ADAPTIVE EMBEDDED CLONAL EVOLUTIONARY PROGRAMMING (AECEP) FOR OPTIMAL DISTRIBUTED GENERATION (DG) LOCATION AND SIZING IN A DISTRIBUTION SYSTEM

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ABSTRACT

Distributed Generation (DG) has gained increasing popularity as a viable element of electric power systems. DG as a small scale generation sources located at or near load center is usually deployed within the distribution system. Installation of DG has many positive impacts such as reducing transmission and distribution network congestion, differing costly for upgrading process, and improving the overall system performance by reducing power losses and enhancing voltage profiles. To achieve these positive impacts from DG installation, the DG has to be optimally placed and sized. Since last decade, Artificial Intelligence (AI) methods have been used to solve complex DG problems because in most cases they can provide global or near global solution. The major advantage of the AI methods is that they are relatively versatile for handling various qualitative constraints. AI methods mainly include Artificial Neural Network (ANN), Expert System (ES), Genetic Algorithm (GA), Evolutionary Programming (EP), Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO). The purpose of this thesis is to presents a new technique namely Adaptive Embedded Clonal Evolutionary Programming (AECEP). The objective of the study is to employ AECEP optimization technique for loss minimization and voltage profile monitoring. First step study started by using a conventional technique as a pre-study of DG location and sizing. The Heuristic Search Technique (HST) was developed to empirically determine the location and sizing of DG for the same purpose. This technique was performed on the IEEE 41-Bus and 69-Bus RDS for several cases in terms of loading conditions. The proposed AECEP was implemented for single DG, two DGs and three DGs installation. The result of the proposed AECEP technique was found in a good agreement with those obtained from the EP and AIS in terms of loss minimization and voltage profile improvement.

ABSTRAK

Generasi Teragih (DG) telah mendapat populariti yang semakin meningkat sebagai elemen yang berdaya maju sistem kuasa elektrik. DG sebagai sumber generasi berskala kecil yang terletak di atau berhampiran pusat beban biasanya ditempatkan dalam sistem pengagihan. Pemasangan DG mempunyai banyak kesan positif seperti mengurangkan kesesakan rangkaian penghantaran dan pengagihan, berbeza mahal proses untuk menaik taraf, dan meningkatkan prestasi keseluruhan sistem dengan mengurangkan kehilangan kuasa dan meningkatkan profil voltan. Untuk mencapai kesan positif daripada pemasangan DG, lokasi dan saiz DG haruslah di tempat yang paling sesuai. Sejak sedekad lalu, kaedah Kepintaran Buatan (AI) telah digunakan untuk menyelesaikan masalah DG yang kompleks kerana dalam kebanyakan kes mereka boleh memberikan penyelesaian global yang berhampiran. Kelebihan utama kaedah AI ialah keupayaan yang serba boleh untuk mengendalikan pelbagai kekangan kualitatif. Kaedah AI terutamanya termasuk Rangkaian Neural Buatan (ANN), Sistem Pakar (ES), Algoritma Genetik (GA), Pengaturcaraan Evolusi (EP), Ant Colony Optimization (ACO) dan Zarah Swarm Optimization (PSO).Tujuan tesis ini adalah untuk membentangkan teknik baru iaitu Adaptive Klon Terbenam Pengaturcaraan Evolusi (AECEP). Objektif kajian berdasarkan AECEP ini adalah untuk meminimumkan kerugian dan pemantauan profil voltan. Langkah pertama kajian bermula dengan menggunakan teknik konvensional sebagai kajian pra-DG untuk memilih lokasi dan saiz. Teknik Pencarian Heuristik (HST) telah dibangunkan untuk menentukan lokasi dan saiz DG bagi tujuan yang sama. Teknik ini telah diuji pada IEEE 41-Bas dan 69-Bas RDS untuk beberapa kes dari segi keadaan beban muatan. AECEP yang dicadangkan telah dilaksanakan untuk pemasangan satu, dua dan tiga DG. Hasil daripada teknik AECEP yang dicadangkan didapati dalam perjanjian yang baik berbanding dengan hasil yang diperolehi dari EP dan AIS dari segi meminimumkan kerugian, peningkatan profil voltan dan masa pengiraan.

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LIST OF SYMBOLS

β	Mutation scale
ε	Accuracy level
x_{jmin}	Minimum random number for every variable
$x_{i,j}$	Parents
x_{jmax}	Maximum random number for every variable
$x_{i+m,j}$	Mutated parents (offsprings)
R	Resistance through the line
N	Gaussian random variable with mean μ and variance γ^2
n	Population number
m	Cloning number
k	Number of control variables
I	Current through the line
f_{min}	Minimum fitness
f_{max}	Maximum fitness
f_i	Fitness for the i^{th} random number
A_2	Offspring population
A_1	Parent population
τ_{nmk}	Cloned population
x_2	Size of DG
x_1	Bus location
pf_{DG}	Power factor of DG
S_{DGi}	Apparent DG generated power
P_{Loss}	Active power loss
P_{Gi}	Generate power source
P_{DGi}	Active DG generated powers
P_D	Power load demand
$\lvert V_i \rvert^{min}$	Minimum voltage at bus i
$\lvert V_i \rvert^{max}$	Maximum voltage at bus i

LIST OF ABBREVIATIONS

ACO	Ant Colony Optimisation
AECEP	Adaptive Embedded Clonal Evolutionary Programming
AI	Artificial Intelligent
AIS	Artificial Immune System
ANN	Artificial Neural Network
CCHP	Combine cooling, heat and power
CHP	Combine heat and power
CIGRE	International Council on Larger Electric Systems
CIRED	Center International Research Environment Development
CO_2	Carbon Dioxide
DG	Distributed Generation
DISCO	Distribution Company
EG	Embedded Generation
EP	Evolutionary Programming
EPRI	Electric Power Research Institute
FACTS	Flexible AC Transmission Systems
FC	Fuel Cell
GA	Genetic Algorithm
HST	Heuristic Search Technique
ICE	Internal Combustion Engines
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
LV	Low Voltage
MT	Micro Turbines
MV	Medium Voltage
P	Real power
PSO	Particle Swarm Optimisation
PV	Load bus
PV	Photovoltaic
Q	Reactive power
Q_d	Reactive power loading
RDS	Radial distribution system
T&D	Transmission & Distribution
TS	Tabu Search
V	Voltage
WECS	Wind Energy Conversion System

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The electric power system is divided into three parts, generation, transmission and distribution systems. Large central generators feed electrical power up through generator transformers to a high voltage interconnected transmission network. Transmission system is used to transport the power, sometimes over considerable distances, which is then extracted from the transmission network and passed down through a series of distributions to final circuits for delivery to the customers. However, recently there has been a considerable revival in interest in connecting generation to the distribution network. This has come to be known as embedded or dispersed generation (Jenkins et al., 2000). Distributed Generation (DG) is the concept of decentralizing the power generation by placing small generating units at or near the load center.

During last few decades there have been many changes in the electric power industry due to the development in distributed generation technologies, economic policy and restructuring. The Centre International Research Environment Development (CIRED) survey (CIRED, 1999) asked representatives from 17 countries what were the policy drivers encouraging embedded generation. The answers included reduction in gaseous emissions mainly Carbon Dioxide (CO_2), energy efficiency or rational use of energy, deregulation, competition policy, diversification of energy sources and national power requirement. The CIGRE report (Petrella, A.J. 1997) listed similar reasons but with additional emphasis on commercial considerations such as availability of modular generating plant, ease of finding sites for smaller generators, short construction times and lower capital costs of smaller plant and generation may be sited closer to load, which may reduce transmission costs.

Distributed generation is power source that can be connected to a distribution network by a Distribution Company (DISCO) at any node or by the customer side of the meter. Distributed resources are strategilacy located and operated in the system to defer or eliminate system upgrades, improve voltage profile, reduce system losses, reinforce grid, and to improve system reliability and efficiency (Devender et al., 2007). According to these benefits, DG is expected to become more important in future generation systems. Traditionally, the electricity supply networks consist of generators representing the supply of electric energy. It can provide an active power and provides or absorbs reactive power in some limit. DG is a new challenge for electric power systems and considered as an alternative source of power to an electrical system (Mendez et al., 2006). These issues of DG also was noted by Jenkins, N. (2000) with significant penetration of DG, the power flows may become reversed and the distribution network is no longer a passive circuit supplying loads but an active system with power flows and voltages determined by the generation as well as the loads.

Ng, H.N. et al (2000) noted that the distribution networks are well-known for their low X/R ratio and significant voltage drop that could cause substantial power losses along the feeders. It is estimated that as much as 13% of the power generation is lost in the distribution networks. Incorporation of DG source in the distribution level has an overall positive impact towards reducing the losses as well as improving the voltage profiles. T.K.A. Rahman et al. (2004) proposed new technique for determining optimal allocation and sizing of Embedded Generation (EG) in a distribution system. The results shown significant reduction in the line losses and voltage profile improvement has been obtained with the installation of EG.

Rigorous study on the impact of DG installation to system losses and voltage profile is conducted in this research. It is a paramount to focus on the optimal placement and sizing of a DG on a distribution system to keep the system in an economical and secured state. With rapid penetration of DG into distribution systems, it is critical to assess its impacts to power system accurately so that these DG units can be applied in a manner that avoid degradation of power quality, increase reliability and flexibility in control of the utility system. On the other hand, DG has great potential to improve distribution system performance and it should be encouraged. Thus, it has become imperative to study changes that DG brings with a change in its location or size of DG.

1.2 Problem Statement

A traditional power system's primary operation is to produce power at central generating stations and distribute that power to electrical consumers at their place of consumption. The system must convey power to the customers, which means it must be dispersed throughout the utility service territory in rough proportion to customer locations and demand. The current distribution system experienced increment of load demand. This is result of rapid industrialization and population growth. The electric demand in an electric utility service territory varies as a function of location depending on the number and types of consumers in each locality (Willis and Scott, 2000). Increase in power consumption can cause serious problems in electric power systems if there are no on-going construction projects of new power plants or transmission lines. Additionally, such increase can result in voltage regulation, current and large power losses in the system. In costly and environmentally effective manner to avoid constructing the new power plants or transmission lines, the DG has been paid great attention as a potential solution for these problems. The whole purpose of DG is to serve the electric demands of individual households, businesses and industrial facilities. It is important that DG planner realize that for DG which small power production units placed right at individual consumer sites. The advantages of DG can be achieved by choosing the proper size of the DG and connecting it at the appropriate location in the system.

DG placement becomes an attractive option for distribution system planning. Actually, DG placement in the radial distribution system is very exhaustive and difficult problem that has been discussed by many researchers (Hao et al., 2002, Hedayati et al., 2008, Kyu-Ho et al., 2002). The DG placement at non suitable location will contributes the negative impacts depending on the distribution system operation, planning and the DG characteristics. Misallocation of DG installation also leads to over compensation or under compensation. Introduction of DG in a system will solve the problem such as voltage regulation and increased in power losses. Now the power flow can be reversed with the DG sending power in either direction from where it is placed. The power flow changes with change in DG location and size and loading conditions. A study can be done to see the impact of DG on criteria like voltage profile and losses in the system.

The solution techniques applied to optimal DG location and sizing are similar to those employed for capacitors. The DG sizing can be solved by analytical, heuristics or Artificial Intelligence (AI)-based techniques. However, analytical and heuristic techniques are not optimal, inaccurate and burdensome in order to solve DG sizing problem. Due to the complexity of the problems, these techniques may fail to find the global optimal solutions. In the recent day, AI-based techniques are used widely as optimization technique to find the optimal size of DG. The new algorithms will give the good solution for the result. Simplicity, accuracy and reliability of the algorithm are vital in the practicality of the technique.

1.3 Objectives of the Research

The objectives of the study are:

1-To develop a new technique for optimizing distributed generation location and sizing named as Adaptive Embedded Clonal Evolutionary Programming (AECEP)

2-To compare the results obtained from the proposed technique with other techniques namely Evolutionary Programming and Artificial Immune System in terms of loss minimization, voltage improvement and computation time.

1.4 Scope of Work

Initially, the research begins with a pre-test study to determine the DG location and sizing using the conventional technique known as Heuristic Search Technique (HST). HST approach was developed to empirically determine the location and sizing of DG which is able to perform loss reduction with voltage profile being monitored. Besides that, it also supports the AI optimization technique hypothesis in attaining very close results to the optimal ones with an advantage of less computation effort.

Secondly, new algorithm based on EP technique is developed for the purpose of optimal DG location and sizing. This study also considers single, two and three DGs installation. The technique is namely Adaptive Embedded Clonal Evolutionary Programming (AECEP). This technique was developed in order to speed up the analysis of determination DG location and sizing. It is observed that the proposed AECEP technique has reduced the computation burdens experienced in the conventional technique as HST. The variation of population size is conducted in order to observe the effect of this variation to loss minimization and voltage profile improvement.

Consequently, AI optimization technique called the Evolutionary Programming (EP) is applied to determine optimal location and sizing of DG to minimize the power losses and also monitoring the voltage profile in the system. Next, Artificial Immune System (AIS) engine is also implemented to perform similar study for the same objectives. This is meant for comparative study.

A computer programming is developed in Matrix Laboratory (MATLAB) to run the optimization process. For the purpose of validation, all the developed techniques are tested on IEEE 41-Bus and 69-Bus Radial Distribution System (RDS).

1.5 Organization of Thesis

This thesis is organized into five chapters and one appendix as follows:

Chapter 1 begins with some preliminary studies on the current issues of DG. It also lists the problem statement, main objectives of this thesis and scope of study.

Chapter 2 provides review of the literature on DG in term of definition, technologies, technical impact on the distribution system and operational modes. The literatures on DG interconnection via analytical methods are reviewed. It also describe in details in the last part of this chapter about literature on artificial intelligence based on optimization technique in order to find the location and sizing of DG. The available solution methods for location and sizing of DG and how they have been applied in distribution systems are summarized.

Chapter 3 discusses on the methodology and development process of the research. Firstly, it describes the problem formulation overview and DG sizing problem architecture which includes the objective function, equality and inequality constraints. A review of application to DG scheme based on power flow studies in larger systems is presented. To investigate the power losses reduction and voltage profile improvement, this chapter also presents the conventional method based on the Heuristic Search Technique (HST). Its algorithm that has been done in this study is first described.

Descriptions on EP and AIS algorithms are presented in this chapter to demonstrate their process. A newly developed technique from original EP termed as Adaptive Embedded Clonal Evolutionary Programming (AECEP) is presented. A few modification has done in original EP to create a new algorithm with apply the AIS process. In fact, recombination may play an important, even dominant role in accelerating the progress to the optimum and enhancing the chances of success of the search procedure.

The sub main topic in this research presents an optimization method based on the Artificial Intelligence (AI). It's started with application of Evolutionary Programming (EP) in order to determine the location and sizing of DG. It discusses how the EP algorithms works and how it is implemented for the research involved in this study. Subsequently, the second optimization technique based on Artificial Immune System (AIS) is also performed for the same purpose and as comparative study.

Chapter 4 presents the results achieved throughout the research. All analysis was tested using two realistic radial distribution systems: IEEE 41-bus and IEEE 69-bus. Discussion on the results is mainly divided into four analyses:

a) DG location and sizing based on the HST
b) Single DG installation for loss minimization in distribution system
c) Two DGs installation for loss minimization in distribution system
d) Three DGs installation for loss minimization in distribution system

Chapter 5 summarizes the conclusions and discusses possible recommendations for future work. Finally, Appendix A1-A4 presents a brief description of the test systems and provides the data of the test systems.

CHAPTER 2

LITERATURE REVIEW

This chapter presents the review of recent publications in the areas of work relative to this thesis. The first section reviews the literature on DG. DG definition is first presented, followed by a review of DG technologies and technical impacts on the distribution system and summary of the literature on DG operation modes. Recent work on DG interconnection via analytical methods are analysed and reviewed in the second section. The third section reviews the DG interconnection via AI techniques.

2.1 DISTRIBUTION GENERATION: AN OVERVIEW

Distributed generation (DG) or embedded generation (EG) in the European term refers to the generation applied at the distribution level. According to Electric Power Research Institute (EPRI) report, it defines distributed generation as the utilization of small (0 to 5 MW), modular power generation technologies dispersed throughout a utility's distribution system in order to reduce the transmission and distribution (T&D) loading or load growth and thereby defer the upgrade of T&D facilities, reduce system losses, improve power quality and reliability (Barker et al., 1998).

One of the best alternatives for a change in the traditional way of generation and delivery arrangement is to introduce distributed generation (DG), which can conveniently located closer to load centers. DG is not a new concept and already created a variety of well documented impacts on distribution network operation and implies significant changes to planning and design practices (Harisson and Wallace, 2005).

By applying generation closer to the load it benefits the transmission and distribution infrastructure, local generation can relieve overburdened transmission and distribution facilities as well as reduce losses and voltage drop. Distribution systems were never designed to include generation; they were designed for one-way power flow, from the utility substation to the end users. Generators violate this basic assumption and generators can disrupt distribution operations if they are not carefully applied (Short, 2004).

Actually, no exact size or voltages are accepted as definitions of DG. The technical issues related to distributed generation, however, can vary significantly and is categorized based on the rating of DG. For example, Ackermann et al.,(2001) stated in his paper that the types of DG are sorted as follow; micro DG (~1W<5kW), small DG (5kW<5MW), medium DG (5MW<50MW) and large DG (50MW<~300MW). In 2001, Electric Power Research Institute (EPRI) redefined the DG capacity to be less than 10MW and by 2003 they identified the DG to have a power output ranging from 1kW to 20kW (EPRI, 2001, EPRI, 2003).

There has been an increased interest in installing distributed generation (DG) at the distribution systems due to considerable advantages such as power loss reduction, cost reduction, environmental friendliness, voltage improvement, postponement of system upgrades and increasing reliability. To achieve one of these advantages, Abu-Mouti and El-Hawary (2011) finds the optimal location and size of the DG to minimize the total system power loss for radial distribution feeder systems. For this reason, different methodologies and tools have been developed and discussed by many researchers to identify optimal place and sizing to install DG. These methodologies are based on analytical and AI optimization techniques.

2.1.1 DG Definition

Many researchers have discussed the DG definition. DG is an electric power source connected directly to the distribution network or the customer site. It has several different names, such as embedded generation, dispersed generation, or decentralized generation, but the definitions are almost the same except that the difference of the generating capacity ranging from a few kilowatts up to ten megawatts for each definition (Wang and Nehrir, 2004). They have pointed out the definition of DG in terms of relatively small in size (relative to the power capacity of the system in which they are placed) and modular in structure. These DG sources are normally placed close to consumption centres and are added mostly at the distribution level.

The Institute of Electrical and Electronics Engineers (IEEE) defines DG as the generation of electricity by facilities that are sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in a power system (Dondi et al., 2002). The DG definition is not yet quantified in terms of size or voltage, usually its application categorizes the definition. DG can be defined as an electric power source of a limited size (generally 10MW or less) and connected to the distribution level at a substation, distribution feeder or customer load (In-Su et al., 2004).

El-Khattam et al., (2003) in their paper quoted that the DG is the use of small-scale power generation technologies located close to the load being served. The premise of DG is to provide electricity to customers at a reduced cost and at a higher efficiency while reducing losses than the traditional utility central generating plant with transmission and distribution wires. Power system restructuring, technology process and tight constraints over the construction of new bulk substation and transmission lines have created increased interest in DG as an alternative for supplying electric power to customers. DGs are small plant connected to the distribution systems (Falaghi and Haghifam, 2007).

2.1.2 DG Technologies

Often the term DG is used in combination with a certain generation technology category for example renewable energy technology. Current practice shows that available technology for DG varies widely. A detailed technical description and analysis of the current status for each of the technologies are presented in the literature review in this section. According to the DG technologies, it can be used without any limit.

DG technologies include a variety of energy sources, i.e. powered by renewable or by fossil fuel-based prime movers. Many of the technologies utilise renewable energy resource. According to the International Energy Agency (IEA), renewable energy resources are defined as resources that are generally not subjected to depletion such as the heat and light from the sun, the force of wind, organic matter (biomass), falling water, ocean energy and geothermal heat (Hansen, 1998). Jones et al., (2007) also state in their paper about DG technologies from renewable energy resources such as photovoltaic, small wind and small biomass. Consequently, the DG based on conventional technologies may involve small combination heat and power (CHP) or small cogeneration, small combined cooling, heat and power (CCHP) and small non-CHP systems.

The topic discussed by Rahman (2003) have pointed out about several DG technologies which are under various stages of development. They include micro turbines, Photovoltaic Systems (PV), Wind Energy Conversion Systems (WECS), gas turbines, gas-fired internal combustion engines, diesel engines and fuel cell systems. At present, wind energy has become the most competitive among all renewable energy technologies (Slootweg and Kling, 2003).

2.1.3 The Advantages of Distributed Generation Technologies

For the discussion of the advantages of DG technologies, Chiradeja (2005) discussed in general about an integration of DG into an existing utility which can result in several benefits. These benefits include line loss reduction, reduced environmental impacts, peak shaving, increased overall energy efficiency, relieved transmission and distribution congestion, voltage support and deferred investments to upgrade existing generation, transmission and distribution systems. Selecting the proper technology is based on many factors and varies from one application to another (Brown et al., 2001).

The additional main merits of DG can be listed as delay upgrading of an existing system, high reliability, possibility to exploit CHP generation and fewer pollution emissions (with respect to traditional power plants). Ackermann et al., (2001) state the DG technologies such as micro-hydro units, PV arrays, wind turbines, diesel engines, solar thermal systems, fuel cells and battery storage consist of a number of small modules, which are assembled in factories. These modules can be installed in a very short time at final power station location. Otherwise, manufacturing and construction on site requires significantly less time than for large centralized power stations. Borbely and Krieder, (2001) carried out their study about DG technology is assembled to provide electrical power to the customer, the grid or both. Furthermore, Internal Combustion Engines (ICE), Micro Turbines (MT), Photo Voltaic (PV) cell and Fuel Cell (FC) are grouped as feasible present or near-term DG technologies. Each one has its own attractive features and drawbacks. Selecting the proper technology differs from one application to another.

Among all these benefits, DG can cause undesirable behaviour on the distribution system if it is not optimally sized. Among others are voltage regulation concerns, power quality issues, overloaded situations and islanding cases. Additional concerns from all the DG benefit listed above, it can also be achieved by proper siting in terms of location and DG unit size. The problem of DG allocation and sizing is the great importance. For that reason, the use of an optimization method is capable to indicate the best solution for a given distribution network which can be very useful for the system planning engineer when dealing with the increase of DG installation.

2.1.4 Technical Impacts of Distributed Generation on the Distribution System

Installation of DG to an electric power grid is not simple plug and play problem. Indeed, as well as operation of the DG itself, it requires a careful consideration for the interaction with existing power network with respect to stability, reliability, protection coordination, power loss and power quality issues (AlHajri and El-Hawary, 2007, Chowdhury et al., 2003, Senjyu et al., 2008). The explanation about network voltage changes, losses and reliability will be discussed in details.

Network Voltage Changes

Every distribution utility has an obligation to supply its customers at a voltage within specified limits. This requirement often determines the design and expense of the distribution circuits and so, over the years, techniques have been developed to make the maximum use of distribution circuits to supply customers within the required voltages. The ratio of the MV/LV transformer has been adjusted using off-circuit taps so that at times of maximum load the most remote customer will receive acceptable voltage. During minimum load, the voltage received by all customers is just below the maximum allowable limit. If an embedded generator is now connected to the end of the circuit then the current flows in the circuit will change and hence the voltage profile floating. The most onerous case is likely to be when the customer load on the network is at a minimum and the output of the embedded generator must flow back to the source (Jenkins et al., 2000).

Losses

DG also causes an impact in electric losses due to its proximity to the load centers. DG units should be allocated in places where they provide a higher reduction of losses. This process of DG allocation is similar to capacitor allocation to minimize losses. The main difference is that the DG units cause impact on both the active and reactive power, while the capacitor banks only have impact in the reactive power flow. In feeders with high losses, a small amount of DG strategically allocated (10-20% of the feeder load) could cause a significant reduction of losses (Alvarado, 2001).

Unfortunately, the electric energy utility does not have absolute control of the installation places, since DG is usually of the consumer's property. In spite of that, it is of great interest for the utility to have a methodology for proper allocation of DG units in order to have an indication of the effects caused in the system by the location suggested by the independent producer (Borges and Falcao, 2003).

Reliability

With the distributed generations (DGs) being integrated to the distributed system, it will undoubtedly enhance the reliability of the consumer's power supply. However, due to the unstableness and interruption of the output of some DGs, such as wind or photovoltaic power generation system, it also undermines the positive effect to a certain extent on the improvement of the distribution system reliability. Therefore, how to comprehensively analyze the impacts of the different types of distributed generators on the distribution system reliability is a critical issue to be addressed (Lin and Wang, 2010).

In many cases, customers choose to operate DG in a net metering mode during normal conditions, but opted to disconnect from the utility and operate as an island during utility service interruptions. To analyze this behavior in ABB's proprietary software tool Performance Advantage-Distribution ™, a composite model consisting of a negative load and a voltage source is used. During normal operation, the negative load reduces overall feeder loading and improves system reliability. During an interruption, a transfer switch disconnects the customer load from the negative load and connects it to an alternate source. Similar to backup models, this transfer can be modeled with a delay or without a delay. When using composite models consisting of both a negative load and a voltage source, care must be taken to ensure that DG units are not "double counted." Double counting will occur if the reliability assessment algorithm reruns a complete power flow after the transfer switch has toggled to the voltage source. If this computational sequence occurs, the negative load will artificially reduce demand and may allow other load transfers that would otherwise be capacity constrained (Brown and Freeman, 2001).

2.1.5 DG Operation Modes

The DG operation modes in an electric power system were described by Short (2004). In this work, the simplest load-flow model of DGs is described as a negative load. The normal load models include constant power, constant impedance and constant current. More accurate representations depend on the type of generators and its controls. Since most synchronous DGs operate in a voltage-following mode with a set injection of real and reactive power, the most accurate model is the constant power model.

Atwa et al. (2010) have conducted an ultimate goal of their work to comprehensively assess the adequacy of radial distribution system, during different modes of operation, when integrated with different types of DG units. Particularly, the different modes of distribution system operation means grid connected mode and islanding mode. The characteristics of DG also related to the DG operation modes. Small and medium size of DGs mostly use asynchronous generators that are not capable of providing reactive power while they must consume it (Pepermans et al., 2005). There are some solutions to solve this issue such as using FACTS devices close to the DG (Bayod et al., 2002). DGs which use synchronous generators depend on the reactive power control strategy are classified into two groups by Zyl and Gaunt (2003).

i. constant Q
ii. constant power factor mode (PQ mode)
iii. voltage regulated mode (PV mode)

In addition, Balaguer et al., (2011) have quoted in their paper that, when the microgrid is cut off from the main grid (intentional- islanding operation), each DG system has to detect this islanding situation and has to be switched to a voltage control mode to provide constant voltage to the local sensitive loads.

2.2 DG INTERCONNECTION VIA ANALYTICAL TECHNIQUES

Many studies have been done on the impact of the DG on the voltage profile and power losses. Methods and procedures of optimally sizing and locating the DG within distribution system are varied according to objectives and solution techniques. In the literature, the optimal DG interconnection is solved by means of employing any analytical techniques.

Greatbanks et al., (2003) presented the determination of optimal sitting of DG by using sensitivity analysis of the power flow equations. While, the sizing method for a set of loading conditions, generation penetration level and power factor is formulated as a security constrained optimization problem. The results have shown that a strategic placement of the DG improves both system security and reliability by improving the voltage profile and reducing the losses.

Kashem et al., (2006) developed an analytical approach to determine the optimal DG sizing based on power loss sensitivity analysis. Their approach was based on minimizing the distribution system power losses and the method was tested using a practical distribution system in Tasmania, Australia. However, it assumes uniformly distributed loads with all the connected loads along the radial feeder having the same power factor and it also assumes no external currents injected into the system buses.

An analytical approach to address the optimal DG placement problem in distribution networks with different continuous load topologies was developed by Wang and Nehrir, (2004). Minimizing the real power losses was the objective of the proposed method. In their approach, the DG units were assumed to have unity power factor and only the overhead distribution lines with neglected shunt capacitance are considered. The candidate bus was selected based on elements of the admittance matrix, power generations and load of the distribution network. The issue of DG optimal size was not addressed in their formulation.

Acharya et al., (2006) used the incremental change of the system power losses with respect to the change of injected real power sensitivity factor. This factor was used to determine the bus that would cause the losses to be minimized when installing a DG. They proposed an exhaustive search by applying the sensitivity factor on all the buses and ranked them accordingly. The observation from their work is the lengthy process of finding the candidate locations and to optimize only the DG real power output. Furthermore, they only considered planning of a single DG.

The application of the famous '2/3 rule', originally developed for optimal capacitor placement to find a suitable bus candidate for DG placement was presented by Willis, (2000). That is to install a DG with a rating of 2/3 of the utilized load at 2/3 the radial feeder length down-stream from the source substation. However, this rule assumes uniformly distributed loads in a radial configuration and a fixed conductor size throughout the distribution network. These assumptions limit its applicability to radial distribution systems and the fact that it is only suitable for single DG planning.

A method to optimal location and sizing of DG in a meshed network for maximizing the potential benefits is outlined in the paper presented by Rau and Wan (1994). The authors only treated the DG sizing problem by utilizing the Generalized Reduced Gradient (GRG) method. The bus locations were assumed to be provided by the system planner for the DG units to be installed. The proposed second order algorithm computes the amount of DG in selected nodes to make up a given total of DG to achieve the desired optimizing objectives. The network under consideration could be a transmission, sub transmission, or distribution network. In their formulation, only the power flow equality constraints were considered, whereas the boundary conditions and the inequality constraints were not taken into account. The benefit expressed in this paper as the minimization of losses, reactive power losses, or loadings in selected lines.

Hedayati et al., (2008) has been presented a method for placement of DG units in distribution networks in their paper. This method is based on the analysis of power flow continuation and determination of most sensitive buses to voltage collapse. After that, the DG units with certain capacity will be installed at these buses via an objective function and an iterative algorithm. In this algorithm, continuation power-flow method is used for the determination of the voltage collapse point or maximum loading, however; it is needed to investigate the impact of DG technologies on static voltage stability and analysis tools for studying of voltage stability. The results of execution of this method on a typical 34-bus test system have clarified the robustness of this method in optimal and fast placement of DG units. The results have showed efficiency of this method for improvement of voltage profile, reduction of power losses and also an increase in power transfer capacity, maximum loading and voltage stability margin.

From the cited references, it was found that DG interconnection via analytical techniques has gained the numerous concerns from the power system researchers. A rigorous reviews outlined in the paper presented by Haghifam et al. (2008) indicated that with advances in technology and restructuring in electric power systems, DGs are found to play an important role in the future.

2.3 DG LOCATION AND SIZING BASED ON ARTIFICIAL INTELLIGENCE TECHNIQUES

Artificial Intelligence (AI) is the intelligence of machines and the branch of computer science that aims to create it. AI have shown great potential as new technique for solving critical problems in different engineering fields where the heuristic methods have not achieved the desired speed and accuracy (Adeli and Jiang, 2003, Adeli and Jiang, 2006, Ghosh-Dastidar et al., 2007, Jiang and Adeli, 2008). Several researches focused on the topic of DG to find an optimal solution of DG sizing and location in the distribution network and some of these studies proposed the use of artificial intelligence as an approach to find the optimal size and location.

Lee and Park, (2009) proposed the method for selecting the optimal locations and sizes of multiple distributed generations (DGs). In this study, a method to determine the optimal locations of multiple DGs is proposed by considering power loss. The optimal sizings are determined by using the Kalman filter algorithm. The objective is to minimize the total power loss of system in a steady state operation. To deal with this optimization problem, the Kalman filter algorithm was applied. When the optimal sizes of multiple DGs are selected, the computation efforts might be significantly increased with many data samples from a large-scale power system because the entire system must be analyzed for each data sample. The proposed procedure based on the Kalman filter algorithm which took only few samples, and therefore reduced the computational requirement dramatically during the optimization process.

Sizing, sitting and scheduling distributed generators using Evolutionary Programming (EP) algorithm was suggested by (Nerves and Roncesvalles, 2009). The distribution system is modeled using a load flow formulation wherein the distributed generator is modeled as injected real and reactive power. EP is implemented by perturbing distributed generator outputs and evaluating the fitness values of the resulting systems. Optimal locations and sizings of DGs are determined using a fitness value based on system loss reduction, while an optimal DG schedule is determined for a 24-hour period using a fitness value based on energy cost. A mathematical model is developed to represent different customer types within the distribution system and different types of energy sources are represented based on their availability and cost. The method is found to be effective and flexible based on results for a 69-bus test system.

Dasan et al. (2009) also solved the DG interconnection problem by basically employing the EP method. This paper addresses the voltage sensitiveness of the loads by incorporating voltage dependent load models in the analysis. Three types of DGs are considered for implementation and DGs are modeled as PQ bus. The suitable location for placing distributed generation (DG) is identified through loss sensitivity factors and L index. EP is used to find the optimal sizing of DG. The objective of this study is to minimize the total losses by optimal sitting and sizing of three types of DG for a mixed realistic load model. The results obtained justify the importance of optimal placement of DG for minimizing losses and maximizing saving while maintaining appropriate voltage profile at all the buses.

For the purpose of comparative study of EP, Abdul Rahim et al. (2009) presented another AI technique based Artificial Immune System (AIS) in their study. The result shows that the AIS technique was capable to simulate with the minimum number of iteration compared to EP. In the further study in 2010, Abdul Rahim et al

(2010) proposed the AIS for the purpose of determining the optimal sizing of DG. The random numbers represent by the real power output of DG as the variable to be optimized. The size of DG is to be set in the interval of 0MW-3MW. The number of variables depends on the number of DGs to be installed in the system. In order to minimize the network losses, the fitness of the AIS is taken to be the total losses in the distribution system. The optimization also took the consideration of the voltage constraint in the system so that the minimum and maximum voltage would not be exceeded. The results show that the proposed technique was capable to minimize the system losses and improve the voltage profile.

Sedighizadeh and Rezazadeh, (2008) presented the application of Genetic Algorithm (GA) to the optimal allocation of DGs in distribution network. The effectiveness of the proposed algorithm to solve the DG allocation problem is demonstrated through a numerical example. The Khoda Bande Loo distribution test feeder in Tehran has been solved in order to achieve the voltage profile improvement and loss reduction in distribution network.

Sulaiman, M.H. et al, (2009) in their paper presents a new technique from GA namely the continuous GA. This technique proposed to find the optimal sizing and location of EG units in the distribution system to minimize the total loss in the system. However, the concept is simple and different from conventional GA. The representation of variables is coded in floating number, not in binary number. In addition, the location and sizing of EG unit can be determined simultaneously by using this technique. By minimizing the loss, the voltage profile at each bus is also improved. This method requires load flow to be run several times. After finding the best location and the sizing simultaneously for EG, the algorithm is finished. However, GA is found to be very exhaustive to converge to an optimal solution. This is indeed computationally burdensome.

Mithulananthan et al., (2004) used the distribution system (DS) real power losses as the fitness function to be minimized through GA. Their formulation of the DG size optimization problem is of an unconstrained type. Moreover, the Newton Rahpson method which is usually inadequate in dealing with the distribution system topology was used in calculating the total power losses. Candidates of DG bus locations were obtained by placing a DG unit at all buses of the tested DS, which is impractical large DS. Furthermore, the multiple DGs case was not addressed.

The other AI technique which has been used in solving the DG problem is Tabu Search (TS). Nara et al., (2001) applied this technique in solving the optimal DG size and assumed that the candidate bus locations for DG unit to be installed were pre-assigned by the distributed planner. The objective of their formulation was to minimize the system losses. The DG size was tested as a discrete variable and the number of the deployed units was considered to be fixed. The DS loads were modeled as balanced, uniformly distributed, constant current loads with a unity power factor.

Particle Swarm Optimization (PSO) is another technique to solve DG optimization problem. PSO is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling (Kennedy and Eberhart, 1995). Raj et al. (2008) employed this technique to determine the size of single and multiple DGs. The optimal location portion of the problem was performed utilizing the NR power flow method to assign those buses with the lowest voltage profiles as the optimal candidate DG locations. The PSO was used to minimize the system real power losses and the voltage profiles boundary conditions were the only constraints required by the authors to be satisfied. Looking on the mechanics of PSO, it is found that there are several random numbers which need to be generated during the velocity updating process. This will possibly lead to diverged solution.

An Immune Algorithm (IA) based optimization approach for solving the distributed generation (DG) placement problem is proposed by Aghaebrahimi et al. (2009). In the distributed generation placement problem, practical DG operating constraints including: load profiles, feeder capacities and allowable voltage limits are all considered while the investment cost, power or energy losses and voltage profile are optimized. In the proposed method, objective function is the power losses and the constraints include the bus voltage limits and line current limits which are represented as antigens. Through the genetic evolution, an antibody that most fits the antigen becomes the solution. In this IA computation, an affinity calculation process is also embedded to guarantee the diversity. The process stagnation can thus be prevented better. In AI, there is possibility for the optimization process to experience longer computation time due to present of cloning process which has increased the number of individual in the population.

Inspiration through the observation on the AI techniques that has been discussed from the literature review in this section first, to enhance the original EP performance. This research suggested a new technique namely Adaptive Embedded Clonal Evolutionary Programming (AECEP). The technique devised the search space reduction strategy to accelerate the mutation process. The results obtained from the proposed techniques are compared with the first analysis obtained by EP and AIS optimization techniques. It has shown superiority to the conventional techniques and also obtains precise solutions compared to analytical methods.

2.4 SUMMARY

This chapter has presented the overview of the installation of the DG in the power system. Based on the previous studies, the general knowledge of DG definition and technologies, the advantages of DG technologies and technical impacts of DG on the distribution system was addressed. An overview of analytical techniques was exposed as the conventional method in order to determine the optimal location and sizing of DG.

The non optimality of EP and potential long computation time experienced in AIS has led to the motivation to propose AECEP in the attempt to reduce computation time and achievement of optimal solution.

CHAPTER 3

RESEARCH METHODOLOGY AND DEVELOPMENT PROCESS

3.1 INTRODUCTION

This chapter presents the methodology and development process of the whole research. It is describes problem formulation overview for DG location and sizing, application of DG on distribution system, DG location and sizing based on the proposed new techniques namely Adaptive Embedded Clonal Evolutionary Programming (AECEP) and AI techniques based on EP and AIS. Two distribution system namely IEEE 41-Bus RDS and IEEE 69-Bus RDS are used to implement the proposed technique performance evaluation is also conducted.

3.2 RESEARCH FRAMEWORK

In general, the overall methodology for this research comprises of five main steps as depicted in Figure 3.1 and briefly discussed as follows:

i) Knowledge Acquisition and Background Study

Generally, this section involves the background study of knowledge acquisition in the whole research. An understanding on DG definitions and technologies, the technical impact of DG on the distribution system, DG operating modes and technique to determine the location and sizing of DG are acquired. This is important so that adequate knowledge have been in place prior to the actual research work.

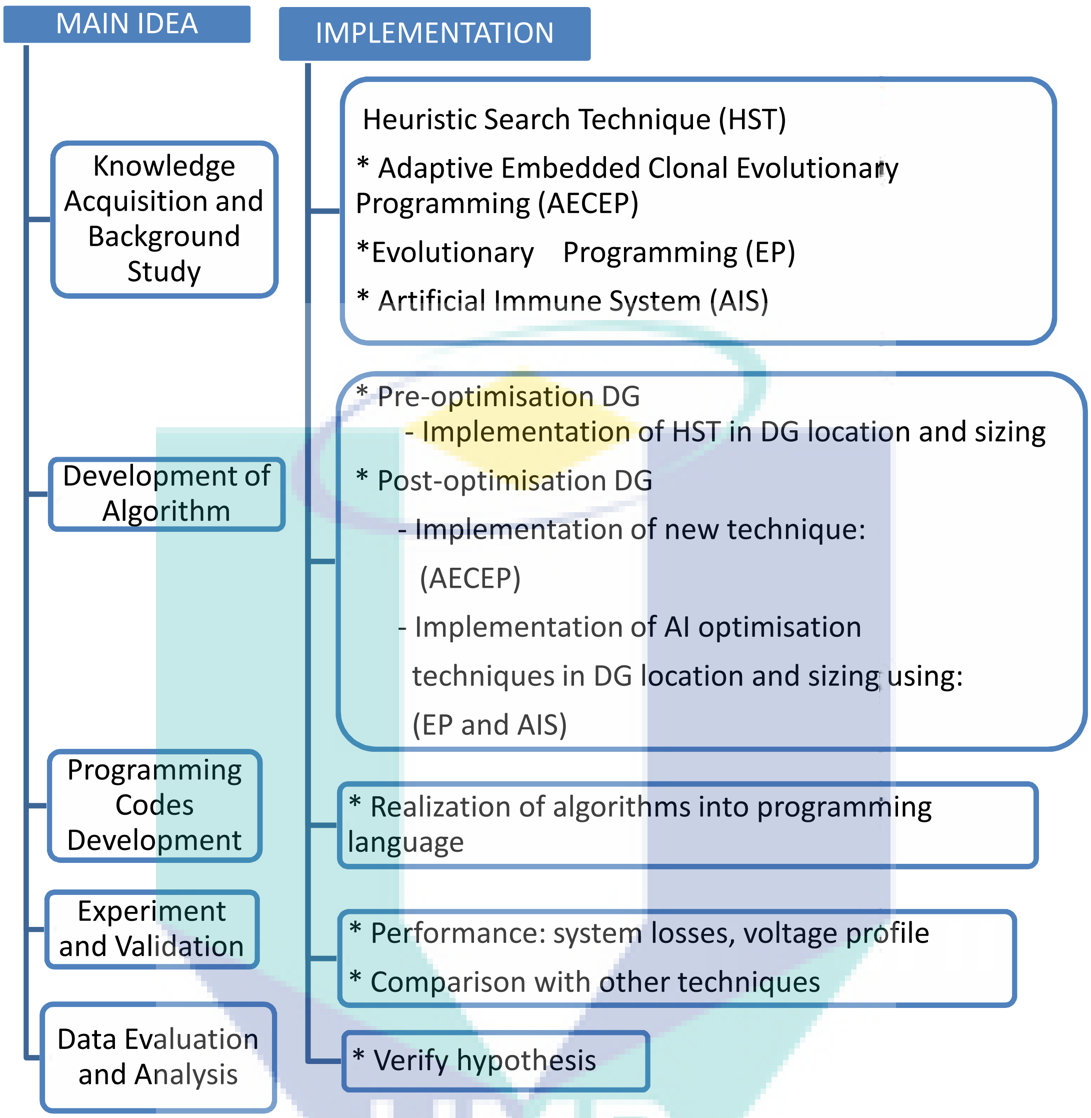

Figure 3.1: Research Design

ii) Development of Algorithm

At this juncture, all the algorithms required to be incorporated and used in the research are developed. In the pre-optimization stage, the DG location and sizing of DG was evaluated by using the Heuristic Search Technique (HST) to determine the system loss and voltage profile condition. Consequently, the algorithm on the determination of DG location and sizing using HST was designed. The new technique based on modification of original EP was consequently constructed. The idea of the proposed technique is the combination of AIS and EP into the mutation process in original EP. All the parameter settings, control variables limit and other constraints are identified and incorporated into the algorithm. Detail processes are discussed in the following sections. In addition, in depth analysis on the existing technique which covers Evolutionary Programming (EP) and Artificial Immune System (AIS) were studied thoroughly.

iii) Programming Codes Development

At this stage, the designed HST, AECEP, EP and AIS algorithms were translated or coded into the programming codes using the Matrix Laboratory (MATLAB). The appropriate functions are developed to ensure that the program run smoothly. The developed codes are tested in stages to ensure that the algorithm have been coded correctly.

iv) Experiment and Validation

In this section, experiment and validation on the developed codes are conducted. Implementations on several test systems are conducted in order to evaluate the performance of the developed algorithm of optimization engines. Chosen objective functions are implemented in the optimization processes.

v) Data Evaluation and Analysis

Results obtained from the experiments are collected and analyses are conducted accordingly.

The breadth and depth of the outlined research framework are rigorously studied such that the adequate contribution is achieved.

3.3 PROBLEM FORMULATION OVERVIEW

There are two main aspects to the optimal DG installation problem. Namely the optimal DG location and the second is the optimal DG sizing. The search for appropriate placement of the DG to be installed is performed via the HST and AI techniques. Optimal DG sizing is a highly nonlinear constrained optimization problem represented by a nonlinear objective function subjected to nonlinear equality and inequality constraints; and boundary restrictions imposed by the system planner. The detailed formulation of DG optimization problem is presented in the following sections.

3.3.1 Objective Function

The objective function to be optimized is the process of choosing the optimal DG location and sizing is minimized the system losses formulated as:

$$F = P_{Loss} = Min \left(\sum_{n=1} I^2 R\right) \tag{3.1}$$

Where, P_{Loss} is the active power loss of the system. I and R is current and resistance through the line.

3.3.2 Equality Constraints

The equality constraints are the nonlinear power flow equations which state that all the real and reactive powers at any DS bus must be conserved. The loss is optimized with the following power balance equation.

$$\sum_{i=1}^{n} P_{LGi} + \sum_{i=1}^{n} P_{Gi} = P_L + P_D \tag{3.2}$$

The active P_{DGi} DG generated powers are respectively modeled as

$$P_{DGi} = -S_{DGi} pf_{DGi} \tag{3.3}$$

Where: P_{DGi} = Active DG generated powers

P_{Gi} = Generate power source

P_D = Power load demand

S_{DGi} = Apparent DG generated power

pf_{DGi} = Power factor of DG

3.3.3 Inequality Constraint

One inequality constraint is to be satisfied for this study. The inequality constraint is the bus voltage magnitude. The bus voltage magnitudes are bounded between two extreme levels imposed by physical limitations. It is customary to tolerate the variation in the voltage magnitudes in the distribution level to be in the vicinity of $\pm 10\%$ of its nominal value (Pansini, 2007). In this research, the power factor is assumed as unity power factor. The inequality constraint on voltage of each bus is expressed as shown in equation (3.5)

$$|V_i|^{min} \le V_i \le |V_i|^{max} \tag{3.4}$$

3.4 APPLICATION OF DISTRIBUTED GENERATION INSTALLATION TO DISTRIBUTION SYSTEM

The DG is connected to an electrical distribution system in order to export the electrical energy to the customers. Since these exports can have a significant effect on the pattern of flows in the network, it is important to check that it will not degrade the quality of supply for the other users of the network. This section describes purposes of power flow computations in larger system and then an application to DG installation to distribution system will be presented.

3.4.1 Heuristic Search Technique for DG Location and Sizing

The search for appropriate placement of the DG location and sizing to be installed is performed via the Heuristic Search Technique (HST). HST is a general method of problem solving, fixing things, or for obtaining knowledge. Learning process does not happen from failure itself but rather from the analysis of the failure, making a change, and through heuristic process. This method has been implemented based on the principle of power flow. The problem is divided by two sub problems which are the location and sizing. In this research, in order to reduce the search space of determination, for DG allocation, the heavily loaded bus was selected. Theoretically, the HST of choosing location buses and size of DG is computed as follows:

$$\text{HST} = \text{number of buses} * \text{size of DG} \tag{3.5}$$

The results from this technique provide the exact but not optimal DG location and sizing values. For example, if one DG units was to be installed in a 69 bus system and the possible DG size is four, the number of possible bus selections would be as large a number as 276 combinations. In other words, all possible DG sizes values are examined at every loaded bus in the system except the slack bus. Though this process is tedious and lengthy, an attempt to find the global optimal placement and sizing for single and multiple DG units is important. This will eventually be optimized using the AI techniques such as EP and AIS. The results obtained are used as a reference when employing the developed AECEP technique in Chapter 4. The complete flowchart of the whole process is presented in Figure 3.2.

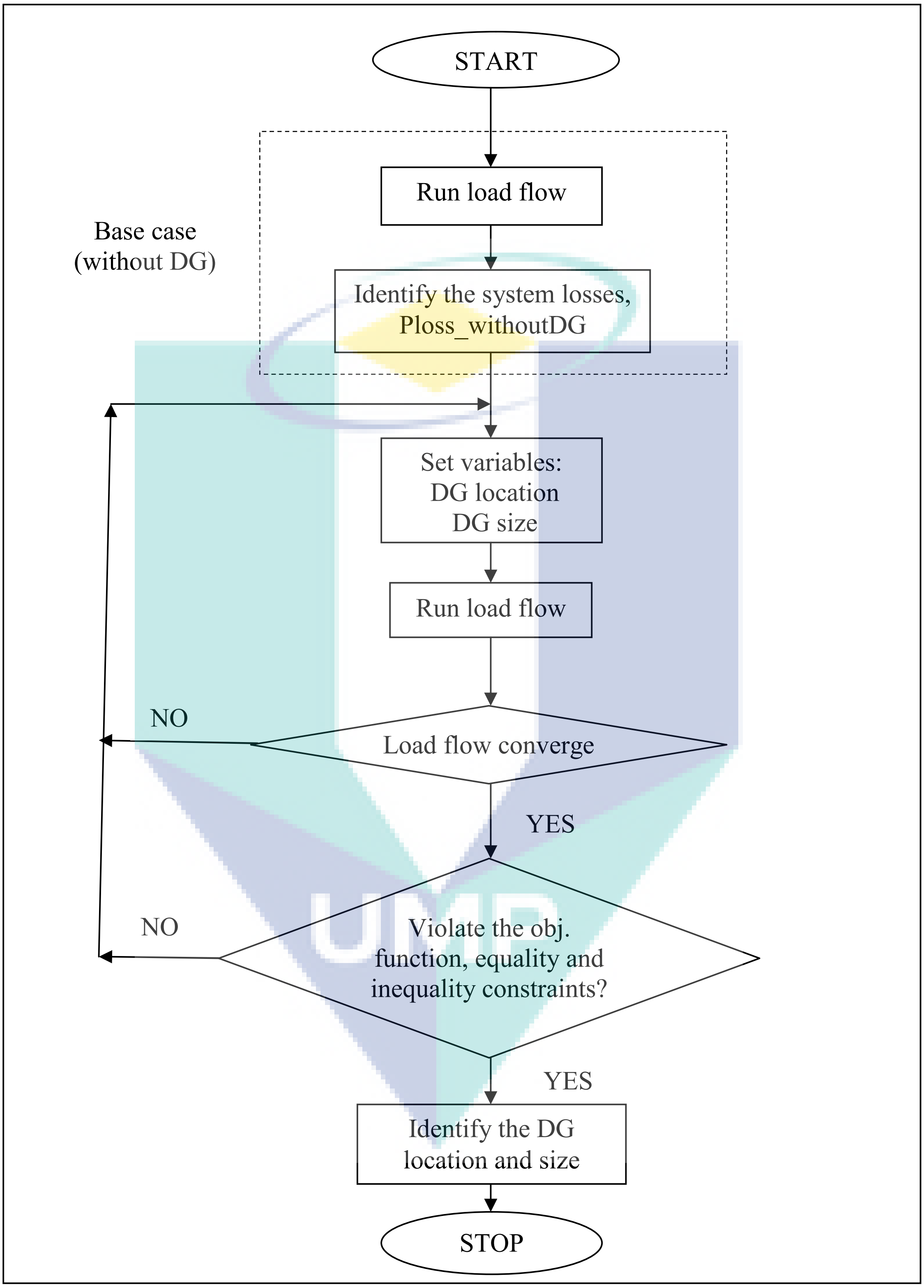

Figure 3.2: Flowchart of Heuristic Search Technique (HST) algorithm

Power flow analysis gives various information of the system like voltages at all the nodes and power losses. Using these results; different studies related to voltage profile and system losses can be performed. The first step of this research is to analyze the IEEE Radial Distribution System (RDS) for power flow with DG connected to them. This analysis is done using power flow software, which can handle single DG that modeled as PQ nodes. The results obtained were compared with the base case (case without DG) in order to see the impact of DG on the voltage profile and losses of the system.

3.5 DG LOCATION AND SIZING BASED ON ARTIFICIAL INTELLIGENCE TECHNIQUES

Many optimization techniques have been employed to solve optimization problems related to DG. Optimization techniques such as Genetic Algorithm (GA), Evolutionary Programming (EP), Particle Swarm Optimization (PSO) and Artificial Immune System (AIS) are promising techniques as reported by (Abdul Rahim et al., 2010, Nerves and Roncesvalles, 2009, Raj et al., 2008, Sedighizadeh and Rezazadeh, 2008). However, these techniques are reported to be time consuming.

3.5.1 DG Location and Sizing Based on Evolutionary Programming

Evolutionary Programming (EP) has been chosen as the initial optimization approach to solve the problem. It is chosen as the benchmark and consequently chosen for comparative study.

General EP Algorithm

Basically, in EP approach, the optimal solution is obtained by evolving a population of candidate solutions over a number of generations or iterations. The first generated population is called as the parents. During each an iteration, a second new population is formed from parents through the use of mutation operator. This operator produces a new solution or offspring by perturbing each component of parent by a random amount. The degree of optimality of each of the candidate solutions or individuals is amount. The degree of optimality of each of the candidate solutions or individuals is measured by their fitness or objective function of the problem. Through the use of tournament scheme, the individuals in parents and offspring population compete with each other. The winning individuals form a new population, which is regarded as next generation. This process is repeated until the fitness of the problem is converged. Through this, the population evolves towards the global optimal point (Musirin, 2003a). Based on the above explanation, the methodology of basic EP algorithm is summarized as follow:

Step 1: Initialization process in EP was conducted by generating a series of random number using a uniform distribution number generator. Generation of random numbers represent the variables which control the objective function. In this study, the random number represents the location and sizing of DG.

Step 2: Fitness Calculation- In this study, system loss was taken as the objective function, which needs to be minimized and it was calculated by solving ac load flow programme. It was done by calling the load flow programme into the EP main programme. Thus in this problem, the objective function was not going to be single mathematical equation but rather a subroutine which is executed accordingly in the EP main programme. Subsequently, evaluation of maximum, minimum, sum and average of fitness would be carried out which would be utilised in the mutation process.

Step 3: Mutation was performed on the generated random numbers, x_i to produce the offsprings. The mutation process was implemented based on the following equation:

$$x_{i+mj} = x_{i,j} + N(0, \gamma^2) \tag{3.6}$$

$$\gamma^2 = \beta(x_{jmax} - x_{jmin})\left(\frac{f_i}{f_{max}}\right) \tag{3.7}$$

where: $0 \leq \beta \leq 1$ $\beta = rand(1,1)$ 1 (3.8)

x_{i+mj} = mutated parents (offspring)

$x_{i,j}$ = parents

N = Gaussian random variable with mean μ and variance γ^2

β = mutation scale

x_{jmax} = maximum random number for every variable

x_{jmin} = minimum random number for every variable

f_i = fitness for the *ith* random number

f_{max} = maximum fitness

The mutation scale β could be manually adjusted in order to achieve better convergence. Large value of β implies large search step, which causes slow convergence of the EP leading to large computation time and vice versa. The value of was β determined by using the heuristic technique is 0.001 that could produce the best results.

Step 4: Selection – The offsprings produced from the mutation process were combined with the parents to undergo a selection process in order to identify the candidates to be transcribed into the next generation. Two selection strategies were tested namely the priority selection and pair wise comparison. In priority selection strategy, the populations were sorted in descending order according to their fitness values since the objective function is to obtain the maximum loadability.

On the other hand, in the pair wise comparison strategy; ten opponents were randomly generated for every combined population. Opponents underwent tournament process with the combined populations via pair wise comparison and number of wins was calculated for every element in the combined population. These populations were sorted in descending order according to the number of wins. The first half populations were then transcribed for the next generation. Comparing the two selection strategies; the priority selection provides a better results and therefore it is employed in the selection process of the developed EP.

Step 5: Convergence test is important to determine the stopping criterion of the evolution process. The pre-determined accuracy is normally dependent on the problem orientation. The convergence criterion is duly specified by the difference between the maximum and minimum fitness ≤ 0.0001. If it is not reached, the process will be repeated.

$$maximum_{fitness} - minimum_{fitness} \leq 0.0001 \quad (3.9)$$

Algorithm for DG Location and Sizing

As mentioned in the previous section, EP involved initialization, fitness calculation, mutation, selection and convergence test. Details explanations on each procedure are described in this section. The methodology of EP with minimum power losses and maximize the voltage profile as the objective function is discussed. The overall EP process is represented in the form of flow chart as illustrated in Figure 3.3.

Step 1: Set the equality and inequality constraints by using eq. (3.2), (3.3), and (3.4).

Step 2: Initialize a random population of individuals:

x_1=bus location
x_2=size of DG (P_{DGi})

Each generated individuals must comply with its equality and inequality constraints. The load flow is executed using Newton-Raphson method.

Step 3: Calculate the value of fitness function based on eq. (3.1). This implemented by running the load flow.

Step 4: Mutation process. Generate offsprings by using eq. (3.6).

Step 5: Repeat step 3 for offspring calculate fitness function. This implemented by running the load flow.

Step 6: Combine the parents and offspring.

Step 7: Choose the best individual among the set of combination using the offspring values via the control variables in tournament or selection process.

Step 8: Identify the individual with minimum fitness function in the converge population.

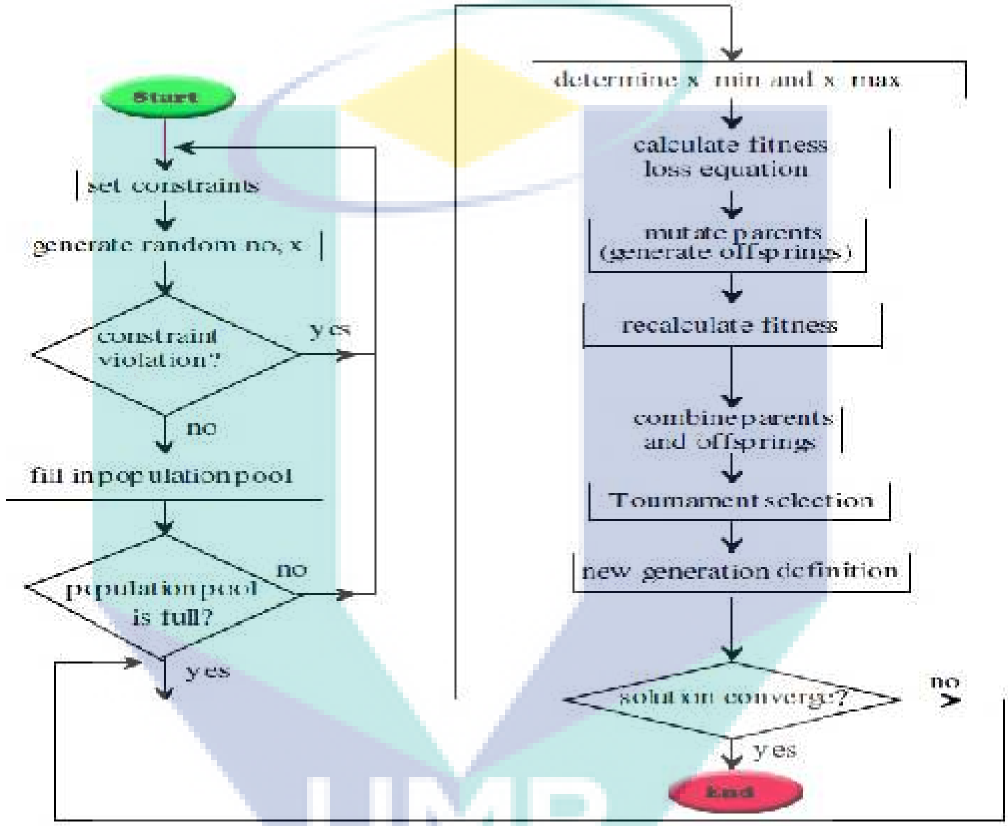

Figure 3.3: Flowchart of Evolutionary Programming to determine DG location and sizing

3.5.2 DG Location and Sizing Based on Artificial Immune System (AIS)

Artificial immune systems are data manipulation, classification, representation, and reasoning methodologies which follow a biologically plausible paradigm. They are massively distributed and parallel, highly adaptive and reactive, and maintain computational reasoning functions.

Algorithm for DG Location and Sizing

The computational procedure of AIS for DG location and sizing consists of the following steps:

Step 1: Initialization of population. For the purpose of determining the optimal location and sizing of DG, the random numbers represent the kW output (P_{DGi}) of DG as size of DG and bus location as the variables to be optimised.

Step 2: Evaluation of the fitness value of each population. In order to minimize the power losses, the fitness of the AIS is taken to be the total losses in the distribution system. The total loss was evaluated by solving the load flow program. It was done by calling the load flow program into the AIS as a main program. The optimization also took the consideration of the voltage constraint in the system so that the minimum and maximum voltage would not be exceeded.

Step 3: Clone process. In this process, the location and size of DG and the total losses as the fitness function were cloned. In this study, the chosen number of clone is 10 (Musirin, 2003b).

Step 4: Mutation process. The value of clone was mutated by implementing the mutation operator. Mutation is the only variation operator used for generating the offspring from each parent. The fitness of the offspring was calculated by calling the load flow program.

Step 5: Selection process. The selection process was done by using the priority selection strategy.

Step 6: Convergence test. This procedure is to determine the stopping criteria of the optimization. The convergence criterion is specified by the difference between the maximum and minimum fitness to be less than 0.0001. If the convergence condition is not satisfied, the processes will be repeated.

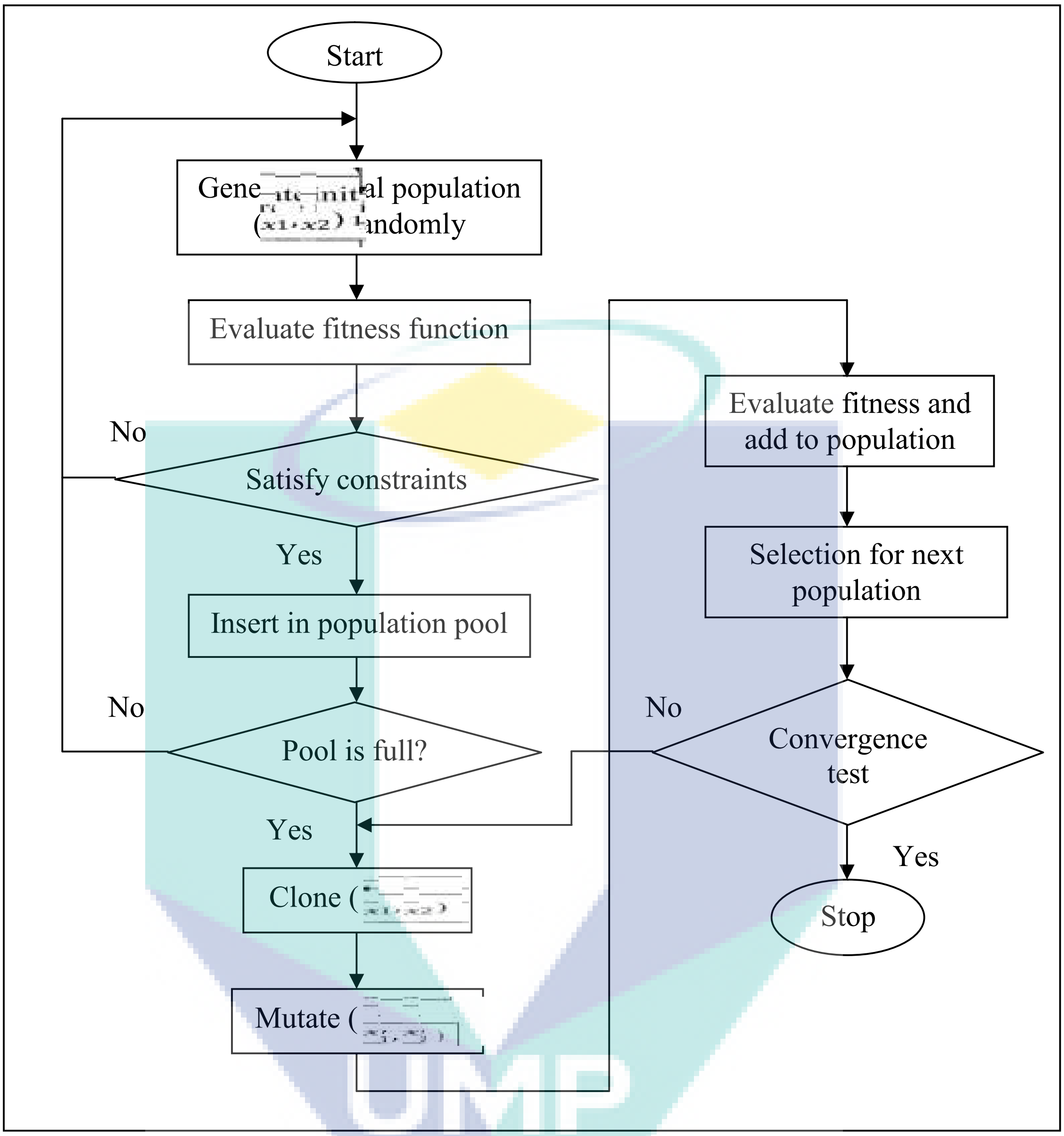

Figure 3.4: Flowchart for implementation of AIS technique in order to obtain the optimal location and sizing of DG.

3.6 PROPOSED ADAPTIVE EMBEDDED CLONAL EVOLUTIONARY PROGRAMMING (AECEP)

The short computation time experienced by the EP has been the merit of EP. EP consumes very less computation time to achieve an optimal solution. In most cases, EP has been proven superior in terms of fast computation time especially in solving power system optimization. Iteration number resulted from EP normally very short, i.e. less than 10 iterations as reported by (Musirin, 2003b). However, EP has a setback in terms of achieving an accurate solution. This is termed as near optimal. On the other hand, AIS also suffers the same experience in the sense of achieving accurate solution. This is due to the fact that AIS inherits the EP characteristic. The only difference between EP and AIS is that, EP has combination process, while AIS undergoes cloning process without combination.

Having working with EP and AIS, in this study Adaptive Embedded Clonal Evolutionary Programming abbreviated as AECEP is proposed. This idea is to incorporate the element of randomized search step, denoted as β into the embedded AIS-EP. β is the scalar value ranging from 0 to 1 which exists in the mutation mathematical formulation in which it is able to search the best search step.

Clonal process in AIS is embedded in the original EP algorithm, while β is added as a randomized factor which has the capability to control the search step. Improper selection of β value will lead to exhaustive optimization process causing inaccurate solution and possible computation burden.

3.6.1 Algorithm of AECEP in DG Installation

In this study, AECEP is implemented in order to minimize the total losses in the distribution system; while monitoring voltage at all buses in the system to be within the acceptable limit. The flowchart of the proposed AECEP is shown in Figure 3.5. The algorithm for AECEP is explained as follows:

Step 1: Initialization. In this process, random numbers are generated using the uniformly distribution random number generators. These candidates are also known as parents. The random number is denoted as x. The general equation for x is given as follows:

$$\text{Parent, } x_{nk} = \begin{bmatrix} x_{11} & x_{12} \cdots & x_{1k} & x_{1k+1} & x_{1k+2} & \cdots & x_{12k} \\ \vdots & \cdots & \cdots & \cdot & \cdot & \cdots & \\ x_{n1} & x_{n2} \cdots & x_{nk} & x_{nk+1} & x_{nk+2} & \cdots & x_{n2k} \end{bmatrix} \quad (3.10)$$

Matrix size= n x $2k$

where ; n = population number is 20

k = number of control variables

The population size is normally chosen between 10 to 20. Based on the experience and past researches (Musirin, 2003b), 20 is the suitable population size to achieve optimal solution. Excessive population size will lead to exhaustive optimization process which does not help to better accuracy. Initialization process can be conducted with the consideration of successful candidates. The random numbers represent DG location and DG sizing in MW. For example, if two DGs are planned to be installed into the system therefore, 4 variables will be required to represent two DG locations and two DG sizings.

Step 2: Fitness Computation

Fitness computation is conducted in order to perform the optimization. In this study, losses in power system will be the fitness which needs to be minimized. This can be referred to objective function in equation 3.1. The total losses are obtained by the load flow.

Step 3: Cloning Process

Cloning process is a process to duplicate the parents. The mathematical equation is given as follows.Cloned Population:

$$\tau_{nmk} = \begin{bmatrix} x_{11} & \cdots & x_{1k} & \cdots & x_{1,k+1} & x_{1,k+2} & \cdots & x_{1,2k} \\ \vdots & & & & & & & \vdots \\ x_{n1} & \cdots & x_{nk} & \cdots & x_{n+1k} & x_{1,k+2} & \cdots & x_{n,2k} \\ x_{21} & \cdots & x_{2k} & \cdots & x_{2,k+1} & x_{1,k+2} & \cdots & x_{2,2k} \\ \vdots & & & & & & & \vdots \\ x_{n1} & \cdots & x_{nk} & \cdots & x_{n,k+1} & x_{1,k+2} & \cdots & x_{n,2k} \\ x_{31} & \cdots & x_{r2} & \cdots & x_{nk+1} & x_{1,k+2} & \cdots & x_{n2k} \\ \vdots & & & & & & & \\ x_{r1} & \cdots & x_{r2} & \cdots & x_{nk+1} & x_{1,k+2} & \cdots & x_{n2k} \end{bmatrix} \quad (3.11)$$

Matrix size of cloned population: *mn* x *2k*

where : *n* = population number

m = cloning number

k = number of control variables

Step 4: Adaptive Mutation

Mutation is a process to produce offspring (children). The mutation process is performed using equation 3.6 and 3.7. β is a scalar value, generated randomly to control the mutation process. β controls the movement of candidates from the valley to hill within the chosen bell-curve. This curve can be the Gaussian, Cauchy or Levy. The matrix sizing for the offspring is similar with that for the cloned population, τ_{nmk}.

Step 5: Fitness 2 Computation

In this phase, fitness values are recalculated using the offspring. In this study, Gaussian mutation technique is employed.

Step 6: Combination

Combination is a process to connect the whole population and population after the cloned process in cascode form. It is can be conceptually represented as in equation 3.12, 3.13 and 3.14.

From the parent population, A_1

$$A_1 = \begin{bmatrix} no & x_1 & x_2 \cdots & x_k & x_{k+1} x_{k+2} \cdots & x_{2k} & F_1 \\ \vdots & \vdots & \vdots \; \vdots & \vdots & \vdots \quad \vdots \quad \vdots & & \vdots \\ n & \cdots & \cdots & \cdots & \cdots \quad \cdots \quad \cdots & x_{n2k} & F_{20} \end{bmatrix} \tag{3.12}$$

and offspring population, A_2. Therefore, the combined population can be written as C.

$$A_2 = \begin{bmatrix} no & x_{1new} & x_{2new} \cdots & x_{1knew} & x_{1k+1new} \cdots & F_1 \\ \vdots & \vdots & \vdots \quad \vdots & \vdots & \vdots \quad \vdots & \vdots \\ n \times m & \cdots & \cdots \quad \cdots & \ddots & \cdots \quad \cdots & F_{20} \end{bmatrix} \tag{3.13}$$

$$C = \begin{bmatrix} A_1 \\ A_2 \end{bmatrix} \tag{3.14}$$

Step 7: Tournament Selection

Tournament selection is a process to prescribe the candidates for the next iteration. If the cloning multiplier m is 10, therefore F1 and F2 will have 20x10=200 populations. Only 20 best members/individual are prescribed from this population. There are many techniques for the selection process such as pair wise comparison, elitism and roulette wheel. Any suitable technique can be adopted for this purpose. But in this study, pair wise comparison was used.

Step 8: Stopping Criterion

The stopping criterion for AECEP is determined by evaluating the difference between maximum fitness or minimum fitness which is supposed to be less than ε. ε is the accuracy level set in the beginning of optimization process. The typical value is 0.0001 (Musirin, 2003b).

The general equation can begiven by:

$$\Delta f = f_{max} - f_{min} \leq 0.0001 \tag{3.14}$$

If Δf does not achieve the desire ε value, the optimization process will repeat.

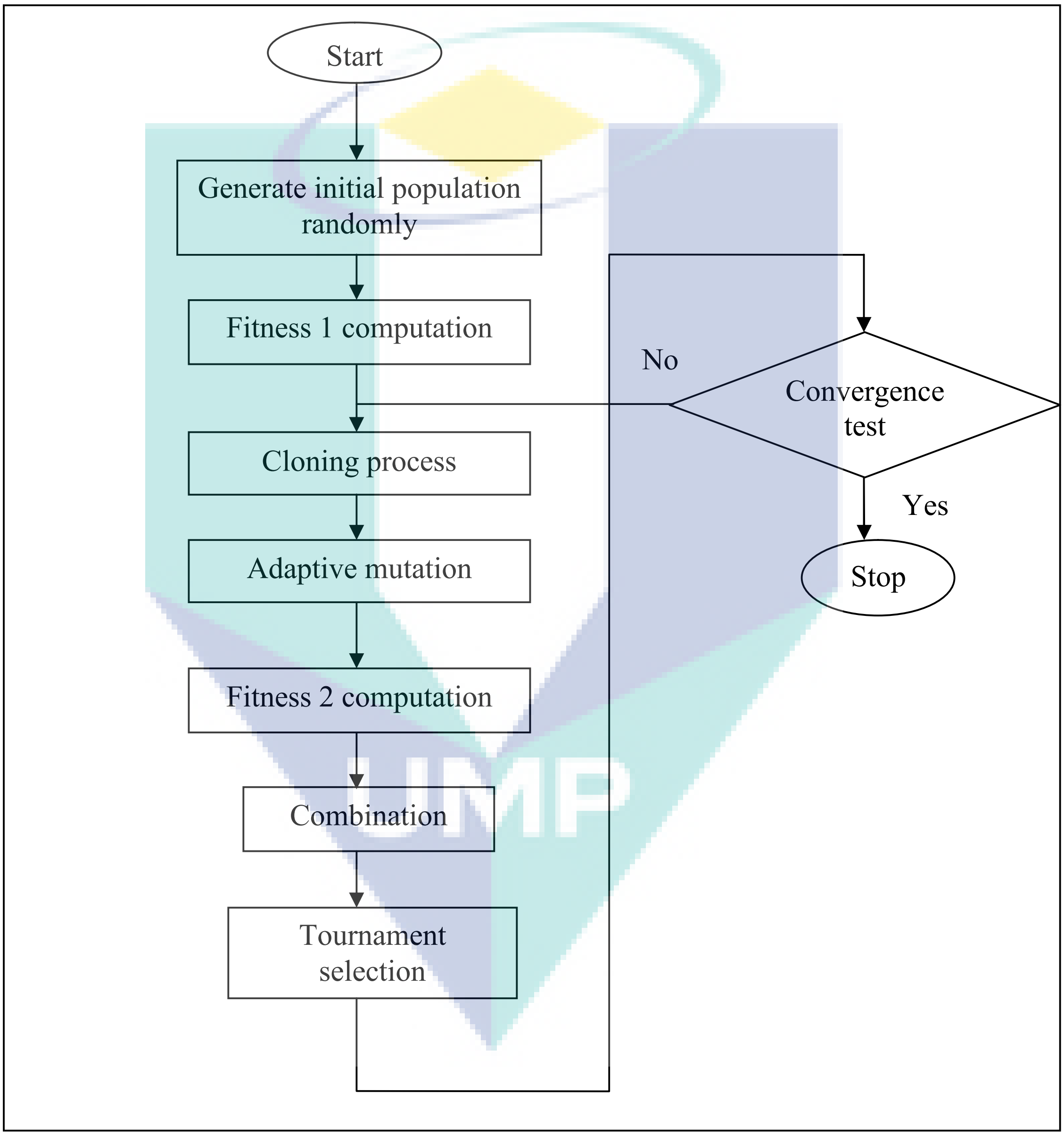

Figure 3.5: Flowchart of AECEP algorithm

3.7 TEST SYSTEMS

The application of location and sizing of DG was tested on radial distribution systems. Tests were performed on the IEEE 41-Bus and IEEE 69-Bus Radial Distribution System. This research deals with the steady-state analysis of an interconnected of DG in power system during normal operation. The system is assumed to be operating under balanced condition and is represented by a single-phase network.

3.7.1 IEEE 41 Bus Radial Distribution System

The technique proposed in the section 3.5 and 3.6 are tested with the IEEE 41 bus distribution system. This system is modified based on the system described in (Baran and Wu, 1989). The single line diagram of a simple 41 bus power system show as in (Minnan and Jin, 2011) . Table 3.1 is shows the parameters of the IEEE 41-Bus RDS in Appendix A1.

3.7.2 IEEE 69 Bus Radial Distribution System

Figure 3.6 shows the one-line diagram of a simple 69-Bus RDS. This system consists of 1 generator, 68 lines and 48 loads. Table 3.2 and Table 3.3 are shows the bus data and line data for IEEE 69-Bus RDS in Appendix A2 and A3.

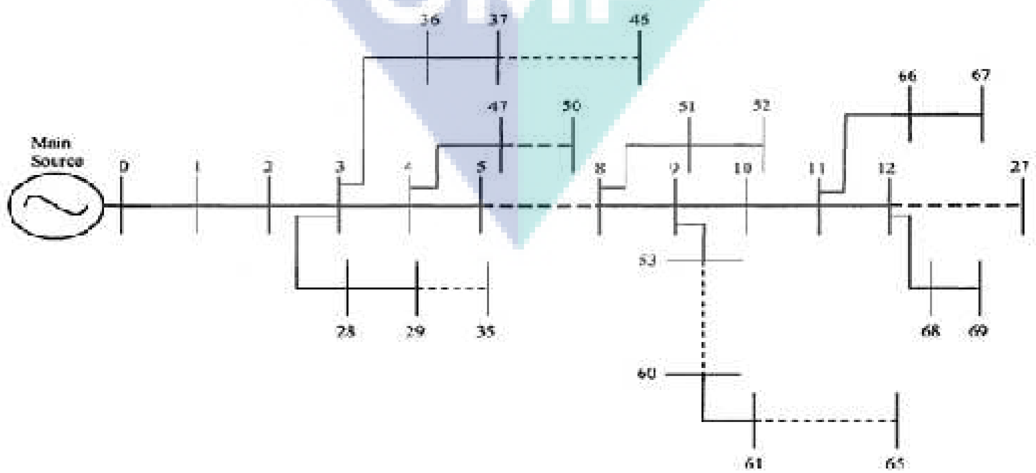

Figure 3.6: Single line diagram for IEEE 69-Bus RDS

3.8 SUMMARY

This chapter has presented the research methodology and development process. The first step taken to identify the DG location and sizing was using Heuristic Search Technique. Through this technique, the effect of system power losses and voltage condition were monitored with the presence DG in the system. The new developed AECEP technique which is applied in order to determine the optimal location and sizing of single, two and three DGs installation. The methodologies are discussed in terms of step by step procedures and also summarized in flowcharts. Then, the AI techniques as EP and AIS were taken place for the same purpose and also involving in the comparison study.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter presents the results and discussions of the DG installation in terms of system loss reduction and voltage profiles. To check the validity of the proposed technique, two sample radial distribution systems were tested. They are the IEEE 41-Bus and IEEE 69-Bus radial distribution system (RDS). Several loading conditions have been simulated for the system under steady state operation mode.

4.2 DG LOCATION AND SIZING BASED ON THE HEURISTIC SEARCH TECHNIQUE (HST)

In this section, DG location and sizing are determined based on Heuristic Search Technique (HST). Only the single DG has been applied in the test system. The purpose of this technique is to investigate the effect of installation DG in radial distribution system in terms of the performance of system losses and voltage profile.

Table 4.1 and Table 4.2 tabulate the results of loaded buses with the largest loads in the IEEE 41-Bus and IEEE 69-Bus RDS. There are seven buses with the largest load as tabulated in the table. The largest load that is the permissible load for the seven buses are tabulated in Table 4.1. From the table, it is observed that buses 23 and 24 have the highest active power demand, P_d. Thus, these buses would be the suitable location for DG installation.

Table 4.1: Loaded buses with the largest loads in IEEE 41-Bus RDS

Largest loaded buses	Active power demand, P_d (MW)	Reactive power demand, Q_d (MVar)
23	0.42	0.2
24	0.42	0.2
31	0.21	0.1
39	0.21	0.1
29	0.2	0.6
6	0.2	0.1
7	0.2	0.1

In IEEE 69-Bus RDS, bus 61 has the largest load of active power demand, P_d with 1.244MW as shown in Table 4.2. On the other hand, the smallest load of active power demand, P_d with 0.026MW has occurred at buses 28 and 29. That means, bus 61 will be selected as DG location based on its load and capability to receive the new backup power source.

Table 4.2: Loaded buses with the largest loads in IEEE 69-Bus RDS

Largest loaded buses	Active power demand, P_d (MW)	Reactive power demand, Q_d (MVar)
45	0.03922	0.0263
46	0.03922	0.0263
49	0.3847	0.2745
50	0.3847	0.2745
28	0.026	0.0186
29	0.026	0.0186
8	0.075	0.054
61	1.244	0.888
11	0.145	0.104
12	0.145	0.104

Results of single DG installation based on the HST in IEEE 41-Bus RDS when bus 14 was reactively loaded are tabulated in Table 4.3.

Table 4.3: Result of single DG installation based on HST in IEEE 41-Bus RDS (0.5MVar reactive loaded at bus 14)

DG location	DG sizing (%)	DG sizing (MW)	Loss Pre-DG (MW)	Loss Post-DG (MW)	Loss Reduction (%)	Voltage Pre-DG, V_{23} (p.u.)	Voltage Post-DG, V_{23} (p.u.)
23	20	0.084	1.479	1.469	0.68	0.951	0.952
23	40	0.168	1.479	1.458	1.42	0.951	0.954
23	60	0.252	1.479	1.448	2.09	0.951	0.956
23	80	0.336	1.479	1.438	2.77	0.951	0.957

Note: The percentage of DG sizing based on (%) of total load at the chosen bus.

In this case, bus 14 was selected as the loaded bus with 0.5MVar of reactive power loading. There are four samples of DG sizing that has been tested at the chosen loaded bus. The initial DG sizes are 20%, 40%, 60% and 80% of particular bus. From this table, the chosen bus for single DG installation is bus 23. The highest percentage of loss reduction is 2.77% with DG sizing of 0.336MW. The voltage, V_{23} after installing the DG shows the increment of 0.957 per unit (p.u.) compared to the voltage before installing the DG with 0.951 p.u.

Table 4.4 tabulates the results of single DG installation based on the HST in the IEEE 69 Bus RDS.

Table 4.4: Result of single DG installation based on HST in IEEE 69-Bus RDS (0.5MVar reactive loaded at bus 11)

DG location	DG sizing (%)	DG sizing (MW)	Loss Pre-DG (MW)	Loss Post-DG (MW)	Loss Reduction (%)	Voltage Pre-DG, V_{61} (p.u.)	Voltage Post-DG, V_{61} (p.u.)
61	20	0.2488	0.435	0.360	17.24	0.901	0.904
61	40	0.4976	0.435	0.299	31.26	0.901	0.907
61	60	0.7464	0.435	0.251	42.30	0.901	0.911
61	80	0.9952	0.435	0.215	50.57	0.901	0.915

Note: The percentage of DG sizing based on (%) of total load at the chosen bus.

Bus 11 was subjected to a reactive load of 0.5MVar. In this case, bus 61 was chosen for DG installation as determined in Table 4.2. In order to achieve the loss reduction and significant voltage improvement, the DG sizes are varied in stages i.e. 20%, 40%, 60% and 80% of total load have been tested at bus 61. These values are tabulated in the table as 0.2488MW, 0.4976MW, 0.7464MW and 0.9952MW. The highest percentage of loss reduction is 50.57% with the DG sizing of 0.9952MW. The voltage, V_{61} after installing the DG shows the increment of 0.904 p.u. as compared to voltage before installing the DG with 0.901 p.u.

Different size generation scenarios are applied to determine the voltage profile and loss reduction in the test system as shown in Table 4.3 and Table 4.4. Without active DG power injection, an expected voltage profile occurs such as the power flow through the system results in a smooth voltage drop. From the results, DG power injection helps to supply the local load, which reduces the flow from the source. When the injected power starts to increase, more loads are supplied locally further reducing the flow from the source. It is also observed that, loss is reduced as the DG sizing increased. The voltage after installed the DG also improved than before installed the DG.

4.3 SINGLE DG INSTALLATION FOR LOSS MINIMISATION IN DISTRIBUTION SYSTEM

In order to determine the optimal single DG location and size for loss minimization, three AI optimization techniques via the AECEP, EP and AIS were implemented. The following subsections present and discuss the corresponding simulation results. The simulations have been run for at least 5 times in order to observe the consistence of results. For the purpose of this thesis, only the best results are presented.

4.3.1 AECEP Based Technique for Single DG Installation

The developed AECEP technique was used to determine the optimal DG location and sizing. This section will discuss the AECEP based technique for single DG installation in distribution system. In general, the analysis is divided into two cases namely the IEEE 41-Bus RDS and 69-Bus RDS.

Case 1: AECEP Implementation in IEEE 41 Bus RDS for Single DG Installation

The results of single DG installation using AECEP technique in IEEE 41 Bus RDS are tabulated in Table 4.5. Two load buses were randomly chosen with their reactive power loading varied in order to observe the effect of load variations to total losses. The participating load buses are buses 23 and 31. Load at these buses was varied between 0.5MVar to 2.0MVar. From the table, the loss values reduce significantly with the installation of DG into the system. It can be seen that when 1.0MVar was subjected to bus 23, the highest percentage of loss reduction is achieved at 37.13%. The optimal DG location is bus 38 and its optimal DG sizing is 0.5455MW. The time taken for the AECEP to converge is 31.69 seconds. The voltage at this optimal bus after installing the DG shows the increment of 0.9032 per unit (p.u) compared to the voltage before installing the DG with 0.902 p.u.

Table 4.5: Single DG installation using AECEP technique when buses 23 and 31 are reactively loaded in IEEE 41-Bus RDS within 31.59 seconds

Loaded Bus	Reactive Loading (MVar)	Loss PreDG (MW)	Loss PostDG (MW)	Loss Red. (%)	Volt. PreDG (p.u)	Volt. PostDG (p.u)	Opt. Loc. (Bus)	Opt. Sizing (MW)
23	0.5	1.1088	0.9698	12.54	0.889	0.9001	37	0.5454
	1.0	1.1493	0.7226	37.13	0.902	0.9032	38	0.5455
	1.5	1.1965	0.7633	36.21	0.903	0.9117	39	0.5459
	2.0	1.2507	0.8105	35.20	0.904	0.9230	41	0.5461
31	0.5	1.2606	1.1384	9.69	0.910	0.9444	37	0.5454
	1.0	1.5815	1.0530	33.41	0.912	0.9651	34	0.3454
	1.5	2.0943	0.8961	57.21	0.925	0.9933	2	0.7667
	2.0	3.0966	2.1742	29.79	0.934	0.9980	28	0.8322

On the other hand, results show that the percentage of loss reduction is 57.21% at Q_{d31}=1.5MVar. The optimal DG location identified by AECEP is bus 2; while its optimal DG sizing is 0.7667MW. The voltage after installing DG also shows the increment compared to the voltage before installing the DG at all loading condition. This information can be used by power system operator to identify the suitable amount of DG to be installed based on choosing loading condition.

Case 2: AECEP Implementation in IEEE 69 Bus RDS for Single DG Installation

This section will discuss the implementation of AECEP in IEEE 69-Bus RDS. In this section, three load buses were chosen to perform the load variation in which total losses are supposed to be minimized. The participating load buses are buses 10, 35 and 65. The results of single DG installation using AECEP technique when buses 10, 35 and 65 were reactively loaded in IEEE 69-Bus RDS are tabulated in Table 4.6. The second column in table shows four reactive power loadings values subjected to the loaded buses. At Q_{d10} and Q_{d35} =0.5MVar, the losses are reduced with corresponding of percentage loss reduction of 8.69% and 8.91% respectively. The optimal DG location for Q_{d10} is bus 53 while its optimal DG sizing is 0.5248MW. While the optimal DG location for Q_{d35} is bus 50 and its optimal DG sizing is 0.4268MW. For loaded bus 65, the results observed that the highest percentage of loss reduction is 49.83% when the optimal DG location is bus 61 with optimal DG sizing of 0.5454MW and loading condition of 1.0MVar subjected to bus 65. The voltage also shows the better improvement after installing the DG at all loading condition. The time taken for the AECEP to converge is 47.38 seconds.

Table 4.6: Single DG installation using AECEP technique when buses 10, 35 and 65 are reactively loaded in the IEEE 69 Bus RDS within 47.38 seconds

Loaded Bus	Reactive Loading (MVar)	Loss PreDG (MW)	Loss PostDG (MW)	Loss Red. (%)	Volt. PreDG (p.u)	Volt. PostDG (p.u)	Opt. Loc. (Bus)	Opt. Sizing (MW)
10	0.5	0.4405	0.4022	8.69	0.945	0.9517	53	0.5248
	1	0.4837	0.4445	8.10	0.948	0.9548	21	0.2248
	1.5	0.5379	0.4975	7.51	0.951	0.9577	16	0.1644
	2	0.6034	0.5616	6.93	0.954	0.9606	43	0.6471
35	0.5	0.4221	0.3845	8.91	0.951	0.9623	50	0.4268
	1	0.4616	0.4240	8.15	0.952	0.9636	18	0.5247
	1.5	0.5291	0.4915	7.11	0.955	0.9645	48	0.3989
	2	0.6270	0.5894	6.00	0.957	0.9660	52	0.2451
65	0.5	0.5462	0.5043	7.67	0.899	0.9091	53	0.5274
	1.0	0.7815	0.3921	49.83	0.901	0.9125	61	0.5454
	1.5	1.1415	0.6156	46.07	0.912	0.9333	66	0.5465
	2.0	1.7127	0.9246	46.02	0.953	0.9589	17	0.3823

4.3.2 EP Based Technique for Single DG Installation

The next AI optimization technique used to determine the single optimal DG location and sizing is EP optimization technique. The first case study was tested and conducted on the IEEE 41-Bus RDS and following by IEEE 69-Bus RDS in the next section.

Case 1: EP Implementation in IEEE 41-Bus RDS for Single DG Installation

Table 4.7 tabulates the results of single DG installation using EP when buses 23 and 31 are reactively loaded in the IEEE 41 Bus RDS. At the loading condition, 1.0MVar at loaded buses 23, the optimal locations for DG to be installed are bus 20. The optimal sizing determined by EP for this case is 0.1652MW. With this DG installation, EP managed to reduce 10.00% losses from its original condition (before DG is installed). On the other hand, at Q_{d31}=0.5MVar, the highest of loss reduction is 37.35%. The optimal DG location was determined at bus 4 and its optimal DG sizing is 0.1684MW. The times taken for EP to converge to an optimal solution is within 33.78 seconds. The voltage also shows the better improvement after installing the DG at all loading condition.

Table 4.7: Single DG installation using EP technique when buses 23 and 31 are reactively loaded in IEEE 41 Bus RDS within 33.78 seconds

Loaded Bus	Reactive Loading (MVar)	Loss PreDG (MW)	Loss PostDG (MW)	Loss Red. (%)	Volt. PreDG (p.u)	Volt. PostDG (p.u)	Opt. Loc. (Bus)	Opt. Sizing (MW)
23	0.5	1.109	1.045	5.77	0.889	0.900	37	0.5903
	1.0	1.149	1.034	10.00	0.902	0.903	20	0.1652
	1.5	1.197	1.098	8.27	0.903	0.909	8	0.2869
	2.0	1.251	1.177	5.92	0.904	0.916	12	0.5947
31	0.5	1.261	0.79	37.35	0.910	0.926	4	0.1684
	1.0	1.581	1.03	34.85	0.912	0.943	17	0.7518
	1.5	2.094	1.40	33.14	0.925	0.977	25	0.6319
	2.0	3.097	2.15	30.58	0.934	0.985	28	0.8767

Case 2: EP Implementation in IEEE 69-Bus RDS for Single DG Installation

Table 4.8 tabulates the results of single DG installation using EP when buses 10, 35 and 65 were reactively loaded in the IEEE 69-Bus RDS. From the table, it is observed that the optimal DG location identified by EP is bus 43 while the sizing is 0.6471MW with the corresponding reactive power loading of 2.0MVar subjected to bus 10. It has also managed to reduce 11.11% total losses from its original values; optimized within 51.62 seconds.

Table 4.8: Single DG installation using EP technique when buses 10, 35 and 65 are reactively loaded in IEEE 69-Bus RDS within 51.62 seconds

Loaded Bus	Reactive Loading (MVar)	Loss PreDG (MW)	Loss PostDG (MW)	Loss Red. (%)	Volt. PreDG (p.u)	Volt. PostDG (p.u)	Opt. Loc. (Bus)	Opt. Sizing (MW)
10	0.5	0.440	0.40	9.09	0.945	0.9516	53	0.5248
	1.0	0.484	0.44	9.09	0.948	0.9545	21	0.2248
	1.5	0.538	0.50	7.06	0.951	0.9574	11	0.1644
	2.0	0.632	0.56	11.11	0.954	0.9603	43	0.6471
35	0.5	0.422	0.38	9.95	0.951	0.9620	50	0.4268
	1.0	0.462	0.42	9.09	0.952	0.9634	18	0.5247
	1.5	0.529	0.49	7.37	0.955	0.9640	48	0.3989
	2.0	0.627	0.59	5.90	0.957	0.9653	52	0.2451
65	0.5	0.546	0.50	8.42	0.899	0.9084	53	0.5274
	1.0	0.781	0.51	34.69	0.901	0.9113	61	0.5454
	1.5	1.141	0.62	45.66	0.912	0.9294	66	0.5465
	2.0	1.713	0.92	46.29	0.953	0.9527	17	0.3823

When loads variations are subjected to buses 35 and 65, the highest loss reduction are 9.95% and 46.29% with the optimal DG location at buses 50 and 17 respectively. The optimal DGs sizing are 0.4268MW and 0.3823MW respectively. For other loading conditions, similar trend can be noticed as shown in the table. It is shown that, with installation of DG in the system, the power losses for all loading conditions have reduced significantly and better improvement in voltage profile. The following sections will present the results for loss minimization implemented using AIS involving the same test systems.

4.3.3 AIS Based Technique for Single DG Installation

In this section, AIS based technique was used for single DG installation in distribution system in order to minimize the power losses.

Case 1: AIS Implementation in IEEE 41 Bus RDS for Single DG Installation

The results of single DG installation using AIS in IEEE 41-Bus RDS are tabulated in Table 4.9. Two load buses were randomly chosen with their reactive power loading varied in order to observe the effect of load variations to total losses. The participating load buses are buses 23 and 31. Load at these buses was varied between 0.5MVar to 2.0MVar.

Table 4.9: Single DG installation using AIS technique when buses 23 and 31 are reactively loaded in IEEE-41 Bus RDS within 35.17 seconds

Loaded Bus	Reactive Loading (MVar)	Loss PreDG (MW)	Loss PostDG (MW)	Loss Red. (%)	Volt. PreDG (p.u)	Volt. PostDG (p.u)	Opt. Loc. (Bus)	Opt. Sizing (MW)
23	0.5	1.1088	1.0476	5.52	0.889	0.897	37	0.5903
	1.0	1.1493	1.0871	5.41	0.902	0.902	20	0.1652
	1.5	1.1965	1.1332	5.29	0.903	0.904	8	0.2869
	2.0	1.2507	1.1861	5.17	0.904	0.911	12	0.5947
31	0.5	1.2606	1.1946	5.24	0.910	0.932	4	0.1684
	1.0	1.5815	1.5045	4.87	0.912	0.954	17	0.7518
	1.5	2.0943	1.9947	4.76	0.925	0.967	25	0.6319
	2.0	3.0966	2.2121	28.56	0.934	0.973	28	0.8767

At Q_{d23}=0.5MVar, bus 37 has been determined as the optimal DG location and while the optimal DG sizing is 0.5903MW identified using AIS. The percentage of loss reduction is 5.52% which is significantly high; optimized within 35.17 seconds. On the other hand, at Q_{d31}=2.0MVar, AIS managed to reduce 28.56% total losses. The optimal DG location is bus 28 and the optimal DG sizing is 0.8767MW. The voltage also shows the better improvement after installing the DG at all loading condition.

Case 2: AIS Implementation in IEEE 69 Bus RDS for Single DG Installation

In this section, the same tests were conducted on the IEEE 69-Bus RDS. Table 4.10 tabulates the results of single DG installation using AIS technique when buses 10, 35 and 65 are reactively loaded in the IEEE 69-Bus RDS. At Q_{d10}=1.0MVar, it is observed that the optimal DG location identified by AIS is bus 21 with its optimal DG sizing is 0.2248MW. The percentage loss reduction is significantly high, i.e. 0.08%. When Q_{d35}=2.0MVar, the optimal DG location is bus 52 with its optimal DG sizing is 0.2451MW. It has also managed to reduce 1.61% total losses from its original value. At Q_{d65}=2.0MVar, the highest of percentage loss is 5.86%. While the optimal DG location is bus 17 and its optimal DG sizing is 0.3823MW. The voltage also shows the better improvement after installing the DG at all loading condition. The time taken for AIS to converge is 55.44 seconds.

Table 4.10: Single DG installation using AIS technique when buses 10, 35 and 65 are reactively loaded in IEEE 69-Bus RDS within 55.44 seconds

Loaded Bus	Reactive Loading (MVar)	Loss PreDG (MW)	Loss PostDG (MW)	Loss Red. (%)	Volt. PreDG (p.u)	Volt. PostDG (p.u)	Opt. Loc. (Bus)	Opt. Sizing (MW)
10	0.5	0.4405	0.4404	0.02	0.945	0.9511	53	0.5248
	1.0	0.4840	0.4836	0.08	0.948	0.9537	21	0.2248
	1.5	0.5380	0.5378	0.04	0.951	0.9562	18	0.1644
	2.0	0.6034	0.6033	0.02	0.954	0.9601	43	0.6471
35	0.5	0.4221	0.4220	0.02	0.951	0.9619	50	0.4268
	1.0	0.4620	0.4615	0.11	0.952	0.9625	18	0.5247
	1.5	0.5291	0.5272	0.36	0.955	0.9637	48	0.3989
	2.0	0.6270	0.6169	1.61	0.957	0.9641	52	0.2451
65	0.5	0.5462	0.5361	1.85	0.899	0.9074	53	0.5274
	1.0	0.7815	0.7614	2.57	0.901	0.9109	61	0.5454
	1.5	1.1415	1.1014	3.51	0.912	0.9245	66	0.5465
	2.0	1.7130	1.6126	5.86	0.953	0.9388	17	0.3823

4.3.4 Comparative Studies for Single DG Installation

In this section, comparative studies were conducted with respect to the results obtained using AECEP, EP and AIS. Table 4.11 shows the results for comparison of single DG installation when bus 23 was subjected to load variations using the three techniques. Loss percentage, voltage profile improvement and computation time are important properties to be highlighted. From the table, it is observed that AECEP outperformed EP and AIS in terms of loss percentage, voltage profile improvement and computation time. At Q_{d23}=1.0MVar, the highest of loss reduction was determined by AECEP with 37.13% compared to EP and AIS were recorded the loss reduction by 10.00% and 5.41% respectively. With the same technique, the voltage also shows the better improvement after installing the DG with 0.9032 p.u as compare to 0.902 p.u before installing the DG. On the other hand, EP and AIS were recorded as 0.903 p.u and 0.902 p.u respectively. The last one important objective to be highlighted in this table is computation times that were achieved the optimal solution for these three techniques. According to the result, the AECEP again to be a winner in terms of less computation time as compared to EP and AIS technique. The AECEP was recorded 31.59 seconds, while EP and AIS were recorded 33.78 seconds and 35.17 seconds respectively. This is due to the fact that in the proposed AECEP technique, the combination between EP and AIS in hybrid form has helped to reduce computation time for optimal solution.

Table 4.12 tabulates the comparison results for single DG installation between AECEP, EP and AIS when bus 65 in the IEEE 69-Bus RDS was reactively loaded. At all reactive loading condition, similar trend can be noticed as previous table. From the table, the result from the AECEP has shows the better voltage profile improvement, highest of loss reduction and less computation time than EP and AIS. For instance, when bus 65 was reactively loaded with 1.0MVar, the voltage profile improvement show from AECEP with 0.9125 p.u, compared to EP and AIS with 0.9113 p.u and 0.9109 p.u respectively. The highest of loss reduction was achieved by implemented AECEP technique; 49.83%. While the EP and AIS were recorded as 34.69% and 2.57% respectively. In term of less computation time, AECEP also achieved the target when the optimal solution was determined at 47.38 seconds follow by EP; 51.62 seconds and AIS; 55.44 seconds.

Table 4.11: Comparison results for single DG between AECEP, EP and AIS when bus 23 in IEEE 41-Bus RDS was reactively loaded

PreDG			PostDG AECEP				PostDG EP				PostDG AIS			
Reactive Loading (MVar)	**Voltage (pu)**	**Loss (MW)**	**Voltage (pu)**	**Loss (MW)**	**Loss (%)**	**Comp. Time (sec)**	**Voltage (pu)**	**Loss (MW)**	**Loss (%)**	**Comp. Time (sec)**	**Voltage (pu)**	**Loss (MW)**	**Loss (%)**	**Comp. Time (sec)**
0.5	0.889	1.1088	0.9001	0.9698	12.54	31.59	0.900	1.045	5.77	33.78	0.897	1.0476	5.52	35.17
1.0	0.902	1.1493	0.9032	0.7226	37.13	31.59	0.903	1.034	10.00	33.78	0.902	1.0871	5.41	35.17
1.5	0.903	1.1965	0.9117	0.7633	36.21	31.59	0.909	1.098	8.27	33.78	0.904	1.1332	5.29	35.17
2.0	0.904	1.2507	0.9230	0.8105	35.20	31.59	0.916	1.177	5.92	33.78	0.911	1.1861	5.17	35.17

Table 4.12: Comparison results for single DG between AECEP, EP and AIS when bus 65 in IEEE 69-Bus RDS was reactively loaded

PreDG			PostDG AECEP				PostDG EP				PostDG AIS			
Reactive Loading (MVar)	**Voltage (pu)**	**Loss (MW)**	**Voltage (pu)**	**Loss (MW)**	**Loss (%)**	**Comp. Time (sec)**	**Voltage (pu)**	**Loss (MW)**	**Loss (%)**	**Comp. Time (sec)**	**Voltage (pu)**	**Loss (MW)**	**Loss (%)**	**Comp. Time (sec)**
0.5	0.899	0.5462	0.9091	0.5043	7.67	47.38	0.9084	0.50	8.42	51.62	0.9074	0.5361	1.85	55.44
1.0	0.901	0.7815	0.9125	0.3921	49.83	47.38	0.9113	0.51	34.69	51.62	0.9109	0.7614	2.57	55.44
1.5	0.912	1.1415	0.9333	0.6156	46.07	47.38	0.9294	0.62	45.66	51.62	0.9245	1.1014	3.51	55.44
2.0	0.953	1.7127	0.9589	0.9246	46.02	47.38	0.9527	0.92	46.29	51.62	0.9388	1.6126	5.86	55.44

4.4 TWO DGS INSTALLATION FOR LOSS MINIMISATION IN DISTRIBUTION SYSTEM

The next study was conducted for installation of two DGs in distribution system. Firstly, the AECEP technique was further utilized to determine the optimal locations and sizing with the loss minimization as the objective function. The following subsections present and discuss corresponding results determined by EP and AIS techniques.

4.4.1 AECEP Based Technique for Two DGs Installation

Case 1 will discuss the AECEP implementation in IEEE 41-Bus RDS for two DGs installation. Then, the same tests were conducted in IEEE 69-Bus RDS as the case 2.

Case 1: AECEP Implementation in IEEE 41 Bus RDS for Two DGs Installation

The results of two DGs installation when buses 23 and 31 are reactively loaded in the IEEE 41-Bus RDS are tabulated in Table 4.13. Buses 23 and 31 were subjected to variation of reactive power loading conditions. The reactive power loading is increased gradually in order to observe the effect of total losses with the installation of DG in the system. Similar loading conditions as previous tests were used to assess the proposed AECEP technique. Different reactive power loading shows different loss reduction. At Q_{d23} and Q_{d31}=2.0MVar, it is observed that the percentages of loss reduction are 53.49% and 49.73% respectively. The optimal DG locations for Q_{d23} are at buses 35 and 29, the optimal DGs sizing are 0.1471MW and 0.5146MW. While at $Q_{d31,}$ the optimal DG locations are at buses 35 and 29. The optimal DGs sizing are 0.4173MW and 0.5887MW. This is achieved within 40.21 seconds. The voltage also shows the better improvement after installing the DG at all loading condition.

Table 4.13: Two DGs installation using AECEP technique when buses 23 and 31 are reactively loaded in IEEE 41-Bus RDS within 40.21 seconds

Loaded Bus	Reactive Loading (MVar)	Volt. Pre-DG (pu)	Volt. Post-DG (pu	Loss Pre-DG (MW)	Loss Post-DG (MW)	Loss Red. (%)	1st Opt. Loc. DG	Opt. Sizing (MW)	2nd Opt. Loc. DG	Opt. Sizing (MW)
23	0.5	0.889	0.900	1.1088	0.6995	36.91	17	0.2771	38	0.5297
	1.0	0.902	0.913	1.1493	0.6538	43.11	21	0.2474	34	0.3287
	1.5	0.903	0.937	1.1965	0.6149	48.63	5	0.2875	27	0.3584
	2.0	0.904	0.956	1.2507	0.5817	53.49	9	0.1471	30	0.5146
31	0.5	0.910	0.935	1.2606	0.8087	35.85	10	0.2471	24	0.5297
	1.0	0.912	0.960	1.5815	1.0072	36.31	16	0.1751	38	0.5297
	1.5	0.925	0.972	2.0943	1.1362	45.75	13	0.2468	40	0.7223
	2.0	0.934	0.990	3.0966	1.5566	49.73	35	0.4173	29	0.5887

Case 2: AECEP Implementation in IEEE 69-Bus RDS for Two DGs Installation

The implementation of AECEP in IEEE 69-Bus RDS for two DGs installation was conducted as case 2. Table 4.14 tabulates the results of two DGs installation in IEEE 69-Bus RDS. Three loaded buses 10, 35 and 65 are reactively loaded from 0.5MVar up to 2.0MVar. It is observed that with increment of reactive loading, power loss will reduce accordingly. At maximum reactive power loading =2.0MVar at all loaded buses shows the highest value of percentage loss. For instance, at Q_{d10} the optimal DG locations determined by AECEP are buses 14 and 41 with their optimal DGs sizing of 0.4496MW and 0.1364MW respectively. The percentage of loss reduction shows the highest value i.e. 33.84%. On the other hand, at Q_{d35} the optimal DG locations are buses 48 and 8 while the optimal DGs sizing are 0.8743MW and 0.1452MW. The percentages of loss reduction also show the highest value i.e. 36.48%. At Q_{d65}, the optimal DG locations are buses 28 and 12 with their optimal DGs sizing of 0.5538MW and 1.059MW respectively. While, the percentages of loss reduction also show the highest value i.e. 35.97%.The voltage also shows the better improvement after installing the DG at all loading condition. The computation time taken to achieve the optimal solution for this technique is within 54.67 seconds.

Table 4.14: Two DGs installation using AECEP technique when buses 10, 35 and 65 are reactively loaded in IEEE 69-Bus RDS within 54.67 seconds

Loaded Bus	Reactive Loading (MVar)	Volt. Pre-DG (pu)	Volt. Post-DG (pu)	Loss Pre-DG (MW)	Loss Post-DG (MW)	Loss Red. (%)	1st Opt. Loc. DG	Opt. Sizing (MW)	2nd Opt. Loc. DG	Opt. Sizing (MW)
10	0.5	0.945	0.959	0.4405	0.3681	16.44	34	0.4752	20	0.7183
	1.0	0.948	0.967	0.4837	0.3767	22.12	29	0.7719	33	0.6158
	1.5	0.951	0.973	0.5379	0.3873	27.99	9	0.1364	13	0.4785
	2.0	0.954	0.982	0.6034	0.3992	33.84	14	0.4496	41	0.1364
35	0.5	0.952	0.973	0.4221	0.3773	10.61	16	0.4752	26	0.4652
	1.0	0.954	0.980	0.4616	0.3851	16.57	27	0.4752	20	0.7183
	1.5	0.956	0.982	0.5291	0.3520	33.47	59	0.8243	59	0.5385
	2.0	0.957	0.991	0.6270	0.3983	36.48	48	0.8743	8	0.1452
65	0.5	0.916	0.934	0.5462	0.4457	18.39	59	0.8243	64	0.5385
	1.0	0.924	0.945	0.7815	0.5371	31.27	51	0.1243	54	0.5385
	1.5	0.944	0.961	1.1415	0.8886	22.15	28	0.5538	66	1.059
	2.0	0.953	0.972	1.7127	1.0967	35.97	28	0.5538	12	1.059

4.4.2 EP Based Technique for Two DGs Installation in Distribution System

The second AI optimization technique namely EP technique was used to determine two DGs location and sizing in this section. Case 1 was conducted of EP implementation in IEEE 41-Bus RDS for two DGs installation.

Case 1: EP Implementation in IEEE 41-Bus RDS for Two DGs Installation

Table 4.15 tabulates the results of two DGs installation using EP when buses 23 and 31 are reactively loaded in IEEE 41-Bus RDS. In this case, these buses were subjected to load variation from 0.5MVar to 2.0MVar. It is also shown that, with the implementation of DG, the power losses of the system for all loading conditions have been decreased significantly. At Q_{d23}=2.0MVar, the highest percentage of loss reduction is 34.44% with the DG being installed at buses 35 and 8. The optimal DGs sizing are 0.3287MW and 0.8656MW. For loaded bus 31, with the same loading condition Q_{d31}=2.0MVar, the results show the optimal DGs location at buses 25 and 40. The optimal DGs sizing are 0.2412MW and 0.2213MW. However, the percentages of loss reduction are 34.12%. The voltage also shows the better improvement after installing the DG at all loading condition for both of loaded buses. This technique achieved within 42.89 seconds to determine the optimal solution.

Table 4.15: Two DGs installation using EP technique when buses 23 and 31 are reactively loaded in IEEE 41-Bus RDS within 42.89 seconds

Loaded Bus	Reactive Loading (MVar)	Volt. Pre-DG (pu)	Volt. Post-DG (pu	Loss Pre-DG (MW)	Loss Post-DG (MW)	Loss Red. (%)	1st Opt. Loc. DG	Opt. Sizing (MW)	2nd Opt. Loc. DG	Opt. Sizing (MW)
23	0.5	0.889	0.897	1.1088	0.76	31.46	21	0.5943	11	0.7632
	1.0	0.902	0.906	1.1493	0.78	32.13	6	0.6231	10	0.4652
	1.5	0.903	0.924	1.1965	0.80	33.14	15	0.2154	4	0.2541
	2.0	0.904	0.947	1.2507	0.82	34.44	35	0.3287	8	0.8656
31	0.5	0.910	0.930	1.2606	0.99	21.46	21	0.5943	11	0.7632
	1.0	0.912	0.941	1.5815	1.06	32.98	9	0.7691	28	0.6325
	1.5	0.925	0.956	2.0943	1.44	31.24	16	0.5362	36	0.3154
	2.0	0.934	0.977	3.0966	2.04	34.12	25	0.2412	40	0.2213

Case 2: EP Implementation in IEEE 69-Bus RDS for Two DGs Installation

Table 4.16 tabulates the results of two DGs installation optimized using EP with buses 10, 35 and 65 are being reactively loaded in IEEE 69-Bus RDS within 56.73 seconds. From the table, it is observed that the optimal DG locations are buses 14 and 41 with the DGs sizing of 0.2496MW and 0.2364MW respectively. The corresponding reactive power loading is 2.0MVar at loaded bus 10 to achieve optimal DGs location and sizing. The percentage of loss reduction is 31.48%. At Q_{d35}=2.0MVar, the optimal DGs location are buses 48 and 8 while the DGs sizing are 0.5743MW and 0.1452MW. The percentage of loss reduction is 35.67%. On the other hand, the percentages of loss reduction also showed the highest when load was increased to 2.0MVar at loaded bus 65. The optimal DGs location are buses 28 and 12 while the DGs sizing are 0.2538MW and 0.1548MW.The voltage also shows the better improvement after installing the DG at all loading condition.

Table 4.16: Two DGs installation using EP technique when buses 10, 35 and 65 are reactively loaded in IEEE 69-Bus RDS within 56.73 seconds

Loaded Bus	Reactive Loading (MVar)	Volt. Pre-DG (pu)	Volt. Post-DG (pu	Loss Pre-DG (MW)	Loss Post-DG (MW)	Loss Red. (%)	1st Opt. Loc. DG	Opt. Sizing (MW)	2nd Opt. Loc. DG	Opt. Sizing (MW)
10	0.5	0.945	0.957	0.4404	0.3872	12.08	34	0.4752	20	0.7183
	1.0	0.948	0.963	0.4837	0.3951	18.32	29	0.7719	33	0.6158
	1.5	0.951	0.967	0.538	0.4011	25.45	9	0.1364	13	0.4785
	2.0	0.954	0.971	0.6033	0.4134	31.48	14	0.2496	41	0.2364
35	0.5	0.952	0.959	0.422	0.3873	8.22	16	0.4752	26	0.4652
	1.0	0.954	0.960	0.462	0.3992	13.59	27	0.4752	20	0.7183
	1.5	0.956	0.969	0.529	0.3761	28.90	59	0.8243	59	0.5385
	2.0	0.957	0.973	0.627	0.4033	35.67	48	0.5743	8	0.1452
65	0.5	0.916	0.930	0.546	0.4675	14.38	59	0.8243	64	0.5385
	1.0	0.924	0.941	0.781	0.5517	29.36	51	0.1243	54	0.5385
	1.5	0.944	0.957	1.141	0.9876	13.44	28	0.5538	66	0.1354
	2.0	0.953	0.966	1.713	1.1212	34.55	28	0.2538	12	0.1548

Previous descriptions have presented the results and discussion for EP implementation to minimize loss involving two DGs installation. Tests were performed on IEEE 41 and 69 Bus RDS. EP was found to be able to reduce total losses significantly. The following section will present the results for loss minimization implemented using AIS involving the same test systems.

4.4.3 AIS Based Technique for Two DGs Installation in Distribution System

In this section, AIS based technique for two DGs installation in distribution system was conducted. Case 1 was discussed the result of AIS implementation in IEEE 41 Bus RDS for two DGs installation.

Case 1: AIS Implementation in IEEE 41 Bus RDS for Two DGs Installation

The results for two DGs installation using AIS when buses 23 and 31 are reactively loaded in IEEE 41 Bus RDS within 43.38 seconds are tabulated in Table 4.17. The highest percentage of loss reduction is 50.02% when two DGs location are installed at two optimal locations identified by AIS, i.e. buses 35 and 8. The optimal DGs sizing are 0.3287MW and 0.8656MW at Q_{d23}=2.0MVar. Similar trend for optimal DGs location and sizing can be noticed at loaded bus 31. However, the percentage of loss reduction is 35.81% while the optimal DG locations are buses 35 and 29. The optimal DGs sizing are 0.4173MW and 0.5887MW respectively. The voltage also shows the better improvement after installing the DG at all loading condition.

Table 4.17: Two DGs installation using AIS technique when buses 23 and 31 are reactively loaded in IEEE 41-Bus RDS within 43.38 seconds

Loaded Bus	Reactive Loading (MVar)	Volt. Pre-DG (pu)	Volt. Post-DG (pu	Loss Pre-DG (MW)	Loss Post-DG (MW)	Loss Red. (%)	1st Opt. Loc. DG	Opt. Sizing (MW)	2nd Opt. Loc. DG	Opt. Sizing (MW)
23	0.5	0.889	0.895	1.1088	0.7421	33.07	21	0.5943	11	0.7632
	1.0	0.902	0.912	1.1493	0.7076	38.43	6	0.6231	10	0.4652
	1.5	0.903	0.933	1.1965	0.6580	45.00	15	0.2154	4	0.2541
	2.0	0.904	0.945	1.2507	0.6251	50.02	35	0.3287	8	0.8656
31	0.5	0.910	0.929	1.2606	0.9457	24.98	10	0.2471	24	0.5297
	1.0	0.912	0.958	1.5815	1.0329	34.69	16	0.1751	38	0.5297
	1.5	0.925	0.963	2.0945	1.3994	33.19	13	0.2468	40	0.7223
	2.0	0.934	0.984	3.0966	1.9877	35.81	35	0.4173	29	0.5887

Case 2: AIS Implementation in IEEE 69-Bus RDS for Two DGs Installation

Table 4.18 tabulates the results of two DGs installation using AIS when buses 10, 35 and 65 are reactively loaded in IEEE 69-Bus RDS. From the table, the loss values reduce significantly with the installation of DG into the system. It can be seen that at reactive power loading in bus 10, i.e. Q_{d10}=2.0MVar; the loss is reduced from 0.6034MW to 0.4002MW with corresponding loss reduction of 33.66%. The optimal DG locations are buses 14 and 41, while their optimal DGs sizing are 0.4496MW and 0.1364MW.

Table 4.18: Two DGs installation using AIS technique when buses 10, 35 and 65 are reactively loaded in IEEE 69-Bus RDS within 57.81 seconds

Loaded Bus	Reactive Loading (MVar)	Volt. Pre-DG (pu)	Volt. Post-DG (pu	Loss Pre-DG (MW)	Loss Post-DG (MW)	Loss Red. (%)	1st Opt. Loc. DG	Opt. Sizing (MW)	2nd Opt. Loc. DG	Opt. Sizing (MW)
10	0.5	0.945	0.965	0.4405	0.3772	14.37	34	0.4752	20	0.7183
	1.0	0.948	0.960	0.4837	0.3844	20.53	29	0.7719	33	0.6158
	1.5	0.951	0.953	0.5379	0.3913	27.27	9	0.1364	13	0.4785
	2.0	0.954	0.946	0.6034	0.4002	33.66	14	0.4496	41	0.1364
35	0.5	0.952	0.964	0.4221	0.3721	11.82	16	0.4752	26	0.4652
	1.0	0.954	0.972	0.4616	0.3842	16.84	27	0.4752	20	0.7183
	1.5	0.956	0.979	0.5291	0.3655	30.91	59	0.8243	59	0.5385
	2.0	0.957	0.984	0.6270	0.4129	34.15	48	0.8743	8	0.1452
65	0.5	0.916	0.929	0.5462	0.4712	13.69	59	0.8243	64	0.5385
	1.0	0.924	0.937	0.7815	0.5448	30.24	51	0.1243	54	0.5385
	1.5	0.944	0.944	1.1410	0.9097	20.27	28	0.5538	66	0.1529
	2.0	0.953	0.953	1.7127	1.1435	33.24	28	0.5538	12	0.3059

At Q_{d35} and Q_{d65}=2.0MVar, the losses are reduced with corresponding of percentage loss reduction of 34.15% and 33.24% respectively. At Q_{d35}, the optimal DG locations are buses 48 and 8 while their optimal DGs sizing are 0.8743MW and 0.1452MW.

On the other hand, at Q_{d65}; the optimal DG locations are buses 28 and 12 while their optimal DGs sizing are 0.5538MW and 0.3059MW. The time taken for the AIS to converge is 57.81 seconds. The voltage also shows the better improvement after installing the DG at all loading condition.

4.4.4 Comparative Studies for Two DGs Installation

The comparison of results for two DGs installation among AECEP, EP and AIS are tabulated in Table 4.19. Bus 23 in the IEEE 41-Bus RDS was subjected to variation of loading condition. Loss percentage, voltage profile improvement and computation time are important properties to be highlighted. From the table, it is observed that AECEP outperformed EP and AIS in terms of loss percentage, voltage profile improvement and computation time. At Q_{d23}=2.0MVar, the highest of loss reduction was determined by AECEP with 53.49% compared to EP and AIS were recorded the loss reduction by 34.44% and 50.02% respectively. With the same technique, the voltage also shows the better improvement after installing the DG with 0.956 p.u as compare to 0.904 p.u before installing the DG. On the other hand, EP and AIS were recorded as 0.947 p.u and 0.945 p.u respectively. The last one important objective to be highlighted in this table is computation times that were achieved the optimal solution for these three techniques. According to the result, the AECEP again to be a winner in terms of less computation time as compared to EP and AIS technique. The AECEP was recorded 40.21 seconds, while EP and AIS were recorded 42.89 seconds and 43.38 seconds respectively. This is due to the fact that in the proposed AECEP technique, the combination between EP and AIS in hybrid form has helped to reduce computation time for optimal solution.

Table 4.20 tabulates the comparison results for two DG installation between AECEP, EP and AIS when bus 65 in the IEEE 69-Bus RDS was reactively loaded. At all reactive loading condition, similar trend can be noticed as previous table. From the table, the result from the AECEP has shows the better voltage profile improvement, highest of loss reduction and less computation time than EP and AIS. For instance, when bus 65 was reactively loaded with 2.0MVar, the voltage profile improvement show from AECEP with 0.972 p.u, compared to EP and AIS with 0.966 p.u and 0.953 p.u respectively. The highest of loss reduction was achieved by implemented AECEP technique; 35.97%. While the EP and AIS were recorded as 34.55% and 33.24% respectively. In term of less computation time, AECEP also achieved the target when the optimal solution was determined at 54.67 seconds follow by EP; 56.73 seconds and AIS; 57.81seconds.

Table 4.19: Comparison results for two DGs installation between AECEP, EP and AIS when bus 23 in IEEE 41-Bus RDS was reactively loaded.

PreDG			PostDG AECEP				PostDG EP				PostDG AIS			
Reactive Loading (MVar)	**Voltage (pu)**	**Loss (MW)**	**Voltage (pu)**	**Loss (MW)**	**Loss (%)**	**Comp. Time (sec)**	**Voltage (pu)**	**Loss (MW)**	**Loss (%)**	**Comp. Time (sec)**	**Voltage (pu)**	**Loss (MW)**	**Loss (%)**	**Comp. Time (sec)**
0.5	0.889	1.1088	0.900	0.6995	36.91	40.21	0.897	0.76	31.46	42.89	0.895	0.7421	33.07	43.38
1.0	0.902	1.1493	0.913	0.6538	43.11	40.21	0.906	0.78	32.13	42.89	0.912	0.7076	38.43	43.38
1.5	0.903	1.1965	0.937	0.6146	48.63	40.21	0.924	0.80	33.14	42.89	0.933	0.6580	45.00	43.38
2.0	0.904	1.2507	0.956	0.5817	53.49	40.21	0.947	0.82	34.44	42.89	0.945	0.6251	50.02	43.38

Table 4.20: Comparison results for two DGs installation between AECEP, EP and AIS when bus 65 in IEEE 69-Bus RDS was reactively loaded.

PreDG			PostDG AECEP				PostDG EP				PostDG AIS			
Reactive Loading (MVar)	**Voltage (pu)**	**Loss (MW)**	**Voltage (pu)**	**Loss (MW)**	**Loss (%)**	**Comp. Time (sec)**	**Voltage (pu)**	**Loss (MW)**	**Loss (%)**	**Comp. Time (sec)**	**Voltage (pu)**	**Loss (MW)**	**Loss (%)**	**Comp. Time (sec)**
0.5	0.916	0.5462	0.934	0.4457	18.39	54.67	0.930	0.4675	14.38	56.73	0.929	0.4712	13.69	57.81
1.0	0.924	0.7815	0.945	0.5371	31.27	54.67	0.941	0.5517	29.36	56.73	0.937	0.5448	30.24	57.81
1.5	0.944	1.1415	0.961	0.8886	22.15	54.67	0.957	0.9876	13.44	56.73	0.944	0.9097	20.27	57.81
2.0	0.953	1.7127	0.972	1.0967	35.97	54.67	0.966	1.1212	34.55	56.73	0.953	1.1435	33.24	57.81

4.5 THREE DGS INSTALLATION FOR LOSS MINIMISATION IN DISTRIBUTION SYSTEM

This section presents the results of three DGs installation for loss minimization in distribution system. The AECEP, EP and AIS technique were implemented in order to determine the optimal DG locations and sizing.

4.5.1 AECEP Based Technique for Three DGs Installation in Distribution System

First, the AECEP based technique for three DGs installation in distribution was tested on IEEE 41-Bus RDS in case 1. Then, the same tests were tested on IEEE 69-Bus RDS in case 2. All the results and discussion were present in this section.

Case 1: AECEP Implementation in IEEE 41-Bus RDS for Three DGs Installation

Table 4.21 tabulates the results of three DGs installation using AECEP when buses 23 and 31 are reactively loaded in IEEE 41-Bus RDS. At Q_{d23}= 2.0MVar, buses 10, 18 and 35 are identified by AECEP as the optimal location for DG installation. The optimal sizings for these buses are 0.3674MW, 0.2336MW and 0.3502MW. The percentage of loss reduction of 37.93% is considered significantly high. The voltage at these optimal buses after installing the DG shows the increment of 0.919 p.u compared to the voltage before installing the DG; 0.889 p.u.

On the other hand, when Q_{d31}=2.0MVar; the optimal DG locations and sizing shows at buses 12, 21 and 30. On the other hand, the percentage of loss reduction is 25.80%. The optimal DGs sizing for these buses are 0.5365MW, 0.2378MW and 0.3593MW. The voltage also shows the better improvement after installing the DG at all loading condition. In order to achieve the optimal solution, this technique required 42.67 seconds.

Case 2: AECEP Implementation in IEEE 69-Bus RDS for Three DGs Installation

The results for the implementations of AECEP for three DGs installation in IEEE 69-Bus RDS are tabulated in Table 4.22. In order to determine the optimal locations and sizing of DG, three loaded bus as buses 10, 35 and 65 were subjected to load variation.

From the table, it is observed that the optimal DG locations are buses 16, 39 and 55 while the optimal DGs sizing are 0.538MW, 0.114MW and 0.531MW respectively. These values are meant for 2.0MVar subjected to bus 10. The percentage of loss reduction also shows the highest value of 24.64%. The voltage after installed the DG increased from 0.954 p.u to 0.977 p.u compare to voltage before installed the DGs.

At Q_{d35} =2.0MVar, the optimal DG locations determined by AECEP are buses 27, 50 and 61 with their optimal DGs sizing are 0.398MW, 0.256MW and 0.175MW respectively. The voltage also shows the better improvement after installing the DG at all loading condition. This also manages to reduce total losses of 31.61%. When 2.0MVar of reactive load was injected to loaded bus 65, the highest of loss reduction was showed at 45.64%. The optimal DG locations are determined at buses 21, 51 and 64 while the optimal DGs sizing are 0.324MW, 0.475MW and 0.282MW. The voltage also shows the increment after installing the DGs; from 0.953 p.u to 0.977 p.u. In term of computation time, AECEP achieved the target when the optimal solution was determined at 55.13 seconds.

Table 4.21: Three DGs installation using AECEP when buses 23 and 31 are reactively loaded in IEEE 41-Bus RDS within 42.67 seconds

Loaded Bus		23				31			
Reactive Loading	**(MVar)**	0.5	1.0	1.5	2.0	0.5	1.0	1.5	2.0
Voltage	**Pre-DG(pu)**	0.889	0.902	0.903	0.904	0.910	0.912	0.925	0.935
	Post-DG(pu)	0.919	0.922	0.934	0.948	0.933	0.957	0.964	0.982
Loss	**Pre-DG (MW)**	1.1088	1.1493	1.1965	1.2507	1.2606	1.5815	2.0943	3.0966
	Post-DG (MW)	0.8109	0.8168	0.8492	0.7763	1.0945	1.2043	1.5936	2.2978
Loss Red.	**(%)**	26.87	28.93	29.03	37.93	13.18	23.85	23.91	25.80
1st Optimal	**Location**	9	7	16	10	5	11	19	12
	Sizing (MW)	0.2663	0.5263	0.2876	0.3674	0.3665	0.6285	0.4693	0.5365
2nd Optimal	**Location**	21	14	21	18	21	26	35	21
	Sizing (MW)	0.2376	0.2316	0.2146	0.2336	0.1378	0.2318	0.2375	0.2378
3rd Optimal	**Location**	13	22	33	35	13	34	39	30
	Sizing (MW)	0.3592	0.3542	0.3592	0.3502	0.2593	0.3543	0.2978	0.3593

Table 4.22: Three DGs installation using AECEP when buses 10, 35 and 65 are reactively loaded in IEEE 69-Bus RDS within 55.13 seconds

Loaded Bus		10				35				65			
Reactive Loading	**(MVar)**	0.5	1.0	1.5	2.0	0.5	1.0	1.5	2.0	0.5	1.0	1.5	2.0
Voltage	**Pre-DG(pu)**	0.945	0.948	0.951	0.954	0.952	0.954	0.956	0.957	0.916	0.924	0.944	0.953
	Post-DG(pu)	0.953	0.965	0.970	0.977	0.968	0.974	0.978	0.989	0.937	0.955	0.968	0.977
Loss	**Pre-DG (MW)**	0.4405	0.4837	0.5379	0.6034	0.4221	0.4616	0.5291	0.627	0.5462	0.7815	1.1415	1.7127
	Post-DG (MW)	0.3389	0.3801	0.4319	0.4547	0.3217	0.3591	0.4231	0.4288	0.4313	0.6377	0.8724	0.9311
Loss Red.	**(%)**	23.06	21.42	19.71	24.64	23.79	22.21	20.03	31.61	21.04	18.40	23.57	45.64
1st Optimal	**Location**	8	9	12	16	6	14	24	27	14	17	12	21
	Sizing (MW)	0.538	0.285	0.531	0.538	0.139	0.537	0.417	0.398	0.156	0.581	0.523	0.324
2nd Optimal	**Location**	34	20	26	39	17	35	43	50	34	29	24	51
	Sizing (MW)	0.174	0.056	0.074	0.114	0.163	0.207	0.264	0.256	0.264	0.356	0.475	0.475
3rd Optimal	**Location**	33	29	48	55	28	49	55	61	46	50	64	64
	Sizing (MW)	0.574	0.237	0.574	0.531	0.574	0.518	0.504	0.175	0.374	0.442	0.182	0.282

4.5.2 EP Based Technique for Three DGs Installation in Distribution System.

In order to determine the optimal DG location and sizing, EP based technique for three DGs installation in distribution system was implemented as the optimisation technique and the results were present in this section.

Case 1: EP Implementation in IEEE 41 Bus RDS for Three DGs Installation

Table 4.23 tabulates the results of three DGs installation using EP when buses 23 and 31 are reactively loaded in IEEE 41 Bus RDS within 43.29 seconds. At Q_{d23}= 2.0MVar, buses 17, 32 and 21 are identified by EP as the optimal location for DG installation. The optimal DGs sizing for these buses are 0.3552MW, 0.5943MW and 0.1346MW. The percentage of loss reduction is 25.15% while the voltage also increased from 0.904 p.u to 0.936 p.u. On the other hand, when Q_{d31}=2.0MVar; the percentage of loss reduction is 25.10%. The voltage profile increased when the load increased. It observed that the voltage after installing the DG is improved than before non-installing the DG in the system. The optimal DG locations are identified by EP are buses 9, 18 and 25. While the DGs sizing are 0.4752MW, 0.5495MW and 0.1183MW.

Case 2: EP Implementation in IEEE 69 Bus RDS for Three DGs Installation

The results for the implementations of EP for three DGs installation in IEEE 69 Bus RDS are tabulated in Table 4.24 within 57.44 seconds. From the table, it is observed that the optimal DG locations are buses 16, 39 and 55 while the optimal DGs sizing are 0.538MW, 0.214MW and 0.331MW respectively. These values are meant for 2.0MVar subjected to bus 10. The percentage of loss reduction shows the highest value at 18.01%. At Q_{d35} and Q_{d65}=2.0MVar, the percentage of loss reduction also shows the highest value; 25.52% and 44.11%. The optimal DG locations determined by EP for Q_{d35} are buses 27, 50 and 61 with their optimal sizing are 0.338MW, 0.256MW and 0.165MW respectively. On the other hand, at Q_{d65}; the optimal DG locations determined are buses 21, 51 and 64 with their optimal sizing are 0.324MW, 0.445MW and 0.276MW

Table 4.23: Three DGs installation using EP when buses 23 and 31 are reactively loaded in IEEE 41-Bus RDS within 43.29 seconds

Loaded Bus		23				31			
Reactive Loading	**(MVar)**	0.5	1.0	1.5	2.0	0.5	1.0	1.5	2.0
Voltage	**Pre-DG(pu)**	0.889	0.902	0.903	0.904	0.910	0.912	0.925	0.934
	Post-DG(pu)	0.916	0.920	0.928	0.936	0.930	0.949	0.957	0.977
Loss	**Pre-DG (MW)**	1.1088	1.1493	1.1965	1.2507	1.2606	1.5815	2.0943	3.0966
	Post-DG (MW)	0.8902	0.8842	0.9035	0.9361	1.1255	1.2836	1.6809	2.3194
Loss Red.	**(%)**	19.72	23.07	24.48	25.15	10.72	18.84	19.74	25.10
1st Optimal	**Location**	10	10	15	17	19	15	19	9
	Sizing (MW)	0.4752	0.4452	0.4752	0.3552	0.4752	0.4152	0.3712	0.4752
2nd Optimal	**Location**	32	32	29	32	32	27	32	18
	Sizing (MW)	0.5495	0.2495	0.5491	0.5943	0.5495	0.3595	0.2895	0.5495
3rd Optimal	**Location**	21	21	35	21	21	21	21	25
	Sizing (MW)	0.1183	0.3183	0.2536	0.1346	0.1183	0.3183	0.2598	0.1183

Table 4.24: Three DGs installation using EP when buses 10, 35 and 65 are reactively loaded in IEEE 69-Bus RDS within 57.44 seconds

Loaded Bus		10				35				65			
Reactive Loading	**(MVar)**	0.5	1.0	1.5	2.0	0.5	1.0	1.5	2.0	0.5	1.0	1.5	2.0
Voltage	**Pre-DG(pu)**	0.945	0.948	0.951	0.954	0.952	0.954	0.956	0.957	0.916	0.924	0.944	0.953
	Post-DG(pu)	0.950	0.962	0.969	0.972	0.956	0.963	0.969	0.971	0.925	0.939	0.951	0.962
Loss	**Pre-DG (MW)**	0.4404	0.4837	0.5378	0.6034	0.4221	0.4616	0.5291	0.627	0.5462	0.7815	1.1415	1.7127
	Post-DG (MW)	0.3612	0.4105	0.4497	0.4947	0.3472	0.3619	0.3966	0.4607	0.4407	0.6501	0.8934	0.9572
Loss Red.	**(%)**	17.98	15.13	16.38	18.01	17.74	21.59	25.04	26.52	19.32	16.81	21.73	44.11
1st Optimal	**Location**	8	10	12	16	6	14	24	27	14	17	12	21
	Sizing (MW)	0.538	0.245	0.531	0.538	0.139	0.537	0.417	0.338	0.156	0.581	0.523	0.324
2nd Optimal	**Location**	34	20	26	39	17	35	43	50	34	29	24	51
	Sizing (MW)	0.174	0.156	0.124	0.214	0.163	0.207	0.264	0.256	0.264	0.356	0.475	0.445
3rd Optimal	**Location**	33	29	48	55	28	49	55	61	46	50	64	64
	Sizing (MW)	0.574	0.237	0.574	0.331	0.574	0.518	0.504	0.165	0.374	0.442	0.182	0.276

4.5.3 AIS Based Technique for Three DGs Installation in Distribution System.

The next AI optimization technique was implemented to determine three DGs were installed in IEEE 41-Bus RDS and 69-Bus RDS is AIS. The results of simulation were present and discuss in this section.

Case 1: AIS Implementation in IEEE 41-Bus RDS for Three DGs Installation

The results of three DGs installation when buses 23 and 31 are reactively loaded in the IEEE 41-Bus RDS are tabulated in Table 4.25. The reactive power loading is increased gradually in order to observe the effect of total losses with the installation of DG in the system. Similar loading conditions as previous tests were used to assess AIS technique. Different reactive power loading shows different loss reduction. At Q_{d23} and Q_{d31}=2.0MVar, it is observed that the percentages of loss reduction are 24.47% and 24.83% respectively. The optimal DG locations at Q_{d23} are buses 7, 37 and 16 and the optimal DGs sizing are 0.3834MW, 0.5042MW and 0.3421MW. While at Q_{d31}, the optimal DG locations are buses 17, 28 and 34; the optimal DGs sizing are 0.5231MW, 0.1394MW and 0.1632MW. These results are achieved within 45.88 seconds.

Case 2: AIS Implementation in IEEE 69-Bus RDS for Three DGs Installation

The implementation of AIS in IEEE 69-Bus RDS for three DGs installation was conducted as case 2. Table 4.26 tabulates the results of three DGs installation in IEEE 69-Bus RDS. Three loaded buses 10, 35 and 65 are reactively loaded from 0.5MVar up to 2.0MVar. It is observed that with increment of reactive loading, power loss will reduce accordingly. At maximum reactive power loading 2.0MVar, all three loaded buses shows the highest percentage of loss reduction at 22.42%, 29.47% and 44.71% respectively. The optimal DG locations at Q_{d10} are buses 16, 40 and 55 with the optimal DGs sizing of 0.538MW, 0.214MW and 0.331MW respectively. On the other hand, at Q_{d65}, the optimal DG locations are buses 28, 48 and 61 while the optimal DGs sizing are 0.338MW, 0.256MW and 0.165MW. However, the optimal DG locations are shows at buses 21, 51 and 64 while the optimal DGs sizing are 0.324MW, 0.445MW and 0.276MW according to loaded bus 65.

Table 4.25: Three DGs installation using AIS when buses 23 and 31 are reactively loaded in IEEE 41-Bus RDS within 45.88 seconds

Loaded Bus		23				31			
Reactive Loading	**(MVar)**	0.5	1.0	1.5	2.0	0.5	1.0	1.5	2.0
Voltage	**Pre-DG(pu)**	0.889	0.902	0.903	0.904	0.910	0.912	0.925	0.934
	Post-DG(pu)	0.907	0.910	0.925	0.934	0.930	0.945	0.951	0.968
Loss	**Pre-DG (MW)**	1.1088	1.1493	1.1965	1.2507	1.2606	1.5815	2.0943	3.0966
	Post-DG (MW)	0.9772	0.8954	0.9182	0.9447	1.1305	1.3081	1.6932	2.3277
Loss Red.	**(%)**	11.87	22.09	23.25	24.47	10.32	17.29	19.15	24.83
1^{st} Optimal	**Location**	35	15	14	7	6	8	10	17
	Sizing (MW)	0.2834	0.1834	0.5105	0.3834	0.2648	0.5464	0.6013	0.5231
2^{nd} Optimal	**Location**	18	28	39	37	18	14	21	28
	Sizing (MW)	0.4194	0.2194	0.3648	0.5042	0.2361	0.2541	0.3124	0.1394
3^{rd} Optimal	**Location**	20	10	20	16	33	29	35	34
	Sizing (MW)	0.2365	0.3192	0.1670	0.3421	0.5142	0.3452	0.1092	0.1632

Table 4.26: Three DGs installation using AIS when buses 10, 35 and 65 are reactively loaded in IEEE 69-Bus RDS within 58.10 seconds

Loaded Bus		10				35				65			
Reactive Loading	**(MVar)**	0.5	1	1.5	2	0.5	1	1.5	2	0.5	1	1.5	2
Voltage	**Pre-DG(pu)**	0.945	0.948	0.951	0.954	0.952	0.954	0.956	0.957	0.916	0.924	0.944	0.953
	Post-DG(pu)	0.949	0.953	0.961	0.970	0.963	0.964	0.972	0.980	0.931	0.947	0.958	0.970
Loss	**Pre-DG (MW)**	0.4405	0.4837	0.5379	0.6034	0.4221	0.4616	0.5291	0.627	0.5462	0.7815	1.1415	1.7127
	Post-DG (MW)	0.3747	0.3912	0.4454	0.4681	0.3350	0.3677	0.4314	0.4422	0.4472	0.6437	0.8811	0.9468
Loss Red.	**(%)**	14.94	19.12	17.18	22.42	20.63	20.34	18.46	29.47	18.12	17.63	22.81	44.71
1st Optimal	**Location**	8	10	12	16	6	14	24	28	14	18	11	21
	Sizing (MW)	0.538	0.245	0.531	0.538	0.139	0.537	0.417	0.338	0.156	0.581	0.523	0.324
2nd Optimal	**Location**	34	21	27	40	18	36	45	48	34	29	21	51
	Sizing (MW)	0.174	0.156	0.124	0.214	0.163	0.207	0.264	0.256	0.264	0.356	0.475	0.445
3rd Optimal	**Location**	33	29	48	55	28	49	55	61	46	50	64	64
	Sizing (MW)	0.574	0.237	0.574	0.331	0.574	0.518	0.504	0.165	0.374	0.442	0.182	0.276

4.5.4 Comparative Studies for Three DGs Installation

The comparison of results for three DGs installation among AECEP, EP and AIS are tabulated in Table 4.27. Bus 23 in the IEEE 41-Bus RDS was subjected to variation of loading condition. Loss percentage, voltage profile improvement and computation time are important properties to be highlighted. From the table, it is observed that AECEP outperformed EP and AIS in terms of loss percentage, voltage profile improvement and computation time. At Q_{d23}=2.0MVar, the highest of loss reduction was determined by AECEP with 37.93% compared to EP and AIS were recorded the loss reduction by 25.15% and 24.47% respectively. With the same technique, the voltage also shows the better improvement after installing the DG with 0.948 p.u as compare to 0.904 p.u before installing the DG. On the other hand, EP and AIS were recorded as 0.936 p.u and 0.934 p.u respectively. The last one important objective to be highlighted in this table is computation times that were achieved the optimal solution for these three techniques. According to the result, the AECEP again to be a winner in terms of less computation time as compared to EP and AIS technique. The AECEP was recorded 42.67 seconds, while EP and AIS were recorded 43.29 seconds and 45.88 seconds respectively. This is due to the fact that in the proposed AECEP technique, the combination between EP and AIS in hybrid form has helped to reduce computation time for optimal solution.

Table 4.28 tabulates the comparison results for three DG installation between AECEP, EP and AIS when bus 65 in the IEEE 69-Bus RDS was reactively loaded. At all reactive loading condition, similar trend can be noticed as previous table. From the table, the result from the AECEP has shows the better voltage profile improvement, highest of loss reduction and less computation time than EP and AIS. For instance, when bus 65 was reactively loaded with 2.0MVar, the voltage profile improvement show from AECEP with 0.977 p.u, compared to EP and AIS with 0.962 p.u and 0.970 p.u respectively. The highest of loss reduction was achieved by implemented AECEP technique; 45.64%. While the EP and AIS were recorded as 44.11% and 44.71% respectively. In term of less computation time, AECEP also achieved the target when the optimal solution was determined at 55.13 seconds follow by EP; 57.44 seconds and AIS ; 58.10 seconds.

Table 4.27: Comparison results for three DGs installation between AECEP, EP and AIS when bus 23 in EEE 41-Bus RDS was reactively loaded.

PreDG			PostDG AECEP				PostDG EP				PostDG AIS			
Reactive Loading (MVar)	Voltage (pu)	Loss (MW)	Voltage (pu)	Loss (MW)	Loss (%)	Comp. Time (sec)	Voltage (pu)	Loss (MW)	Loss (%)	Comp. Time (sec)	Voltage (pu)	Loss (MW)	Loss (%)	Comp. Time (sec)
0.5	0.889	1.1088	0.919	0.8109	26.87	42.67	0.916	0.8902	19.72	43.29	0.907	0.9772	11.87	45.88
1.0	0.902	1.1493	0.922	0.8168	28.93	42.67	0.920	0.8842	23.07	43.29	0.910	0.8954	22.09	45.88
1.5	0.903	1.1965	0.934	0.8492	29.03	42.67	0.928	0.9035	24.48	43.29	0.925	0.9182	23.25	45.88
2.0	0.904	1.2507	0.948	0.7763	37.93	42.67	0.936	0.9361	25.15	43.29	0.934	0.9447	24.47	45.88

Table 4.28: Comparison results for three DGs installation between AECEP, EP and AIS when bus 65 in IEEE 69-Bus RDS was reactively loaded.

PreDG			PostDG AECEP				PostDG EP				PostDG AIS			
Reactive Loading (MVar)	Voltage (pu)	Loss (MW)	Voltage (pu)	Loss (MW)	Loss (%)	Comp. Time (sec)	Voltage (pu)	Loss (MW)	Loss (%)	Comp. Time (sec)	Voltage (pu)	Loss (MW)	Loss (%)	Comp. Time (sec)
0.5	0.937	0.5462	0.916	0.4313	21.04	55.13	0.925	0.4407	19.32	57.44	0.931	0.4472	18.12	58.10
1.0	0.955	0.7815	0.924	0.6377	18.40	55.13	0.939	0.6501	16.81	57.44	0.947	0.6437	17.63	58.10
1.5	0.968	1.1415	0.944	0.8724	23.57	55.13	0.951	0.8934	21.73	57.44	0.958	0.8811	22.81	58.10
2.0	0.977	1.7127	0.953	0.9311	45.64	55.13	0.962	0.9572	44.11	57.44	0.970	0.9468	44.71	58.10

4.6 Effect of Number of DG Installation in the Distribution System

The results for the effect of number of DG installation in the distribution system are discussed in details in this section. Numerous experiments were conducted to the system, as to realize the effect of number of DG installation adequate to converge to a solution with minimize solution. The results are shows in the comparison table for the proposed AECEP technique only.

Table 4.29 shows the results for effect of number of DG installation when bus 23 was reactively loaded using AECEP technique in IEEE 41-Bus RDS. From the table, when the system was installed with two DG units, the loss shows the good reduction compared to one and three DG units installation. The percentage of loss reduction is achieved at highest; 53.49% when the reactive loading condition is up to 2.0MVar. The voltage profile also shows the better improvement with the increment of load variations. The voltage is within the acceptable limit which is 0.956 p.u. In order to achieve the optimal solution for this case, 40.21 seconds are required to run the AECEP engine. These results observed that the most suitable number of DG unit to install in the IEEE 41 Bus RDS is two DGs unit.

The different scenarios can be seen in Table 4.30. This table shows the results for effect of number of DG installation when bus 65 was reactively loaded using AECEP technique in IEEE 69-Bus RDS. The highest of loss percentage can be found when single DG unit are installed into the system. At Q_{d65}=1.0MVar, the highest of loss percentage was recorded as 49.83%. On the other hand, the voltage profile has improved after installing the DG within the acceptable value; 0.9125 p.u. In addition, less computation time are recorded as 47.38 seconds in order to determine the optimal solution for location and sizing of DG. This results show that the single DG unit is most suitable to install into the system IEEE 69 Bus RDS according to the highest potential in terms of highest of loss percentage, voltage profile improvement and less computation time.

Table 4.29: Results for the effect of number of DG installation when bus 23 was reactively loaded using AECEP technique in IEEE 41-Bus RDS

Reactive Loading (MVar)	1 DG			2 DG			3 DG		
	Loss (%)	Voltage (pu)	Comp. Time (sec)	Loss (%)	Voltage (pu)	Comp. Time (sec)	Loss (%)	Voltage (pu)	Comp. Time (sec)
0.5	12.54	0.9001	31.59	36.91	0.900	40.21	26.87	0.919	42.67
1.0	37.13	0.9032	31.59	43.11	0.913	40.21	28.93	0.922	42.67
1.5	36.21	0.9117	31.59	48.63	0.937	40.21	29.03	0.934	42.67
2.0	35.20	0.9230	31.59	53.49	0.956	40.21	37.93	0.948	42.67

Table 4.30: Results for the effect of number of DG installation when bus 65 was reactively loaded using AECEP technique in IEEE 69-Bus RDS

Reactive Loading (MVar)	1 DG			2 DG			3 DG		
	Loss (%)	Voltage (pu)	Comp. Time (sec)	Loss (%)	Voltage (pu)	Comp. Time (sec)	Loss (%)	Voltage (pu)	Comp. Time (sec)
0.5	7.67	0.9091	47.38	18.39	0.934	54.67	21.04	0.916	55.13
1.0	49.83	0.9125	47.38	31.27	0.945	54.67	18.40	0.924	55.13
1.5	46.07	0.9333	47.38	22.15	0.961	54.67	23.57	0.944	55.13
2.0	46.02	0.9589	47.38	35.97	0.972	54.67	45.64	0.953	55.13

4.7 Summary

A significant study in order to determine the optimal DG location and sizing was presented in this chapter. The first section in this chapter presents the HST to investigate the effect of DG installation in distribution system. The important effects to be highlighted in the results are the system loss and voltage profile after single DG installation into the system. From the results, it is observed that the installation the DG into the system with the suitable location and sizing are developing into the positive impact to the system.

The next section was continue with the proposed AECEP technique has been implemented in order to determine single, two and three DGs installation. This technique has been successfully tested on the IEEE 41 and 69 Bus RDS. Then, EP and AIS have also been implemented for the same purpose. The simulations have been run for at least five times in order to observe the consistent of results. For the purpose of this study, only the best results are presented. The comparative studies were also conducted for each technique that has been tested. From the comparison results, it is discovered that AECEP, EP and AIS performed well in most cases. In terms of loss minimization, voltage profile improvement and less computation time, simulation results demonstrated that the proposed AECEP technique is feasible for all terms.

The last section is presented the effect of number of DG installation in the distribution system. The results are shows in the comparison table for the proposed AECEP technique only. After a numerous experiments were conducted to the system, it is discovered that the most suitable number of DG to be installed for IEEE 41 Bus RDS in order to minimize losses and voltage profile improvement is two DGs unit. On the other hand, for IEEE 41 Bus RDS the most suitable number of DG to be installed is single DG unit. However, the both results are shows good indicator to engineer planner to realize the effect of number of DG installation adequate to converge to a solution with minimize solution.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

This thesis has presented the study on Adaptive Embedded Clonal Evolutionary Programming termed as AECEP. In the beginning of this study, a conventional method based on Heuristic Search Technique (HST) was presented in order to determine the location and sizing of DG. The algorithm of DG location and sizing was developed and combine together in one programme. In order to avoid exhaustive computation time, the location for DG installation was chosen at the heavily loaded bus. The sizing of DG was chosen in stages from 20%, 40%, 60% and 80% of total load demands at the chosen load bus. The results revealed that the installation of DG into the RDS with suitable location and sizing managed to reduce system losses and voltage profile improvement. However, this technique is only effective for small test system while for large test system, the fast optimization technique is required. For large test system a very exhaustive number of experiments are required to conduct various DG installations with numerous sizing. This is conducted as the pilot study in order to see the variation of DG sizing to loss reduction in the distribution system.

Consequently, Adaptive Embedded Clonal Evolutionary Programming (AECEP) technique was developed to determine the optimal location and sizing of DG in distribution system. AECEP is developed by incorporating cloning process into the original EP algorithm with the adaptive element being embedded together. The adaptive element is search step, β; where this factor has also been considered as one of control of AECEP to achieve optimal solution. This algorithm was derived to avoid the weakness experienced in the original EP and AIS. The proposed AECEP algorithm was utilized to perform single DG installation, two DG installations and three DG installations. The implementation of AECEP on all these DG installations considers loss minimization as the objective function. Concurrently, voltage at all buses and computation time are also monitored.

In order to evaluate its performance in terms of ability to minimize loss, voltage profile improvement and fast computation time; comparative studies are conducted with respect to original EP and AIS. Results from the comparative study indicated that the implementation of AECEP is superior to EP and AIS in terms of loss reduction, voltage profile improvement within comparatively short computation time.

Evaluation on the effect of number of DG installation in the distribution system was subsequently conducted. In order to investigate the effectiveness of the proposed AECEP technique, the results are shows in the comparison table for bus 23 in IEEE 41 Bus RDS and bus 65 in IEEE 69 Bus RDS. The results for both IEEE bus systems are different; it is because of effect of logistic of loaded buses in the systems. The variations of reactive load also manage to reduce the loss and improve the voltage profile.

Overall, this thesis has fulfilled it's intend objectives to develop a new technique for determining the optimal location and sizing of DG namely AECEP and also implemented it in EP and AIS technique for the comparison purpose. As conclusion, the proposed AECEP was successfully implemented as the optimal solution for optimizing DG location and sizing. The results revealed that the AECEP has performed better in terms of loss minimization and voltage profile improvement. This technique also required less computation time to determine the optimal solution compared with EP and AIS technique. Simultaneously, AECEP was avoiding the computational burden that was experience to conventional technique.

5.2 RECOMMENDATIONS FOR THE FUTURE WORK

For the future work, it is suggested to apply this technique to other different field in power system. For example, include the DG operation under power system protection control. Optimization function can also be extended to include other objectives such as cost of generations and this can be tested with different optimization techniques like Particle Swarm Optimization (PSO) and other computational intelligence techniques. Apparently, the analysis only considered the static stability condition of a system and not focused on the type of DG technologies. Therefore, in future work it is recommended that further research should be undertaken for evaluating the dynamic voltage stability condition that directly involves the dynamic properties of the system and considering type of DG technologies.

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APPENDIX A1

Table 3.5: Parameters of the IEEE 41 Bus RDS

Line Index	To Bus Index	From Bus Index	Line Resistance, R (ohm)	Line Reactance, X (ohm)	Load Active Power, P_d (kW)	Load Reactive Power, Q_d (kVAR)
1	1	2	0.0992	0.0470	100	60
2	2	3	0.4930	0.2511	90	40
3	3	4	0.3660	0.1864	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.8190	0.7070	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	0.7114	0.2351	200	100
8	8	9	1.0300	0.7400	60	20
9	9	10	1.0440	0.7400	60	20
10	10	11	0.1966	0.0650	45	30
11	11	12	0.3744	0.1238	60	35
12	12	13	1.4680	1.1550	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.5910	0.5260	60	10
15	15	16	0.7463	0.5450	60	20
16	16	17	1.2890	1.7210	60	20
17	17	18	0.7320	0.5470	90	40
18	18	19	0.1640	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	22	23	0.4512	0.3083	90	50
23	23	24	0.8980	0.7091	420	200
24	24	25	0.8960	0.7011	420	200
25	25	26	0.2030	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.0590	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.9630	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.3410	0.5302	60	40
33	33	34	0.2030	0.1034	60	25
34	34	35	0.2842	0.1447	60	25
35	35	36	1.0590	0.9337	60	20
36	36	37	0.8042	0.7006	120	70
37	37	38	0.5075	0.2585	200	600
38	38	39	0.9744	0.9630	150	70
39	39	40	0.3105	0.3619	210	100
40	40	41	0.3410	0.5302	60	40

APPENDIX A2

Table 3.6: Bus data for IEEE 69 bus radial distribution system

Bus No	Bus Code	Vm (p.u)	Angle	Pd (MW)	Qd (Mvar)	Pg (MW)	Qg (Mvar)	Qmin (Mvar)	Qmax (Mvar)	Qsh (Mvar)
1	1	1.0000	0.0000	0	0	0	0	0	0	0
2	0	1.0000	0.0000	0	0	0	0	0	0	0
3	0	1.0000	0.0000	0	0	0	0	0	0	0
4	0	1.0000	0.0000	0	0	0	0	0	0	0
5	0	1.0000	0.0000	0	0	0	0	0	0	0
6	0	1.0000	0.0000	0.0026	0.0022	0	0	0	0	0
7	0	1.0000	0.0000	0.0404	0.03	0	0	0	0	0
8	0	1.0000	0.0000	0.075	0.054	0	0	0	0	0
9	0	1.0000	0.0000	0.03	0.022	0	0	0	0	0
10	0	1.0000	0.0000	0.028	0.019	0	0	0	0	0
11	0	1.0000	0.0000	0.145	0.104	0	0	0	0	0
12	0	1.0000	0.0000	0.145	0.104	0	0	0	0	0
13	0	1.0000	0.0000	0.008	0.0055	0	0	0	0	0
14	0	1.0000	0.0000	0.008	0.0055	0	0	0	0	0
15	0	1.0000	0.0000	0	0	0	0	0	0	0
16	0	1.0000	0.0000	0.0455	0.03	0	0	0	0	0
17	0	1.0000	0.0000	0.06	0.035	0	0	0	0	0
18	0	1.0000	0.0000	0.06	0.035	0	0	0	0	0
19	0	1.0000	0.0000	0	0	0	0	0	0	0
20	0	1.0000	0.0000	0.001	0.0006	0	0	0	0	0
21	0	1.0000	0.0000	0.114	0.081	0	0	0	0	0
22	0	1.0000	0.0000	0.0053	0.0035	0	0	0	0	0
23	0	1.0000	0.0000	0	0	0	0	0	0	0
24	0	1.0000	0.0000	0.028	0.02	0	0	0	0	0
25	0	1.0000	0.0000	0	0	0	0	0	0	0
26	0	1.0000	0.0000	0.014	0.01	0	0	0	0	0
27	0	1.0000	0.0000	0.014	0.01	0	0	0	0	0
28	0	1.0000	0.0000	0.026	0.0186	0	0	0	0	0
29	0	1.0000	0.0000	0.026	0.0186	0	0	0	0	0
30	0	1.0000	0.0000	0	0	0	0	0	0	0
31	0	1.0000	0.0000	0	0	0	0	0	0	0
32	0	1.0000	0.0000	0	0	0	0	0	0	0
33	0	1.0000	0.0000	0.014	0.01	0	0	0	0	0
34	0	1.0000	0.0000	0.0195	0.014	0	0	0	0	0
35	0	1.0000	0.0000	0.006	0.004	0	0	0	0	0
36	0	1.0000	0.0000	0.026	0.01855	0	0	0	0	0
37	0	1.0000	0.0000	0.026	0.01855	0	0	0	0	0
38	0	1.0000	0.0000	0	0	0	0	0	0	0
39	0	1.0000	0.0000	0.024	0.017	0	0	0	0	0
40	0	1.0000	0.0000	0.024	0.017	0	0	0	0	0
41	0	1.0000	0.0000	0.0012	0.001	0	0	0	0	0
42	0	1.0000	0.0000	0	0	0	0	0	0	0
43	0	1.0000	0.0000	0.006	0.0043	0	0	0	0	0
44	0	1.0000	0.0000	0	0	0	0	0	0	0
45	0	1.0000	0.0000	0.03922	0.0263	0	0	0	0	0
46	0	1.0000	0.0000	0.03922	0.0263	0	0	0	0	0
47	0	1.0000	0.0000	0	0	0	0	0	0	0
48	0	1.0000	0.0000	0.079	0.0564	0	0	0	0	0

49	0	1.0000	0.0000	0.3847	0.2745	0	0	0	0	0
50	0	1.0000	0.0000	0.3847	0.2745	0	0	0	0	0
51	0	1.0000	0.0000	0.0405	0.0283	0	0	0	0	0
52	0	1.0000	0.0000	0.0036	0.0027	0	0	0	0	0
53	0	1.0000	0.0000	0.00435	0.0035	0	0	0	0	0
54	0	1.0000	0.0000	0.0264	0.019	0	0	0	0	0
55	0	1.0000	0.0000	0.024	0.0172	0	0	0	0	0
56	0	1.0000	0.0000	0	0	0	0	0	0	0
57	0	1.0000	0.0000	0	0	0	0	0	0	0
58	0	1.0000	0.0000	0	0	0	0	0	0	0
59	0	1.0000	0.0000	0.1	0.072	0	0	0	0	0
60	0	1.0000	0.0000	0	0	0	0	0	0	0
61	0	1.0000	0.0000	1.244	0.888	0	0	0	0	0
62	0	1.0000	0.0000	0.032	0.023	0	0	0	0	0
63	0	1.0000	0.0000	0	0	0	0	0	0	0
64	0	1.0000	0.0000	0.227	0.162	0	0	0	0	0
65	0	1.0000	0.0000	0.059	0.042	0	0	0	0	0
66	0	1.0000	0.0000	0.018	0.013	0	0	0	0	0
67	0	1.0000	0.0000	0.018	0.013	0	0	0	0	0
68	0	1.0000	0.0000	0.028	0.02	0	0	0	0	0
69	0	1.0000	0.0000	0.028	0.02	0	0	0	0	0

APPENDIX A3

Table 3.7: Line data for IEEE 69 bus radial distribution system

Line No	From bus	To Bus	R (p.u)	X (p.u)	½ B (p.u)	Tr-tap
1	1	2	0.0005	0.0012	0	1
2	2	3	0.0005	0.0012	0	1
3	3	4	0.0015	0.0036	0	1
4	4	5	0.0251	0.0294	0	1
5	5	6	0.366	0.1864	0	1
6	6	7	0.3811	0.1941	0	1
7	7	8	0.0922	0.047	0	1
8	8	9	0.0493	0.0251	0	1
9	9	10	0.819	0.2707	0	1
10	10	11	0.1872	0.0619	0	1
11	11	12	0.7114	0.2351	0	1
12	12	13	1.03	0.34	0	1
13	13	14	1.044	0.345	0	1
14	14	15	1.058	0.3496	0	1
15	15	16	0.1966	0.065	0	1
16	16	17	0.3744	0.1238	0	1
17	17	18	0.0047	0.0016	0	1
18	18	19	0.3276	0.1083	0	1
19	19	20	0.2106	0.0696	0	1
20	20	21	0.3416	0.1129	0	1
21	21	22	0.014	0.0046	0	1
22	22	23	0.1591	0.0526	0	1
23	23	24	0.3463	0.1145	0	1
24	24	25	0.7488	0.2475	0	1
25	25	26	0.3089	0.1021	0	1
26	26	27	0.1732	0.0572	0	1
27	3	28	0.0044	0.0108	0	1
28	28	29	0.064	0.1565	0	1
29	29	30	0.3978	0.1315	0	1
30	30	31	0.0702	0.0232	0	1
31	31	32	0.351	0.116	0	1
32	32	33	0.839	0.2816	0	1
33	33	34	1.708	0.5646	0	1
34	34	35	1.474	0.4873	0	1
35	3	36	0.0044	0.0108	0	1
36	36	37	0.064	0.1565	0	1
37	37	38	0.1053	0.123	0	1
38	38	39	0.0304	0.0355	0	1
39	39	40	0.0018	0.0021	0	1
40	40	41	0.7283	0.8509	0	1
41	41	42	0.31	0.3623	0	1
42	42	43	0.041	0.0478	0	1
43	43	44	0.0092	0.0116	0	1
44	44	45	0.1089	0.1373	0	1

45	45	46	0.0009	0.0012	0	1
46	4	47	0.0034	0.0084	0	1
47	47	48	0.0851	0.2083	0	1
48	48	49	0.2898	0.7091	0	1
49	49	50	0.0822	0.2011	0	1
50	8	51	0.0928	0.0473	0	1
51	51	52	0.3319	0.1114	0	1
52	9	53	0.174	0.0886	0	1
53	53	54	0.203	0.1034	0	1
54	54	55	0.2842	0.1447	0	1
55	55	56	0.2813	0.1433	0	1
56	56	57	1.59	0.5337	0	1
57	57	58	0.7837	0.263	0	1
58	58	59	0.3042	0.1006	0	1
59	59	60	0.3861	0.1172	0	1
60	60	61	0.5075	0.2585	0	1
61	61	62	0.0974	0.0496	0	1
62	62	63	0.145	0.0738	0	1
63	63	64	0.7105	0.3619	0	1
64	64	65	1.041	0.5302	0	1
65	11	66	0.2012	0.0611	0	1
66	66	67	0.0047	0.0014	0	1
67	12	68	0.7394	0.2444	0	1
68	68	69	0.0047	0.0016	0	1