained in Appendix D [53]. The system is connected to the main substation of 132/12.66 kV, where the power and voltage base values are 100 MVA and 12.66 kV, respectively. In addition, all the DGs assumed to function in Power-Voltage (PV) mode whilst the loads are presumed to be power constant.

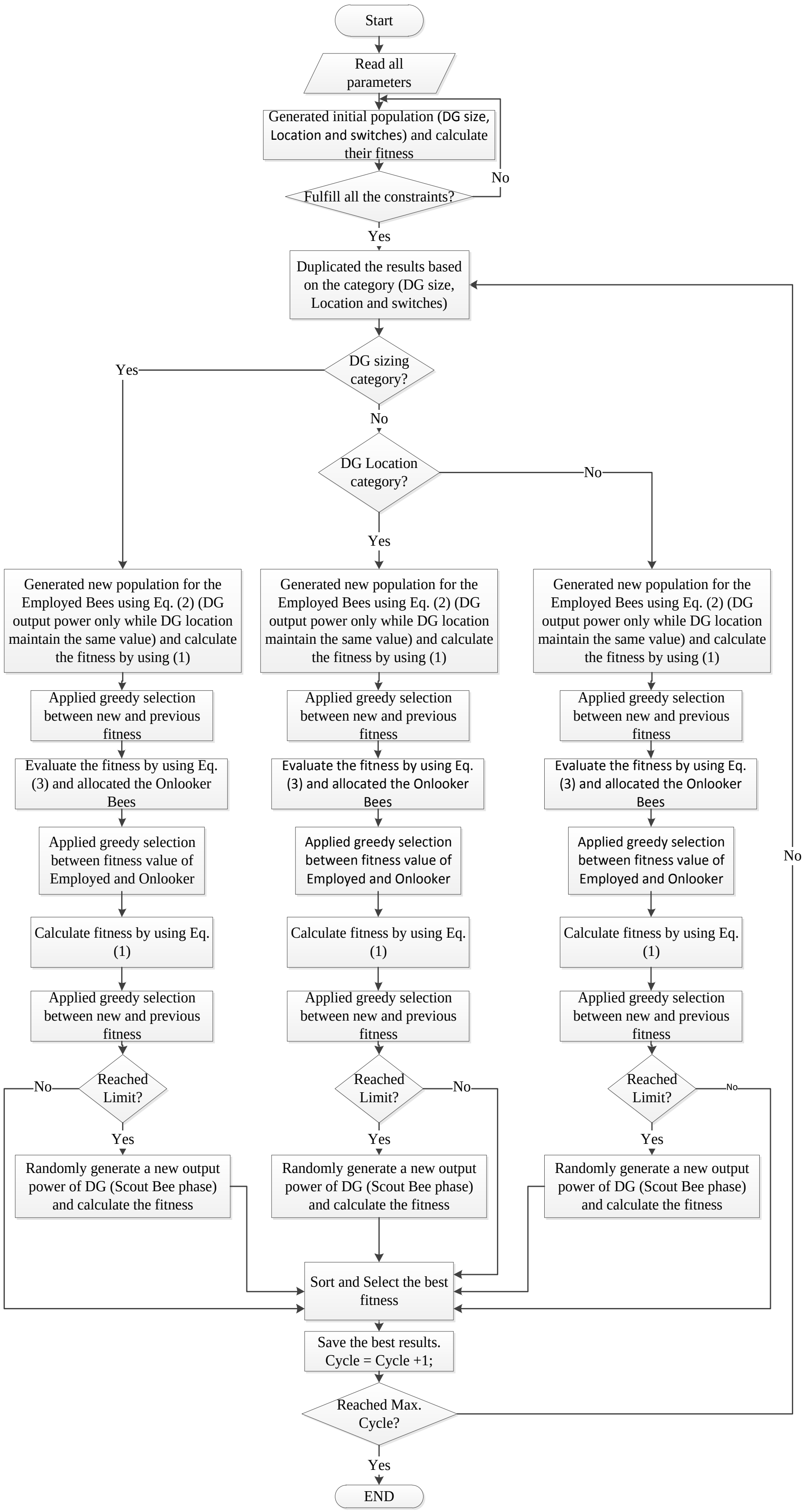


Fig. 5.1. Flow chart of AIBC to determine optimal DG coordination with network reconfiguration

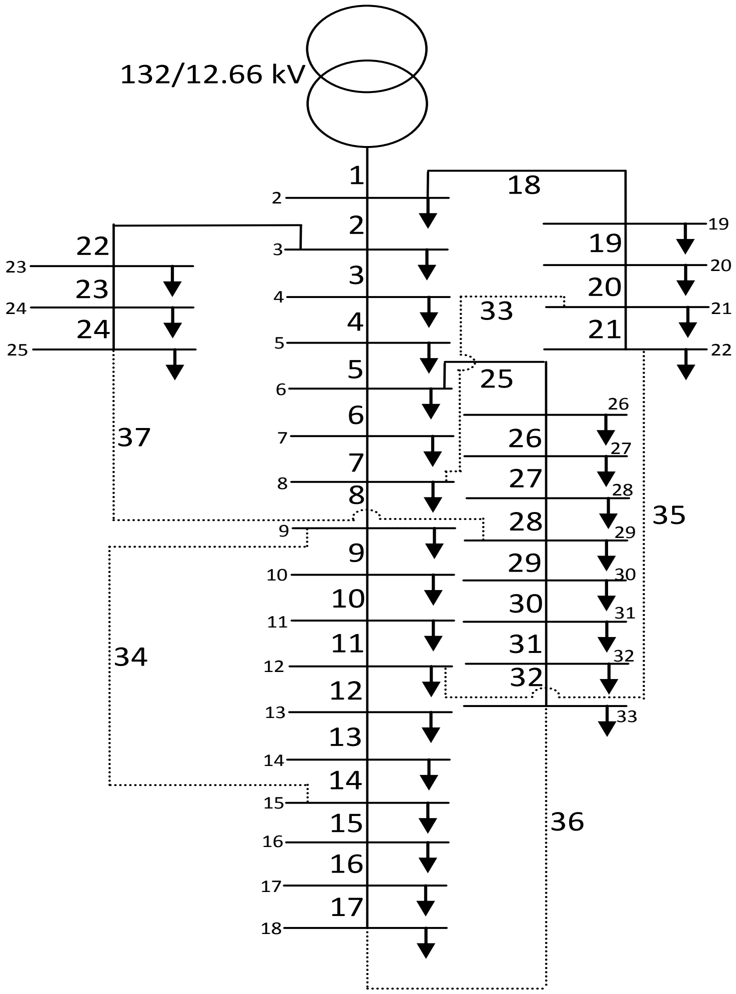


Fig. 5.2. 33-bus test system with optional lines

5.4 Solutions for Harmonization between DG and Network Reconfiguration

Five case studies are considered in this section as presented in Table 5.1. Case 1 is set as a reference case that doesn't imposed any coordination methods (network reconfiguration or DG installations). For case 2, network reconfiguration is applied on the case 1 (base case), whereas for the case 3, DGs are installed at predetermine location and the outputs are optimize via AIBC. In Case 4, three DG units are installed at a predetermined location and determination of optimal output power and reconfiguration of the network will done simultaneously by using the AIBC. On the other hand, for the case 5, both of DG coordination (locations and DG outputs) and network reconfiguration will be executed simultaneously.

Table 5.1: Description for case studies in DG coordination with Network Reconfiguration

Case Studies	Description
1	This case is original network of test system without DG and network reconfiguration (base case).
2	Applied network reconfiguration technique in the base case.
3	Installed three DG units at similar location as in chapter 4 and optimize the DGs output by using AIBC.
4	Installed three DG units at similar location as in chapter 4 (optimal location obtained in ABC) and optimize the DG output with network reconfiguration simultaneously on the base case.
5	Optimize the location and output of the DG with network reconfiguration simultaneously (**proposed approach**) on the base case.

Table 5.2 shows the results for open switches, DGs' outputs and locations, total power loss, statistical analysis (best, average, worst and standard deviation), saving percentage, increment of minimum voltage improvement and calculation time achieved by all cases. In the case 3, since there is no reconfiguration technique applied, the opened switch's numbers are similar to the initial condition (case 1). Furthermore, for the cases 3 and 4, the location of the DGs are based from results in chapter 4 (separate analysis) and only the output and/or reconfiguration action are optimized, whereas, for the case 5, all the variables are optimized by AIBC. All the cases are runs independently for 50 times. In addition, all control parameters for limit, maximum cycle and total number of bees are set at 120, 100 and 140, respectively.

From the obtained results, the simultaneous reconfiguration and DG coordination gives the lowest power losses value compared to the other cases. Nearly to 95.53% of power loss reduction is achieved in the case 5 compared to original total power losses value, 203.19 kW (Case 1). The power losses value that is given by the case 5 is actually being influenced by combination of both factors: network reconfiguration and DG coordination. This can be proved by referring to the results for reconfiguration and DG sizing in the cases 2 and 3, respectively. In the case 2, performing the reconfiguration process, the power losses in the network only reduced up to 31.11 %, whereas, for the case 3 about 83.63 %. This shows that that the power loss reductions for single approach (either optimal reconfiguration or optimal DG output power) are not superior as in the power loss reductions as in the case 5. In the case 4, savings of power loss reduction increases about 10.15 % from the saving in the case 3. This increment is caused by DGs output power and reconfigurations are determined, simultaneously. Figure 5.3 shows final result for case 5 when the coordination of DG and network reconfiguration is carried out simultaneously.

Table 5.2: Summary of results of 33-bus system for DG coordination and network reconfiguration

		Case				
Method	**Descriptions**	**1**	**2**	**3**	**4**	**5**
AIBC	Branch Opened	33, 34, 35, 36, 37	7, 9, 14,28,32	33, 34, 35, 36, 37	3,23,28, 34, 35	5, 11, 13, 23, 27
	Optimal Location	-	-	6,16,25	6,16,25	8,25,32
	Optimal Output Power (MW)	-	-	1.70,0.53, 0.77	0.99,0.69, 1.44	1,1.14, 0.79
	Total Power Loss (kW)	203.19	139.98	33.26	12.63	9.08
	Best (kW)	-	139.98	33.26	12.63	9.08
	Mean (kW)	-	157.07	33.26	13.45	12.46
	Worst (kW)	-	193.05	33.26	14.95	18.52
	Standard Deviation (kW)	-	12.97	1.06×10^{-6}	0.53	2.04
	Saving (%)	0	31.11	83.63	93.78	95.53
	Minimum Voltage Improvement (%)	-	3.43	6.44	8.95	8.95
	Calculation Time (Seconds)	-	302.40	81.44	1194.94	1550.70

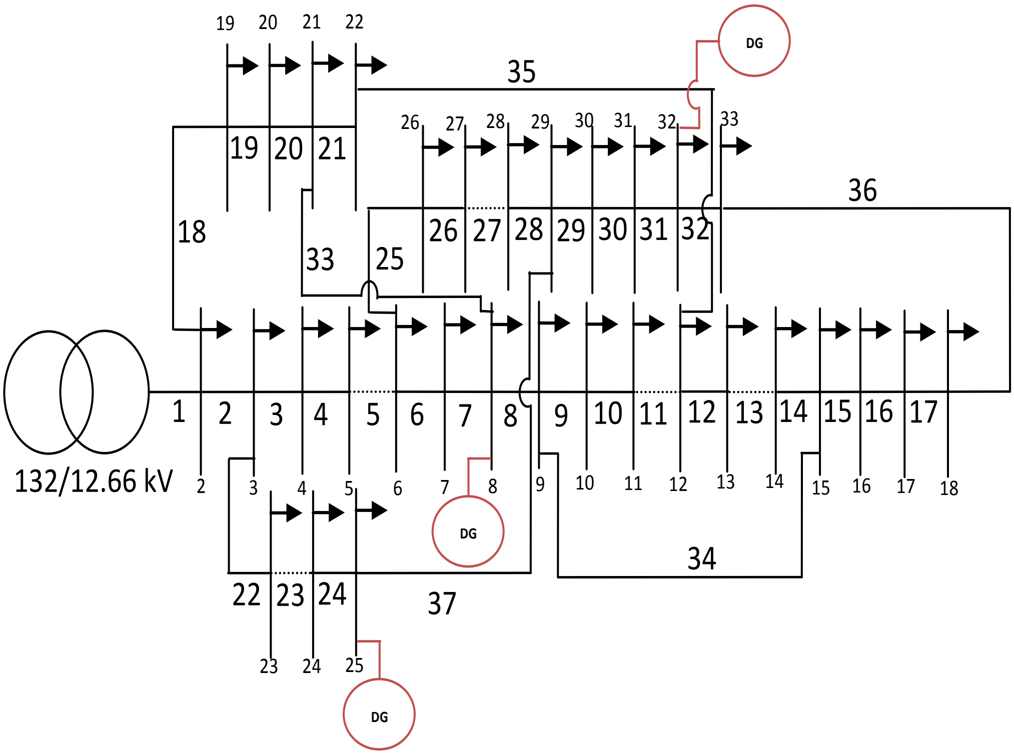


Fig. 5.3. Final result for case 5

The voltage profile of the system is enhanced simultaneously with the reduction of the power losses. The Fig. 5.4 shows the comparison of voltage profile for all cases. It can be clearly seen that the cases 3, 4 and 5 shows the significant voltage improvement compared to the base case due to the presence of DG in the test system. Moreover, the reconfiguration process improves the voltage profile according to the case 2. In case of the case the DG's connection (case 3), the voltage profile is improved contrary to the case 2. Furthermore, the application of configuration technique and DG's coordination implies that that almost all bus voltage is close to unity value (cases 3, 4 and 5). Overall, the simultaneous combination technique of DG coordination and network reconfiguration technique increases the voltage performance in the distribution system.

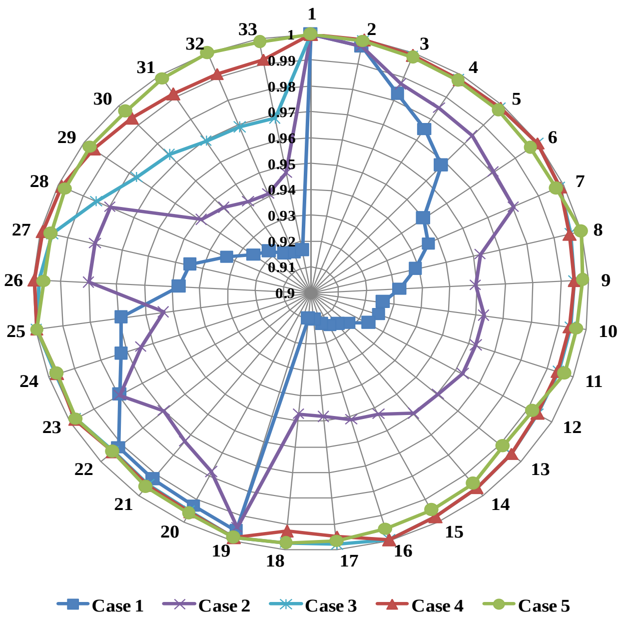


Fig. 5.4. Comparison of voltage profiles for all cases on 33-bus system

Overall, the results show significant improvements in voltage performance. This can be observed through increment of minimum voltage for all cases with respect to the base case. For the case 2, minimum voltage increase by 3.43% when network reconfiguration is applied. A further voltage enhancement can be obtained in the case 3 which is 6.44%. It can be seen that the presence of DG in the distribution network gives a substantial increment of the minimum voltage compared with network reconfiguration in the case 2. Nevertheless, when the solution has both approaches, more increment of minimum voltage can be achieved as shown in the cases 4 and 5, which both have the same percentage improvement at 8.95%.

The simultaneous analysis also gives a positive impact to the stability of the system. Since there are a lot of voltage stability methods available nowadays, suitable method for measuring the voltage stability should be chosen carefully. In this analysis, Combined-Voltage Stability Index (C-VSI) [85], is used as performance evaluation technique. In the ref. [85], the authors shows that the C-VSI is more sensitive to voltage drop compared to other evaluation techniques, especially for the system that have DG. This index is work based on the closer of the C-VSI is to “1”, the higher tendencies for the system to collapse. In other words, when the index value is near to zero, the network is stable whereas when the value is near to 1, the system becomes unstable.

The Figure 5.5 presents results of the maximum C-VSI value after the application of the reconfiguration and/or optimal DG coordination. It is mentioned that the C-VSI_{max} decreases for the case 2 to 5. Specifically, the C-VSI_{max} equals to 0.1276, 0.0876, 0.0509 and 0.0339 for the cases 2, 3, 4 and 5, respectively. Thus, the combination of DG and reconfiguration action implies the improvement of the system stability. Consequently, the technique of the DG location, output power and reconfiguration (case 5) provides the most stable system compared with other cases.

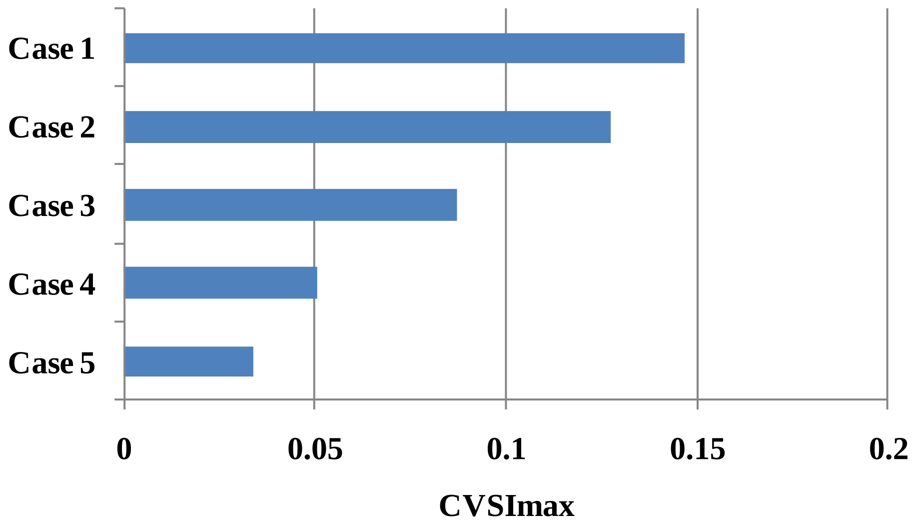


Fig. 5.5. Comparison of stability index for all cases on 33-bus system

In order to prove the effectiveness of the proposed method, several comparisons with other techniques are summarized in Table 5.3. However, the studies in refs. [34] and [71] are assumes that the DGs are in PQ mode instead of PV mode. Thus, in order to make a fair comparison with the proposed method, the refs. [34] and [71] are simulated in PV mode. All comparisons are made based on optimal switching option, power losses, DG sizes and DG locations, for the same test system. For the case 2, the proposed method provides better results compared with ref. [53]; nevertheless, the study in ref. [71] has the best result in this category. The open branches for the proposed method are almost similar with them of the paper [71], with an exception of one branch open (branch number 28 for the proposed method and 37 for the ref. [71] result). In the case 3, the AIBC gives lower power losses with the ref. [71] study, but almost the same result as ref. [34]. For the case 4, AIBC presents better power losses reduction compared with the results of the ref. [71]

paper. The open branches for the case 2 are totally different with other reference, with an exception of one branch open (branch number 28) is similar. In addition, all DGs location for this case has different locations. While, for the last case which is the case 5, there are no comparison due to the lack of available results in existing literature. Ultimately, the proposed method produces the best results when compared to the other methods.

From the whole analysis, optimization of DG location, output and reconfiguration simultaneously gives the best option to the power system planner to have the lowest power loss value in the existing network. However, this approach can be applied only if the DG units are not being installed yet in the system. If the DG unit has already existed, the simultaneous analysis between DG output power and reconfiguration technique still can give superior results.

Table 5.4 shows variation of the best result of total power losses at different parameters settings for solving the case 5. All simulation results are performed at 50 trials with different random seeds and each of trial is run for 100 cycles. Based on the results obtained, it can be observed that the total number of bees and limit plays a vital role to obtain better results. Increase the total number of bee's means that the algorithm will increase the exploitation process; meanwhile, for higher number of limits mean exploration process will be reduced.

Table 5.3: Comparison of different parameter settings for Case 5

Scenario	Parameter Setting		Total Power Losses (kW)
	Total Number of Bees	Limit	
1	100	120	9.71
	140	120	9.08
	200	120	9.13
2	100	550	10.25
	140	770	9.61
	200	1100	9.51

Table 5.3: Comparison with other method available in literature review

Method		Case 2	Case 3	Case 4	Case 5
AIBC	Branch open	7,9,14,28,32	33, 34, 35, 36, 37	3, 23,28,34,35	5,11,13,23,27
	Power Losses (kW)	139.98	33.26	12.63	9.08
	DG size in MW (Bus number)	-	1.70(6) 0.53(16) 0.77(25)	0.99(6) 0.69(16) 1.44(25)	1.00(8) 1.14(25) 0.79(32)
Branch Exchange [53]	Branch open	6,11,31,34,37	-	-	-
	Power Losses (kW)	143.50	-	-	-
	DG size in MW (Bus number)	-	-	-	-
Particle Swarm Optimization [34]	Branch open	-	33, 34, 35, 36, 37	-	-
	Power Losses (kW)	-	33.19	-	-
	DG size in MW (Bus number)	-	1.76(6) 0.58(16) 0.78(25)	-	-
Harmony Search Algorithm [71]	Branch open	7,9,14,32,37	33, 34, 35, 36, 37	7, 10, 14, 28, 32	-
	Power Losses (kW)	138.06	47.11	*38.89	-
	DG size in MW (Bus number)	-	0.57(17) 0.11(18) 1.05(33)	0.56(31) 0.53(32) 0.58 (33)	-

*The result had been simulated again due to different mode of DG and power flow in original manuscript.

5.5 Conclusion

In this chapter, distribution network loss minimization via simultaneous distributed generation coordination with network reconfiguration was proposed. The AIBC method is used to execute the proposed approach. Five case studies are conducted to test the performance of the proposed approach (case 5). The results showed that determination of optimal DG location, output power and network reconfiguration simultaneously gives better results with 95.53% of power loss reduction, minimum voltage improvement by 8.95% as well as low C-VSI index value compared to other case studies. In addition, a comparison with other optimization technique showed promising results in decreasing the total loss reduction in the distribution system, regardless of whether the methods are executed sequentially (case 4) or simultaneously (case 5).

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Overall Conclusion

The power loss is one of important issues need to be consider by the utility especially to the operational planning division. Improper planning of power system, especially distribution system can gives negative impacts such as high power losses and unstable voltage condition. As previously discussed, there are several approaches can be used to reduce the power losses, which are installed DG, installed capacitor and change the original topology of the system (network reconfiguration). To deal with any of this approach, special techniques or methods are required. In general, these methods can be categorized into four main groups, which are analytical, numerical, heuristic and meta-heuristic. Each of this group has its own advantages and disadvantages.

Based from literature review, meta-heuristic is more popular among the researchers due to easy to implement and robust. Therefore, in this thesis, a new hybrid optimization, which is known as Artificial Immune Bee Colony (AIBC) was introduced. The effectiveness of the proposed method has been tested at various dimensional problems in solving the DG coordination and successfully gives better quality of solutions compared to the original ABC.

Further investigation was carried to achieve better results (power loss reduction) than the previous analysis. As discussed in the literature review section, many researchers consider only one approach to reduce power loss, for example, installing DG in the test system without regard to other approaches. This will cause the process to further reduce the power loss may be difficult to achieved. Therefore, in this thesis, a combination between network reconfiguration and DG coordination has been proposed. In the analysis, it was shown that simultaneous analysis between the two approaches produce better compared to separate analysis.

Overall, it can be concluded that the introduction of the network reconfiguration and DG with help of AIBC has improves the system performance, particularly reduction of power loss which the results are important reference for the construction and operation planning division.

6.2 Contributions

The main contributions of this research can be listed as below:

a) A new optimization technique, which is known as Artificial Immune Bee Colony (AIBC) has been introduced in this research. In the analysis, it was shown that this technique can solve DG coordination problem better than the original ABC. In addition, the AIBC is able to provide faster convergence.

b) Simultaneous approach between the DG coordination and network reconfiguration has been proposed. By using this approach, further improvement on power loss reduction, voltage profile and stability index can be achieved.

6.3 Future Work

Some future works that can be done to improve this in the future are as follows:

a) By combining three approaches simultaneously. For example, combine DG coordination; capacitor coordination and network reconfiguration, simultaneously. By performing this approach, greater power loss reduction can be obtained.

b) Towards more practical analysis, different types of loads should be considered instead of constant power as in this thesis.
c) Multi-objective function should be implemented in the optimization process, for example, minimize power loss and total cost.
d) In the simultaneous between the DG coordination and network reconfiguration, capacity limit for each line should be considered.

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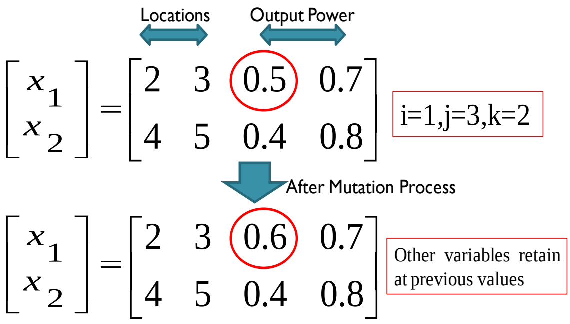
APPENDIX A

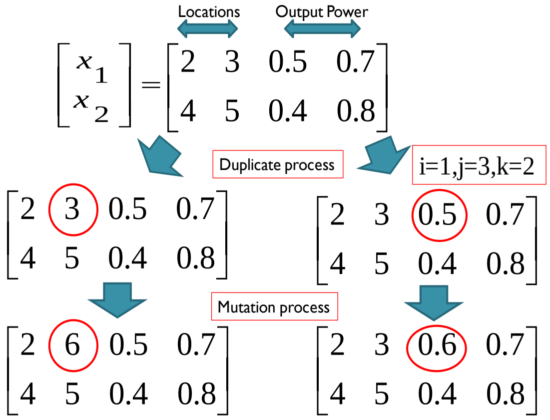
COMPARISON OF MUTATION PROCESS BETWEEN ABC AND AIBC

A comparison between ABC and AIBC method was carried out to see the differences in the mutation process. To simplify this example, let assumed the total number of variables are four (two for DG locations and another two for DG output power) and number of Employed bees are two. For *i*=1, it can clearly been seen that for the ABC, only one variable is changed after mutation process, whereas for the AIBC, two variables changed.

ABC



AIBC



APPENDIX B

DATA FOR 33-BUS TEST SYSTEM

From Bus	To Bus	R (ohm)	X (ohm)	P-load (MW)	Q-load (MVAr)
1	2	0.0922	0.0477	0.100	0.060
2	3	0.4930	0.2511	0.090	0.040
3	4	0.3660	0.1864	0.120	0.080
4	5	0.3811	0.1941	0.060	0.030
5	6	0.8190	0.7070	0.060	0.020
6	7	0.1872	0.6188	0.200	0.100
7	8	0.7114	1.2351	0.200	0.100
8	9	1.0300	0.7400	0.060	0.020
9	10	1.0400	0.7400	0.060	0.020
10	11	0.1966	0.0650	0.045	0.030
11	12	0.3744	0.1238	0.060	0.035
12	13	1.4680	1.1550	0.060	0.035
13	14	0.5416	0.7129	0.120	0.080
14	15	0.5910	0.5260	0.060	0.010
15	16	0.7463	0.5450	0.060	0.020
16	17	1.2890	1.7210	0.060	0.020
17	18	0.7320	0.5740	0.090	0.040
2	19	0.1640	0.1565	0.090	0.040
19	20	1.5042	1.3554	0.090	0.040
20	21	0.4095	0.4784	0.090	0.040
21	22	0.7089	0.9373	0.090	0.040
3	23	0.4512	0.3083	0.090	0.050
23	24	0.8980	0.7091	0.420	0.200
24	25	0.8960	0.7011	0.420	0.200
6	26	0.2030	0.1034	0.060	0.025
26	27	0.2842	0.1447	0.060	0.025
27	28	1.059	0.9337	0.060	0.020

28	29	0.8042	0.7006	0.120	0.070
29	30	0.5075	0.2585	0.200	0.600
30	31	0.9744	0.963	0.150	0.070
31	32	0.3105	0.3619	0.210	0.100
32	33	0.341	0.5302	0.060	0.040

APPENDIX C

DATA FOR 69-BUS TEST SYSTEM

From Bus	To Bus	R (ohm)	X (ohm)	P-load (MW)	Q-load (MVAr)
1	2	0.0005	0.0012	0	0
2	3	0.0005	0.0012	0	0
3	4	0.0015	0.0036	0	0
4	5	0.0251	0.0294	0	0
5	6	0.366	0.1864	0.003	0.002
6	7	0.3811	0.1941	0.04	0.03
7	8	0.0922	0.047	0.075	0.054
8	9	0.0493	0.0251	0.03	0.022
9	10	0.819	0.2707	0.028	0.019
10	11	0.1872	0.0619	0.145	0.104
11	12	0.7114	0.2351	0.145	0.104
12	13	1.03	0.34	0.008	0.005
13	14	1.044	0.345	0.008	0.006
14	15	1.058	0.3496	0	0
15	16	0.1966	0.065	0.046	0.03
16	17	0.3744	0.1238	0.06	0.035
17	18	0.0047	0.0016	0.06	0.035
18	19	0.3276	0.1083	0	0
19	20	0.2106	0.0696	0.001	0.001
20	21	0.3416	0.1129	0.114	0.081
21	22	0.014	0.0046	0.005	0.004
22	23	0.1591	0.0526	0	0
23	24	0.3463	0.1145	0.028	0.02
24	25	0.7488	0.2745	0	0
25	26	0.3089	0.1021	0.014	0.01
26	27	0.1732	0.0572	0.014	0.01
3	28	0.0044	0.0108	0.026	0.019

28	29	0.064	0.1565	0.026	0.019
29	30	0.3978	0.1315	0	0
30	31	0.0702	0.0232	0	0
31	32	0.351	0.116	0	0
32	33	0.839	0.2816	0.014	0.01
33	34	1.708	0.5646	0.02	0.014
34	35	1.474	0.4673	0.006	0.004
3	36	0.0044	0.0108	0.026	0.019
36	37	0.064	0.1565	0.026	0.019
37	38	0.1053	0.123	0	0
38	39	0.0304	0.0355	0.024	0.017
39	40	0.0018	0.0021	0.024	0.017
40	41	0.7283	0.8509	0.001	0.001
41	42	0.31	0.3623	0	0
42	43	0.041	0.0478	0.006	0.004
43	44	0.0092	0.0116	0	0
44	45	0.1089	0.1373	0.039	0.026
45	46	0.0009	0.0012	0.039	0.026
4	47	0.0034	0.0084	0	0
47	48	0.0851	0.2083	0.079	0.056
48	49	0.2898	0.7091	0.385	0.275
49	50	0.0822	0.2011	0.385	0.275
8	51	0.0928	0.0473	0.041	0.028
51	52	0.3319	0.1114	0.004	0.003
9	53	0.174	0.0886	0.004	0.004
53	54	0.203	0.1034	0.026	0.019
54	55	0.2842	0.1447	0.024	0.017
55	56	0.2813	0.1433	0	0
56	57	1.59	0.5337	0	0
57	58	0.7837	0.263	0	0
58	59	0.3042	0.1006	0.1	0.072
59	60	0.3861	0.1172	0	0
60	61	0.5075	0.2585	1.244	0.888
61	62	0.0974	0.0496	0.032	0.023
62	63	0.145	0.0738	0	0
63	64	0.7105	0.3619	0.227	0.162
64	65	1.041	0.5302	0.059	0.042
11	66	0.2012	0.0611	0.018	0.013
66	67	0.0047	0.0014	0.018	0.013
12	68	0.7394	0.2444	0.028	0.02
68	69	0.0047	0.0016	0.028	0.02

APPENDIX D

DATA FOR 33-BUS TEST SYSTEM INCLUDING TIE LINES

From Bus	To Bus	R (ohm)	X (ohm)	P-load (MW)	Q-load (MVAr)
1	2	0.0922	0.0477	0.100	0.060
2	3	0.4930	0.2511	0.090	0.040
3	4	0.3660	0.1864	0.120	0.080
4	5	0.3811	0.1941	0.060	0.030
5	6	0.8190	0.7070	0.060	0.020
6	7	0.1872	0.6188	0.200	0.100
7	8	0.7114	1.2351	0.200	0.100
8	9	1.0300	0.7400	0.060	0.020
9	10	1.0400	0.7400	0.060	0.020
10	11	0.1966	0.0650	0.045	0.030
11	12	0.3744	0.1238	0.060	0.035
12	13	1.4680	1.1550	0.060	0.035
13	14	0.5416	0.7129	0.120	0.080
14	15	0.5910	0.5260	0.060	0.010
15	16	0.7463	0.5450	0.060	0.020
16	17	1.2890	1.7210	0.060	0.020
17	18	0.7320	0.5740	0.090	0.040
2	19	0.1640	0.1565	0.090	0.040
19	20	1.5042	1.3554	0.090	0.040
20	21	0.4095	0.4784	0.090	0.040
21	22	0.7089	0.9373	0.090	0.040
3	23	0.4512	0.3083	0.090	0.050
23	24	0.8980	0.7091	0.420	0.200
24	25	0.8960	0.7011	0.420	0.200
6	26	0.2030	0.1034	0.060	0.025
26	27	0.2842	0.1447	0.060	0.025
27	28	1.059	0.9337	0.060	0.020

28	29	0.8042	0.7006	0.120	0.070
29	30	0.5075	0.2585	0.200	0.600
30	31	0.9744	0.963	0.150	0.070
31	32	0.3105	0.3619	0.210	0.100
32	33	0.341	0.5302	0.060	0.040
33	7	2	2	-	-
34	8	2	2	-	-
35	11	2	2	-	-
36	17	0.5	0.5	-	-
37	24	0.5	0.5	-	-

APPENDIX E

LIST OF PUBLICATIONS

A. List of Journals

1. M.N. Muhtazaruddin, J.J. Jamian, G. Fujita, M.A. Baharudin, M.W. Wazir and H. Mokhlis "Distribution Network Loss Minimization via Simultaneous Distributed Generation Coordination with Network Reconfiguration", Arabian Journal for Science and Engineering, Springer**,** Vol. 39, No. 6, pp. 4923-4933, June 2014.
2. Mohd Nabil Bin Muhtazaruddin, Jasrul Jamani Bin Jamian and Goro Fujita "Determination of Optimal Output Power and Location for multiple Distributed Generation Sources Simultaneously by using Artificial Bee Colony", IEEJ Transactions on Electrical and Electronic Engineering , John Wiley & Sons , Vol. 9, No. 4, pp. 351-359, July 2014.
3. Mohd Nabil Muhtazaruddin, Jasrul Jamani Jamian, Danvu Nguyen, Nur Aisyah Jalalludin and Goro Fujita "Optimal Capacitor Placement and Sizing via Artificial Bee Colony", International Journal of Smart Grid and Clean Energy, Engineering and Technology Publishing, Vol. 3, No. 2, April 2014.

B. List of Published Conference Papers

1. *Mohd Nabil Bin Muhtazaruddin, Mohd Wazir Mustafa, Goro Fujita* "Short – Term Load Forecasting Via Artificial Neural Network", SEATUC Symposium, Bangkok, Thailand, 5 – 7 March **2012.**

2. *Mohd Nabil Bin Muhtazaruddin, Mohd Wazir Mustafa, Goro Fujita* “Artificial Neural Network for forecasting Next Day”, Annual Meeting IEE Japan, Hiroshima, Japan, 23 – 14 March **2012.**
3. *M.N. Muhtazaruddin, J.J Jamian, G. Fujita* “Reactive Power Control in PV Grid Connected for Overvoltage prevention”, Annual Conference of Power and Energy Society IEE of Japan, Hokkaido, Japan, 12 – 14 September **2012**
4. *M.N. Muhtazaruddin, G. Fujita* “Voltage Control in PV Grid Connected Mode for Overvoltage Reduction”, IEEE PES International Conference on Power System Technology (POWERCON), Auckland, New Zealand, 30 October – 2 November **2013.**
5. *Mohd Nabil Bin Muhtazaruddin, Jasrul Jamani Bin Jamian and Goro Fujita* “Determine Location and Sizing of DG via Artificial Bee Colony”, SEATUC Symposium, Bandung, Indonesia, 4 – 6 March **2013.**
6. *Mohd Nabil Bin Muhtazaruddin and Goro Fujita* “Optimal Distributed Generation Coordination by using Aritificial Bee Colony”, International Conference on Intelligent System Applications to Power System (ISAP), Tokyo, Japan, 1 – 4 July **2013.**
7. *Mohd Nabil Bin Muhtazaruddin and Goro Fujita* “Distribution Network Power Loss by using Artificial Bee Colony”, International Universities’ Power Engineering Conference, Dublin, Ireland, 2 – 5 September **2013**
8. *Mohd Nabil Bin Muhtazaruddin, Jasrul Jamani Bin Jamian, Nguyen Duc Tuyen and Goro Fujita* “Distribution Generation Coordination by using Artificial Immune Bee Colony”, SEATUC Symposium, Johor Bahru, Malaysia, 4 – 5 March **2014.**
9. *Mohd Nabil Bin Muhtazaruddin, , Nguyen Duc Tuyen, Goro Fujita and Jasrul Jamani Bin Jamian* “Optimal Distributed Generation and Capacitor Coordination for Power Loss Minimization”, IEEE PES Transmission and Distribution, Chicago, United State of America, 14 – 17 April **2014.**
10. *Mohd Nabil Bin Muhtazaruddin, Jasrul Jamani Bin Jamian, Nguyen Duc Tuyen and Goro Fujita* “Effect of Reverse Power Flow in Determine Optimal Distributed Generation Sizing and Location”, International Conference on Electrical Engineering (ICEE), Jeju Island, South Korea, 15 – 19 June **2014.**

C. List of Others Published Conference Papers

1. *J.J Jamian, G. Fujita, H. Mokhlis, M.W. Mustafa, M.N. Muhtazaruddin* "Optimizing Distributed Generators Size with consideration of Voltage Stability Index in Radial Distribution network using TVA-REPSO", Annual Conference of Power and Energy Society IEE of Japan, Hokkaido, Japan, 12 – 14 September **2012.**
2. *Jasrul Jamani Bin Jamian, Mohd Nabil Bin Muhtazaruddin and Goro Fujita,* "Optimal Allocation of Battery Switching Based on Pre-determined Stability Condition Indicator", SEATUC Symposium, Bandung, Indonesia, 4 – 6 March **2013.**
3. *Dieu Ngoc Vo, Khai Phuc Nguyen, Goro Fujita, Mohd Nabil Bin Muhtazaruddin and Dung Anh Le,* "Pseudo-Gradient Based Particle Swam Optimization for Security Constrained Optimal Power Flow", International Conference on Intelligent System Applications to Power System (ISAP), Tokyo, Japan, 1 – 4 July **2013.**
4. *Nguyen Duc Tuyen, Mohd Nabil Bin Muhtazaruddin, Goro Fujita and Toshihisa Funabashi,* "Shunt Active Power Filter for 3-phase 3-Wire Nonlinear Load under Unbalanced and Distorted PCC Voltage using Notch Adaptive Filter", IEEE PES Transmission and Distribution, Chicago, United State, 14 – 17 April **2014.**
5. *Nguyen Duc Tuyen, Junpei Takehara, Mohd Nabil Bin Muhtazaruddin, and Goro Fujita,* "Adaptive Notch Filter: A solution for 3-phase 4-wire Shunt Active Power Filter under Non-ideal", International Conference on Electrical Engineering (ICEE), Jeju Island, South Korea, 15 – 19 June **2014.**
6. *Nguyen Duc Tuyen, Goro Fujita and Mohd Nabil Bin Muhtazaruddin,* "3-phase 4-wire Shunt APF under Non-ideal PCC Voltage using Adaptive Notch Filter", IEEE Power & Energy General Meeting, Washington DC, United State of America, 27 – 31 July **2014.**