OPTIMAL PLACEMENT AND SIZING OF DISTRIBUTED GENERATION CONSIDERING COSTS OF OPERATION PLANNING

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A report submitted in partial fulfilment of the requirements for the Bachelor of Electrical Engineering (Industrial Power)

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

"I hereby declare that I have read through this report entitle "Optimal Placement and Sizing of Distributed Generation Considering Costs of Operation Planning" and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)."

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Date :

I declare that this report entitles "Optimal Placement and Sizing of Distributed Generation Considering Costs of Operation Planning" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : Loo Soon Lii

Date :

Dedicated to my beloved Parents, my siblings

Lecturers and all my friends

For their love and sacrifice.

ACKNOWLEDGEMENT

In the name of God, the most gracious, the most merciful, with the highest praise to God that I manage to complete this final year project successfully without difficulty.

My respected supervisor, Dr. Aida Fazliana Binti Abdul Kadir for the great mentoring that was given to me throughout the project. She has provided guidance, motivation, encouragement, patience and advice during this period.

Last but not least, I would like to thank for my fellow seniors and friends who taught and guide me about the final year project. They have taught me a lot knowledge and have also tried their best to teach me as much as possible to enable me to accomplish this degree project. Their cooperation is greatly appreciated.

Finally, appreciation is also extended to the committee who always provide me a lot of useful information about the final year project on how and what to do during the semester.

ABSTRACT

Distributed Generation (DG) can be defined as power generation at the distribution site or on-site generation. DG technology has been growing rapidly in industries as this technology can increase the overall efficiency to the power systems. The optimal placement and sizing of DG is vital as it significantly affects the distribution system. Improper placement and sizing can lead to power losses and interrupt the voltage profile of distribution systems. Studies have been done to solve the DG placement and sizing problem considering various factors and one of the common factor is minimising the power losses. However, it is not adequate by only considering the power losses, whereas, the costs of the generation, investment, maintenance and losses of the distribution system must be taken in consideration. Otherwise, it will create disadvantages after the installation of DG such as the system with DG is generating the same amount of energy but higher costs or losses compared to the conventional generation. In this research, DG chosen to be study is Photovoltaic (PV) type which are Monocrystalline and Thin-film. Costs of operation planning with respect to the power losses is considered which include the costs of investment, maintenance, power loss and generation are determine for optimal placement and sizing of DG. Proposed method algorithm Improved Gravitational Search Algorithm (IGSA) is used in the MATLAB environment to find the optimal placement and sizing of DG and is tested with the IEEE 34-bus system and IEEE 69-bus system. The performance of IGSA is then compared with Gravitational Search Algorithm (GSA) and Particle Swarm Optimisation (PSO) to find out which algorithm gives the best fitness value and convergence rate. Both Monocrystalline PV and Thin-film PV are compared based on the results obtained. The purpose of this report is to identify the operation planning cost based on the optimisation results and improves the optimal placement and sizing of DG in future, in order to provide maximum economical, technical, environmental benefits and increase the overall efficiency to the power system.

ABSTRAK

Penjana teragih (PT) boleh ditakrifkan sebagai penjanaan kuasa pada sistem pengagihan. Teknologi PT telah berkembang pesat dalam industri dan teknologi ini boleh meningkatkan kecekapan keseluruhan pada rangkaian sistem kuasa. Penempatan dan saiz PT yang optimum adalah penting kerana ia memberi kesan ketara kepada sistem pengagihan. Penempatan dan saiz yang tidak betul boleh membawa kepada kehilangan kuasa dan mengganggu profil voltan sistem pengagihan. Kajian telah dilakukan untuk menyelesaikan masalah penempatan dan saiz PT berdasarkan pelbagai faktor dan salah satu faktor yang biasa digunakan ialah meminimumkan kehilangan kuasa pada sistem pengagihan. Tetapi, ia adalah tidak mencukupi dengan hanya mempertimbangkan kehilangan kuasa, malahan, kos penjanaan, pelaburan, penyelenggaraan dan kerugian oleh sistem pengagihan perlu diambil kira dalam pertimbangan. Jika tidak, ia akan mewujudkan kelemahan selepas pemasangan PT seperti sistem dengan PT menjana jumlah tenaga yang sama tetapi kos atau kerugian adalah lebih tinggi berbanding dengan penjanaan konvensional. Dalam kajian ini, PT yang dipilih adalah jenis Fotovolta (FV) iaitu Monocrystalline dan *thin-film*. Kos perancangan operasi berkenaan dengan kehilangan kuasa dalam sistem dipertimbangkan termasuk kos pelaburan, penyelenggaraan, kehilangan kuasa dan penjanaan yang menentukan untuk penempatan dan saiz PT yang optimum. Kaedah cadangan iaitu Algoritma Carian Graviti Diperbaiki (ACGD) digunakan dalam MATLAB untuk mencari penempatan dan saiz PT yang optimum dan diuji dengan sistem 34-bas IEEE dan sistem 69-bas IEEE. Prestasi ACGD kemudiannya dibandingkan dengan Algoritma Carian Graviti (ACG) dan Pengoptimuman Kuruman Zarah (PKZ) untuk memperolehi objektif dan kadar penumpuan terbaik. Kedua-dua FV Monocrystalline dan FV *thin-film* dibandingkan berdasarkan keputusan yang diperolehi. Tujuan laporan ini adalah untuk mengenal pasti kos perancangan operasi berdasarkan keputusan pengoptimuman dan menambahbaikkan penempatan dan saiz PT yang optimum pada masa depan, untuk memberi kesan ekonomi, teknikal, faedah alam sekitar yang maksimum dan meningkatkan kecekapan keseluruhan sistem kuasa.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

DG	-	Distributed Generation
PV	-	Photovoltaic
Mono	-	Monocrystalline
Poly	-	Polycrystalline
TF	-	Thin-film
PSO	-	Particle Swarm Optimisation
GSA	-	Gravitational Search Algorithm
IGSA	-	Improved Gravitational Search Algorithm
C_P	-	Costs of Operation Planning
C_I	-	Investment Cost
C_M	-	Maintenance Cost
C_L	-	Power Loss Cost
C_{DG}	-	Generation Cost
IEEE	-	Institute of Electrical and Electronics Engineers
SEDA	-	Sustainable Energy Department Authority
FiT	-	Feed-in Tariff
BOS	-	Balanced of System

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

In this modern era, electricity demand is increasing due to the economic growth. Increasing in energy consumption can be overcome by promoting the technology of distributed generators in distribution systems using renewable resources. Currently in Malaysia, the main energy resources are from oil and natural gas. By introducing the distributed generation technology, it helps to generate energy more efficient and also reduce environment pollution such as air pollution from the burning of fossil fuels [1].

Typical distribution systems are operating without any generation on the systems. By adding generation at the distribution system, it provides benefits to the power system. DG is a technology that could help to enable efficient, renewable energy production both in developed and developing world. Despite their small size, DG technologies are having a stronger impact in electricity markets [2].

Many of different research works on the optimal placement and sizing of DG have been discussed from viewpoint of used optimisation method and objective functions. The most efficient and popular approaches for solving the DG placement and sizing problems is the heuristics methods such as Particle Swarm Optimisation (PSO) and Gravitational Search Algorithm (GSA). The importance of proper placement and sizing of the distributed generators is to improve the reliability and stability of power system [2]. Improper placement and sizing can lead to power losses and interrupt the voltage profile of distribution systems [2].

By using renewable resources as DG units can be very effective in improving technical, economical and especially environmental characteristics of distribution systems [1]. In Asia, the most suitable renewable resource is solar where photovoltaic (PV) DG is used to generating power from the solar energy such as monocrystalline, polycrystalline and thin-film [3]. To have realistic solutions for DG placement and sizing, the costs of operation planning of the renewable energy-based generating units must be considered so that it can minimise DG's investment and operating costs and compensating for system losses along the planning period [2].

1.2 Problem Statement

Improper placement and sizing may lead to some disadvantages such as overvoltage, excessive power losses and stability issues [1]. Therefore, the best types of DG units with the best size should be installed at the best locations in distribution systems. In most of previous works, a very limited number of optimisation algorithms, applied to DG placement and sizing problems where the applied optimisation methods are not known to be the best one. Besides, researches such as in [4], [5], [6], [7], [8], [9] aims were power and energy losses in the power system but it is not adequate by only considering the power losses in determining the placement and sizing of DG. In terms of finding the optimal placement and sizing of DG, the type of DG must be known and the costs of operation planning should not be ignored. The DG installed in the distribution system is generating power, thus the generation cost of the DG must be known in the operation planning. Besides, the efficiency of the DG will be reducing after a lengthy period and maintenance must be done to improve the performance of DG. Power losses will be present as the DG changes the original power flows of the transmission and distribution system. The cost of all these problems must be taken in consideration seriously, if not, it will create disadvantages after installation of DG in the distribution system. Thus, to find the optimal placement and sizing of DG, investment cost, maintenance cost, power loss cost and generation cost should be including in the costs of operation planning.

1.3 Objectives

The objectives of this study are:

- To determine the optimal placement and sizing of photovoltaic distributed generation.
- To compare the performance of proposed method IGSA with PSO and GSA in terms of fitness value and convergence rate.
- To compare the type of PV DG (Monocrystalline or Thin-film) based on the Costs of Operation Planning (C_P).

1.4 Scope

This study focuses on finding the optimal placement and sizing of DG considering the costs of operation planning. In Malaysia, the most suitable renewable energy resources to be used is sunlight so Photovoltaic (PV) generation units are chosen as the type of DG to be study. In this study, two types of PV are chosen to be study and compare which are Monocrystalline and Thin-film based on the costs of operation planning. The proposed method for this study is Improved Gravitational Search Algorithm (IGSA) and is performed in MATLAB environment to solve the problem. The performance of IGSA is then compared with Gravitational Search Algorithm (GSA) and Particle Swarm Optimisation (PSO) to find out which algorithm gives the best fitness value and convergence rate. The costs of operation planning of DG in distribution system are assessed by investment cost, maintenance cost, power loss cost and generation cost. The placement and sizing of the photovoltaic DG is then tested in IEEE 34-bus system and IEEE 69-bus system.

1.5 Report Organisation

This report is divided into five chapter, which are introduction, literature review, methodology, results and discussion and finally conclusion. In Chapter 1 introduction, overview of the project is presented. In this chapter, the research background, problem statement, objectives, and scopes of the project are discussed. In Chapter 2 literature review, research about DG, solar PV and costs of operation planning for optimal placement and sizing of DG are presented. Also, some previous works related to the optimal placement and sizing of DG are reviewed. In Chapter 3 methodology, the methods to optimise the placement and sizing of DG and formulas to calculate the costs of operation planning is presented in detail with the case study. In Chapter 4, the results are presented with analysis. Discussion on the results obtained is also included in this chapter. Finally, in Chapter 5, the overall research is summarised and concluded based on the objectives.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Distributed power generation has been developing rapidly in power systems seeing that it is an innovation that could help to produce energy more efficient compare to traditional large generators. DG is a small power generating unit installed at the distribution network or consumer site as a better way for centralized generation. Figure 2.1 shows the integration of renewable DG is at the distribution system, where the generation now is nearer to the load compared to conventional generation.

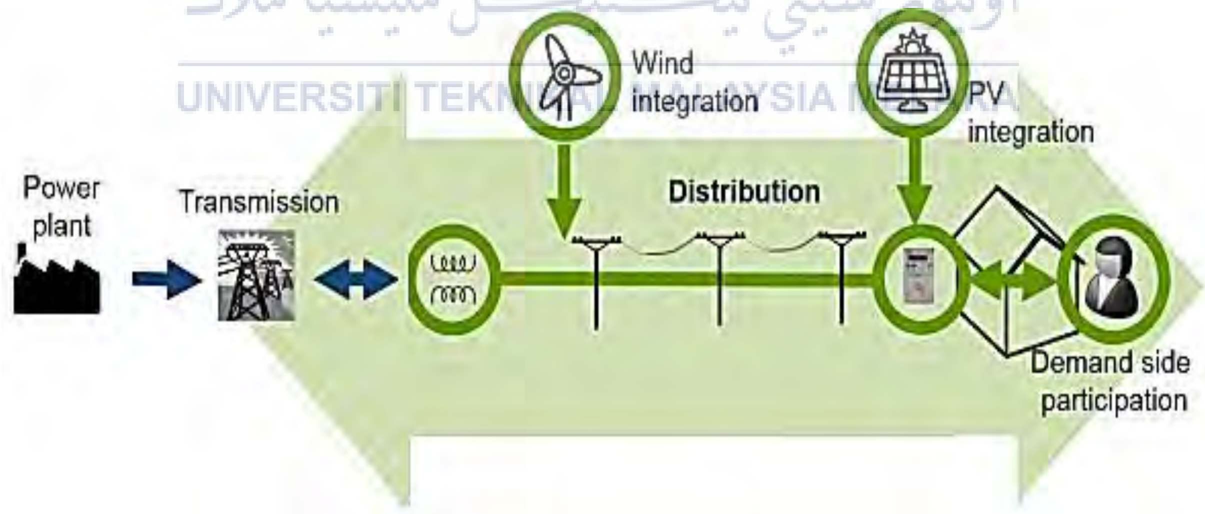

Figure 2.1: Integration of Wind DG and PV DG in Distribution System

DG can produces from less than a kilowatt (kW) to hundreds of megawatts (MW) [2] and it may be grid-connected or work standalone. It is categorized into four sizes based on its capacity. Micro DGs rated between 1 to 5 kW, small DGs rated between 5 kW to 5 MW, medium DGs rated between 5 MW to 50 MW and large DGs rated between 50 MW to 500 MW. Figure 2.2 below shows the criteria for classification of DG [10].

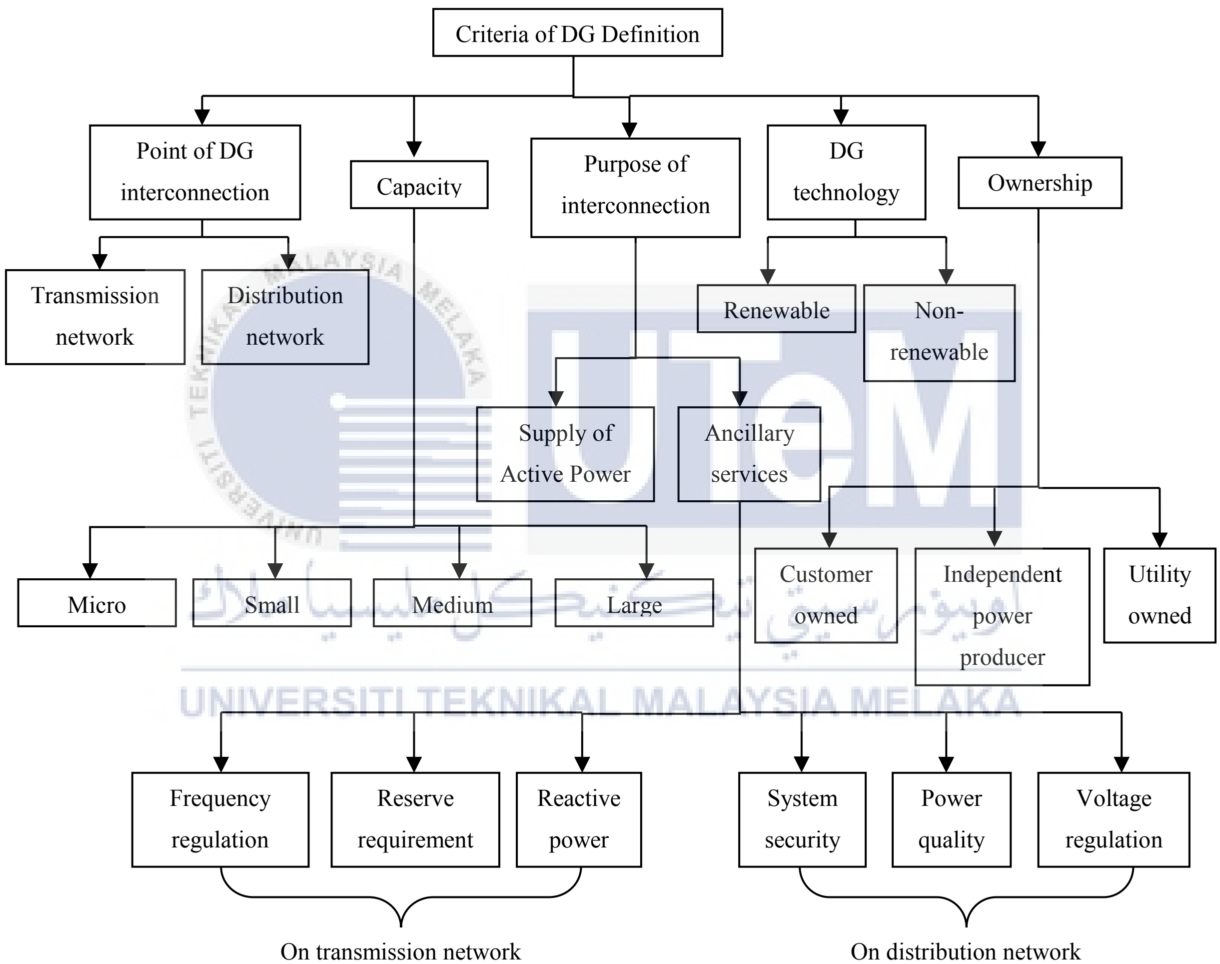

Figure 2.2: Criteria for Classification of DG [10]

2.2 Type of DGs

According to Wichit Krueasuk [11], DGs are classified into 3 types; Type 1 DGs, generate only real power; Type 2 DGs, supplying only reactive power; and Type 3 DGs, supplying real power but absorb reactive power. DGs can based on renewable energy sources such as diesel generators and microturbines; or non-renewable energy sources such as solar photovoltaic, wind power, hydroelectricity and fuel cells [1].

2.2.1 Diesel Generators

For standalone operation, diesel generators are most commonly used as it can be started and turn off easily. Microturbines are rapid and mechanically straight forward devices. Currently, its productivity is constantly expanding and its cost is consistently diminishing [1]. But the commonly fuels it used are natural gas and biogas where the emissions from the fuels are not environmental friendly. Figure 2.3 shows the diesel generator that commonly used for standalone operation.

Figure 2.3: Standalone Diesel Generator

2.2.2 Solar Photovoltaic

Solar photovoltaic (solar PV) converts sunlight into energy supply. Solar PV uses the inverter technology to connect with the grid. In Thailand, a tropical country like Malaysia has enough of sunshine to generate electricity using the solar PV [12]. Incorporation of solar PV with grid network would help with supplementing the persistently expanding of power requires [12]. For example, Figure 2.4 shows the grid connected solar farm in Melaka, Malaysia. More prominent utilization of PV technology can likewise build unwavering quality of the power network. Solar PV is widely used because it is clean, free and sustainable. However, it is a very expensive technology in the early stage but the cost decrease rapidly due to the highly efficient of this solar energy [1]. The primary disadvantage of solar PV is that their yield power is an element of solar irradiation and temperature which fluctuate always, in this manner, their output power is not fixed at various times [1].

Figure 2.4: Grid Connected Solar Farm in Melaka, Malaysia

2.2.3 Wind Power

Wind power is just like solar PV which is free and clean. There are two types of wind farm, onshore wind farm and offshore wind farm. Since the output power of wind turbines depends on the wind speed and wind speed changes after some time, the output power of wind turbines is time-subordinate. Along these lines, wind generating units like solar PV experience the intermittency of their output power [1]. Figure 2.5 shows the wind power plant in Xinjiang, China.

Figure 2.5: Wind Power Plant in Xinjiang, China

2.2.4 Hydroelectricity

Hydroelectricity captures the energy from the gravitational force of falling water and generates power. Besides solar and wind, hydro is the most normally used kind of renewable energy in generating power. Although hydroelectricity does not give any pollution, but the construction of hydroelectricity power station affects the local ecosystems. The loss of habitat may not appear to be serious but if this region was home to a jeopardized animal type, the dam development could further threaten that species danger of termination [13]. Figure 2.6 shows the Itaipu Dam in Brazil.

Figure 2.6: Itaipu Dam in Brazil

2.2.5 Fuel Cells

Fuel cells are quick picking up prevalence since they are proficient and environment friendly. There are numerous sorts of fuel cells presently a work in progress such as phosphoric acid, proton exchange membrane, molten carbonate, solid oxide, alkaline and direct methanol [10]. The fuel used is hydrogen which can be produced from electrolysis process of water. The electric energy is produced through chemical reaction of positively charged hydrogen ions with oxygen or another oxidizing agent [1] as shown in the Figure 2.7.

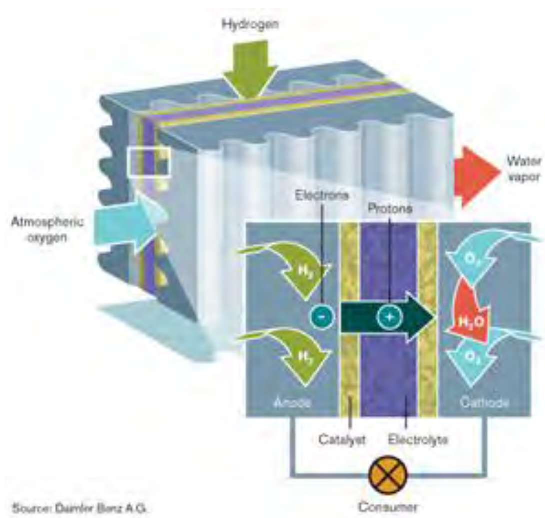

Figure 2.7: The Operation of Fuel Cell

2.3 Benefits of DG

In terms of benefits, distributed generators which are smaller in size compared to traditional power plant generation keep on improving in cost and productivity, drawing nearer and nearer to the performance of large power plants. In the meantime, utilities confront critical impediments when constructing power plants and transmission lines [14]. Unlike large power plants, DG unit can be installed in short time and easily since it is smaller and requires lesser space. In facts, DG technology diminishes the need for vast scale utility projects.

With proper placement of DG at the distribution system, it helps to improve the voltage profile of the power system. H.Iyer et al. (2005) investigate the effect of the presentation of DG on the voltage profile at the distribution system and proposes some straightforward new thoughts to measure and enhance the voltage profile without the need to utilize discrete and random optimisation methods [15]. Voltage profile improvement index (VPII) is used to determine the voltage profile with DG and without DG.

Besides, DG can reduce power losses of the system if installed with the best possible location and size. Circuit installed with DG give positive outcome towards the power losses since it bolster the power generation at the distribution side which is nearer to the load or consumer [4]. Thus, they evacuate the need of transmit mass power, and subsequently; the weight on transmission system is decreased [1]. In overall results, it shows that power losses with DG are lower contrast to the power system without DG.

As we all know, renewable energy is renewable and easily regenerated. DG that based on renewable energy is very environmental friendly as an example, solar produce energy without any burning process unlike fossil fuels. In particular, renewable energy is accessible wherever all through the world thus there is no way of the sources getting to be drained in future [16]. For instance, solar energy is wherever as the sun will dependably be there consistently.

DG technology is growing rapidly and can replace the high cost grid system. Also, due to the high efficiency of DG, the cost is decreasing. The DG can supply primary power and for backup power when shortage occur. It can black start the generation without depending on the transmission network [2]. Besides, supplying energy to the rural areas is difficult and costly. DG technology is a decent decision to overcome this problem as the cost of transmission and distribution will be lower [1].

2.4 Types of Solar PV Panel

Monocrystalline (Mono), Polycrystalline (Poly) and Thin-film (TF) panels are the most common solar PV panel that we can find in the market now. The first generation of solar PV technology use the crystalline silicon technology which the production of modules started in 1963 by Sharp Corporation of Japan [17]. Thin-film or amorphous is the second generation of PV technology where the silicon cells are made up of silicon atoms in a thin layer rather than a crystal structure [18].

Table 2.1 shows the characteristics of Monocrystalline, Polycrystalline and Thin-film panels [3]. Energy yield and temperature coefficient are both related. It can be seen that the temperature coefficient for Thin-film is better than monocrystalline and polycrystalline. Solar module actually does not perform better with too high temperature, when it reaches a certain temperature, heat loss will occur. Thus, the energy yield of Thin-film is the best among these three solar modules.

In Table 2.2, the advantages and disadvantages of each type of PV module are listed down [18]. The monocrystalline has high efficiency but it does not perform well when the temperature is too high while polycrystalline is opposed of monocrystalline. Thin-film performs better in hot temperature but it required double of space areas compared to monocrystalline and polycrystalline to produce same amount of energy.

Table 2.1: Characteristics of Monocrystalline, Polycrystalline and Thin-film [3]

Characteristics	**Monocrystalline**	**Polycrystalline**	**Thin-film**
			
Colour	Black Dark	Dark Blue	Grey
Efficiency	High	Less compare to Mono	High
Energy Yield	Low	Low	High
Cost	High	Less compare to Mono	Less
Temperature Coefficients Characteristics	Moderate	Moderate	Excellent

Table 2.2: Advantages and Disadvantages of Monocrystalline, Polycrystalline and Thin-film [18]

Type of PV	Advantages	Disadvantages
Monocrystalline (Mono)	• Highest efficiency of any cells on the market under standard operating conditions	• Due to higher production costs, it is more expensive than other cells • Do not perform as well as Poly and TF under higher temperature (eg: 25^{o}C) • All cells are subject to 'de-rating' as the ambient temperature increases, and Mono cells tend to produce less at higher temperature
Polycrystalline (Poly)	• Typically offer a lower cost per watt of power produced • Better temperature de-rating co-efficient compare to Mono • Produce more power in hotter weather	• Slightly less efficient than Mono
Thin-film (TF)	• Best shade tolerance of any solar technology • Performs best under hotter temperatures compare to others	• Lowest conversion efficiency • Twice the space to achieve same power output as crystalline panel

2.5 System Cost of Distributed Generation

In designing DG, the system cost is one of the factor that should not be ignored because this factor can be used as assessment to know what size or how large should the DG system be, what is the cost of DG can produce electric power, is it a good investment and is it worth to installed the DG system instead of the original system [19]. In simple words, investor surely prefer a system that can give more advantages than the costs.

Basically, costs of DG systems can be divided into fixed cost and variable cost. Fixed cost or also known as Single Budget Expenses is a one-time cost that is spent during construction and installation which also includes equipment, land, permits, site developing and preparation, taxes, insurance, labour and testing cost [20]. Variable cost is the cost for the DG systems to operate and maintain the system such as the maintenance cost, parts replacement, taxes and insurance [20]. In the Figure 2.8 [17], we can see that the average system cost with the average system size of the PV plants are quite different. This is because the system cost depends on the market and manufacturer which is different between countries.

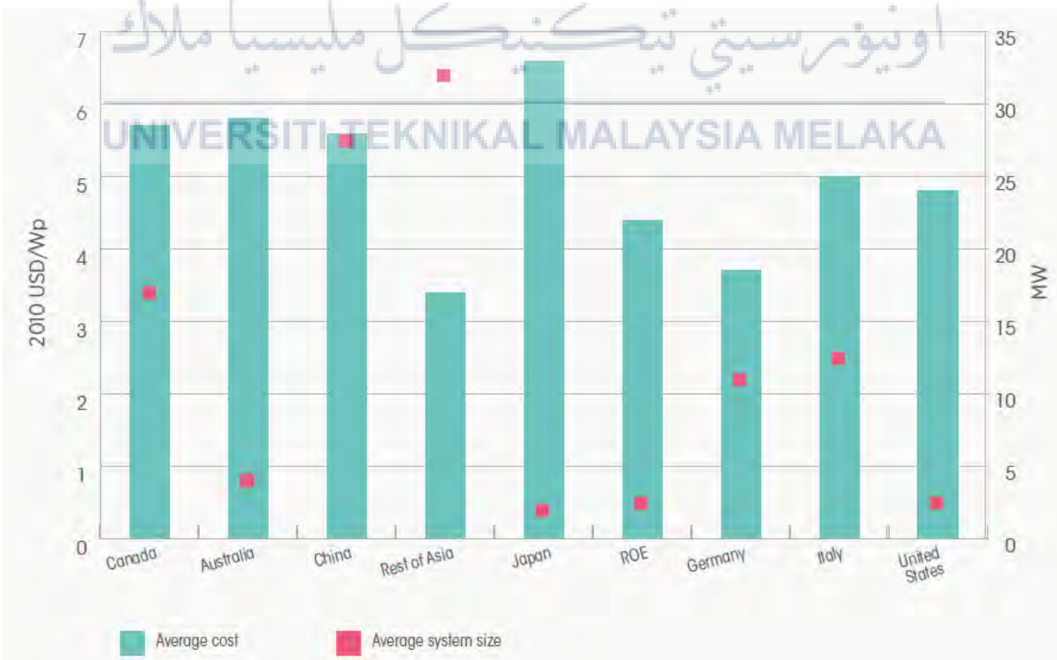

Figure 2.8: Average Prices and Sizes of PV Plants by Country in 2010 [17]

In [19], there are three type of methods that can used to assess the DG costs which are simple payback period, internal rate of return (IRR) and life cycle costing (LCC). Simple payback period is time required to pay back the investment cost but it is less accurate as the calculation only includes the system cost to the cost saved per year. IRR is difficult to calculate than simple payback period but it is more accurate in competing the investments. As we all know, the future energy prices will be different from the current one for example one ringgit in the future will be less valuable compare to one ringgit today. Thus, the value must be discounted and the discount rate will be considered in the calculation. Lastly, the approach of life cycle costing (LCC) can correctly rank the investment choice. LCC considered the cost of money, DG system capital cost, maintenance, insurance, operational costs, fuel and taxes [19].

2.6 Review on Optimal Placement and Sizing of DG

In 2013, K.Bhumkittipich et al. [12], using PSO (Particle Swarm Optimisation) to reduce power losses for the placement of DG in the radial distribution systems. In this research, the authors focused on one DG on determining its optimal placement and size considering the maximum loss reduction. The study was tested on 26-bus radial distribution system. Result showed that with the suitable DG sizing, the proposed method can minimise the power losses by 61% and the minimum power loss occurs in bus 14. Also, the average voltage levels improved from 0.9977 per unit to 0.9985 per unit after the DG was installed. The authors concluded that the PSO method has capably reduce the real power loss and improve the voltage profile fulfilling transmission line limits and constraints.

In 2011, S.Selvi Ramalakshmi [9] proposed a fuzzy adaptive evolutionary programming to determine the optimal sitting and sizing of DG in existing distribution system. The objectives of this paper are to reduce the cost of real power loss, DG capital cost and voltage deviation index. IEEE 34-bus system is used to evaluate the effectiveness of the fuzzy algorithm in determining the optimal sitting and sizing of DG. For the case study, two different cases were considered; case 1, DG at one location and case 2, DG at multiple location. The results showed that multiple DG in distribution system is better because it minimises the objective function more compare to a DG at one location. Also, effectiveness of DG in minimising the power losses is high.

In [21], GA (Genetic Algorithm) is used to find the optimal placement and sizing of DG based on existing grid topology. The objective of this paper is to find the optimal placement and sizing of CHP (Combined Heat Power) and PV generating units and reduce the network loss along the grid lines over a time of 24 hours. This study divides the period of 24 hours in three scenarios which are low load, medium load and high load. The author analysed the problem by two season, summer and winter. Based on the result, it showed that during summer, more PV are operating while during winter more CHP are operating to minimise the network losses.

In 2011, a new algorithm with the combination of GA (Genetic Algorithm) and PSO (Particle Swarm Optimisation) was proposed by M.H. Moradi et al. in [22]. Also, in this paper, same as most of the other researches, the goals are to reduce the network loss and to improve voltage regulation and voltage profile. To obtain the optimal placement and sizing of DG, the authors combined both algorithm to achieve better result. All three objectives function in this paper are combined into one with no units and qualified as ratio. Initially, the optimal location of DG is solved by GA algorithm then the result is passed to PSO algorithm to determine the best sizing of DG. Thus, it is more time consuming compared to only one algorithm is applied alone. The authors concluded that the combination algorithm proposed have higher capability in determining the optimal placement and sizing of DG.

A BFA (Bacterial Foraging Algorithm) based for optimal placement and sizing of DG was proposed by V. Rashtchi et al. in 2012 [23]. The objective function of this research is exactly same in [22] as mention in above paragraph. BFA uses the theory of animals foraging where abolish the animals with poor foraging techniques and support those animals that have effective foraging strategies since they will probably gain conceptive achievement. The results showed that BFA approach have the best minimum objective function compare to SFLA (Shuffled Frog Leaping Algorithm) and GA. In case study of 33 bus system and 69 bus system, results of BFA converges faster compared to SFLA and GA.

In [7], the optimal placement and sizing of DG is determine by GSA (Gravitational Search Algorithm). The multi-objective in this paper are minimising total losses and average voltage total harmonic distortion (THDv). The authors compared the effectiveness of GSA with PSO and evolutionary programming (EP). From the test case of 69-bus radial distribution system, the results show that GSA has the best convergence rate. The power loss and average THDv are lesser in the system with DG compare to system without DG. The authors concluded that GSA performs better in reducing power losses and THDv.

Three optimisation techniques was used in [8] to find the optimal capacity and location of DG in distribution system which are PSO, CRPSO (Craziness Based Particle Swarm Optimisation) and GSA. CRPSO is the enhance version of PSO which has a better global search ability. These techniques were implemented to 12-node radial and 69-node radial distribution network. The objective for this study is to minimise active power loss and improve voltage profile of the system. The results showed the optimal placement for 12-node test case is at bus 9 and for 69-node test case is at bus 61 which has the lowest power losses.

In [24], the author used 4 techniques to determine the DG optimal placement which are CSA (Cuckoo Search Algorithm), GSA, PSO and GA. Load flow analysis is first calculated to determine the real power loss and using the result obtained, optimisation methods are performed to determine the optimal placement and sizing of the DG in 33-bus distribution test system. The results showed that the real power loss of the system decreases as the number of DG increases from without DG to three DGs. Comparing the time consumed for the optimisation, GA is the slowest follow by CSA then PSO while GSA is the fastest.

2.7 Chapter Summary

There are many types of DG in the market, but considering the sustainable energy, PV type of DG is the most popular. In this research, two types of PV are chosen to be study which are Monocrystalline and Thin-film. After reviewing of others paper, mainly power losses are the objective in determining the optimal placement and sizing of DG and limited type of optimisation used. But to have realistic solutions for DG placement and sizing, the costs of operation planning of the renewable energy-based generating units must be considered. More optimisation methods should be used to find out and compare which one performs better. In this research, the costs of operation planning of PV DG will be determined based on the optimisation results obtained. One of the most popular software used is MATLAB as most of the algorithm can be perform in this software. Some of the research works are multi-objective based such as in [22], [23]. In next chapter, proposed algorithm IGSA; algorithm that to be compared, GSA, PSO and overall project flow for the research will explain in detail and in flowchart. Also, the problem formulation for the research are explained in the next chapter.

CHAPTER 3

METHODOLOGY

3.1 Introduction

There are lots of research on the optimal placement and sizing of DG are available. Different type of methods or algorithm are being used by the researchers to solve the problem. Also, different types of DG technology are being mentioned especially the renewable type as it is more sustainable and the source of energy is free. In this report, the main goal is to calculate the costs of operation planning after the installation of DG in the distribution system. Based on the minimum fitness value, the location and sizing of DG can be obtained through the proposed method, PSO. IEEE 34-bus system and IEEE 69-bus system are used as the test system for the study. GSA and IGSA also will be used to find the optimal placement and sizing of DG and results from all methods are compared to find out the best optimisation. Lastly, based on the optimisation results, the costs of operation planning of both Monocrystalline and Thin-film PV are calculated.

3.2 Problem Formulation

In this optimisation problem, the optimal placement and sizing of DG can be calculated by the fitness function which is power loss. The cost of planning is then calculated by using the optimisation results. The objective function for the optimisation problem is the minimum power loss of the power system and calculated as equation (3.1) [25].

$$\min f = P_{loss} \tag{3.1}$$

Where,

f : fitness function

P_{loss} : total power loss

The total power loss can be defined by equation (3.2) [25].

$$P_{loss} = \sum_{i=1}^{n} I_i^2 R_i \tag{3.2}$$

Where,

n : number of branch

I_i : the current of i^{th} branch

R_i : the i^{th} branch resistance

The constraint for this research is the voltage limit and DG capacity. The voltage limit must be keep in standard limit and it should limit the DG capacity between the maximum and minimum levels as follow [26]:

$$V_{min} \leq |V_i| \leq V_{max} \tag{3.3}$$

$$\sum_{i=1}^{N} P_{i-max} \leq P_{DG\ max} \tag{3.4}$$

Where,

V_{min} : lower bound of the voltage limit

V_{max} : upper bound of the voltage limit

$P_{DG\ max}$: permitted penetration of capacity of DG.

The costs of operation planning can be calculated as equation (3.5) [26]

$$C_P = C_I + C_M + C_L - C_{DG} \tag{3.5}$$

Where,

C_I : investment cost of DG

C_M : maintenance cost of DG

C_L : power loss cost

C_{DG} : generation cost by DG

The investment cost and maintenance cost of DG are fixed in this research and will be mentioned in the case study section. While the power loss cost and generation cost by DG are shown in the equation (3.6) and (3.7) respectively.

$$C_L = \sum_{i=1}^{12} N_i \times loss \times hrs \times FiT\ rate \quad (3.6)$$

$$C_{DG} = annual\ energy\ output \times FiT\ rate \quad (3.7)$$

The annual energy output can be calculated as equation (3.8)

$$annual\ energy\ output = \sum_{i=1}^{12} N_i \times DG\ capacity \times \eta \times hrs \quad (3.8)$$

Where,

η : efficiency of DG

hrs : hours of energy produced by DG

N_i : number of days of i^{th} month

3.3 Heuristic Methods

In this research, three heuristics methods are used to determine the optimal placement and sizing of DG considering the costs of operation planning which are PSO, GSA and IGSA. The proposed method for this research is IGSA and the result is compared with GSA and PSO in the case study of IEEE 34-bus system and IEEE 69-bus system.

3.3.1 Particle Swarm Optimisation (PSO)

In 1995, particle swarm optimisation (PSO) was developed by James Kennedy (social-psychologist) and Russell Eberhart (electrical engineer) inspired by the common behaviour of bird flocking [11]. Particle swarm is like a system model of a group of basic creatures doing same activity with same objective such as food searching. The advantage of PSO over other optimisation techniques is easier to implement and program with basic mathematical and logic operations but more parameters tuning is required [12].

The PSO is an optimisation tool that gives a population-based search technique where the particles change their position with time [11]. Initially, each particle will adjust it position according to its personal experience (*Pbest*) and the overall experience of the nearby particles (*Gbest*), making use of the best position to decide the next position in search space. Figure 3.1 below shown is the concept of PSO in search space.

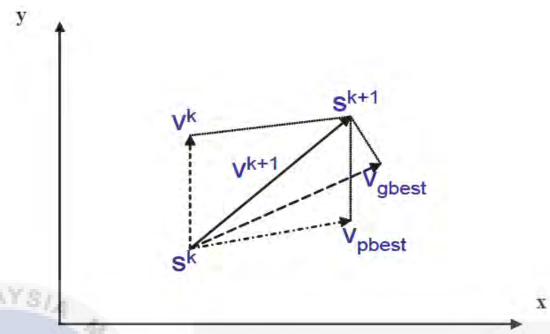

Figure 3.1: Concept of PSO in Search Space [12]

In this research, the fitness or objective function is the power losses. The control variables are the placement and sizing of DG and the constraints of this project are the DG sizing and voltage. Figure 3.2 shows the process of PSO implemented in MATLAB environment.

Description of PSO flowchart [11] are as below:

1. Input line and bus data, and bus voltage limits.
2. Randomly generates an initial population (array) of particles with random positions and velocities on dimensions in the solution space. Set the iteration counter $k = 0$.
3. For each particle if the bus voltage is within the limits, calculate the power loss. Otherwise, that particle is infeasible.
4. For each particle, compare its objective value with the individual best. If the objective value is lower than *Pbest*, set this value as the current *Pbest*, and record the corresponding particle position.
5. Choose the particle associated with the minimum *individual best Pbest* of all particles, and set the value of this *Pbest* as the current *overall best Gbest*.

6. Update the velocity and position of particle using equations (3.9) and (3.10) respectively [12].

$$v_i^{k+1} = wv_i^k + c_1 r_1 \left(pbest_i - s_i^k\right) + c_2 r_2 \left(gbest - s_i^k\right) \tag{3.9}$$

$$s_i^{k+1} = s_i^k + v_i^{k+1} \tag{3.10}$$

Where,

$c_1 . c_2$: the weighting factor

$r_1 . r_2$: the random numbers between 0 and 1

w : the weighting function

v_i^k : the current velocity of particle *i* at iteration *k*

v_i^{k+1} : the modified velocity of particle *i*

s_i^k : the current position of particle *i* at iteration *k*

s_i^{k+1} : the modified position of particle *i*

$pbest_i$: the personal best of particle *i*

$gbest_i$: the global best of the group

According to [11], the weighting function is calculated by:

$$w = w_{max} - \frac{w_{max} - w_{min}}{k_{max}} . k \tag{3.11}$$

where, w_{max} and w_{min} are the maximum and minimum of the weights respectively. k and k_{max} are the current and maximum iteration. The most commonly used for w_{max} and w_{min} are 0.9 and 0.4 respectively and for $c_1$and c_2 the most appropriate value is 2 in many cases [27].

7. If the iteration number reaches the maximum limit, proceed to next step. Otherwise, set iteration index *k* = *k* + 1, go back to step 3.
8. Print out the optimal solution to the target problem. The best position includes the optimal locations and size of DG, and the corresponding fitness value.

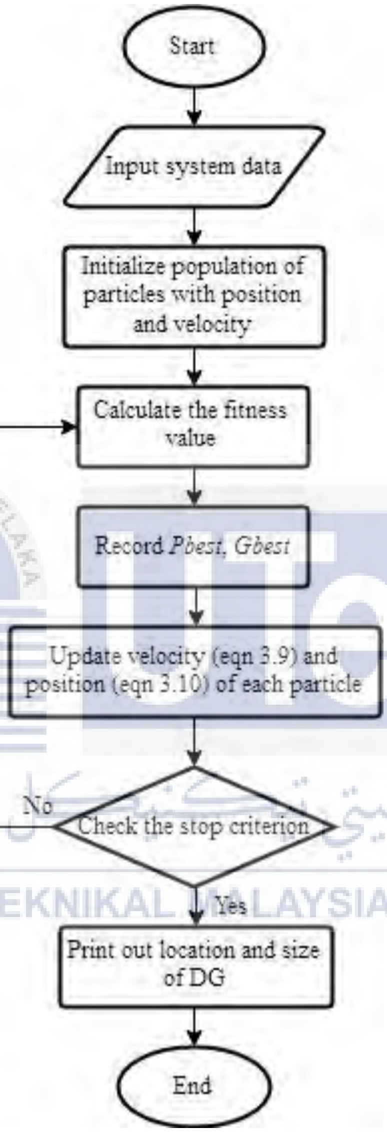

Figure 3.2: Particle Swarm Optimisation (PSO) Flowchart [11]

3.3.2 Gravitational Search Algorithm (GSA)

In 2009, gravitational search algorithm was proposed by Esmat Rashedi based on the law of gravity. This algorithm is based on the Newtonian gravity: "Every particle in the universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them" [28]. Figure 3.3 shows the concept of GSA in search space. The solution in the GSA population are called agents, these agents interact with each other through gravity force. The performance of each agent in the population is measured by its mass. Each agent is considered as object and all objects move towards other objects with heavier mass due to the gravity force. This step represents a global movement of the object, while the agent with a heavier mass moves slowly, which represents the exploitation step of the algorithm. The best solution is the solution with the heavier mass. Figure 3.4 shows the process of GSA implemented in MATLAB environment.

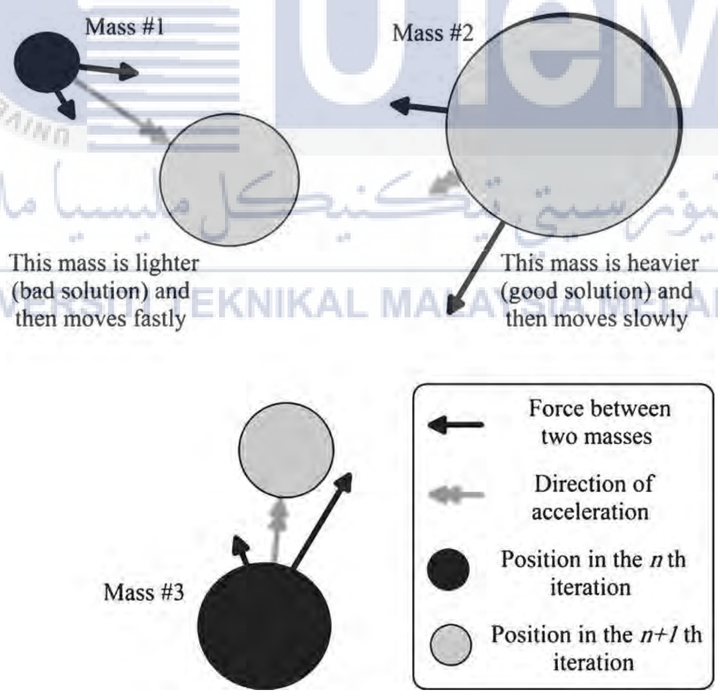

Figure 3.3: Concept of GSA in Search Space

Description of GSA flowchart [28] are as below:

1. Positions of the N number of agents are initialized randomly [7].

$$X_i = \left(x_i^1, \ldots x_i^d, \ldots, x_i^n\right), for\ i = 1,2, \ldots, N. \tag{3.12}$$

   Where,

   x_i^d : the positions of the i^th^ agent in the d^th^ dimension

   n : space dimension

2. For minimisation problems, the fitness evolution is performed by evaluating the best and worst fitness for all agents at each iteration [7].

   Minimisation problems:

$$best(t) = \min_{j\epsilon\{1,\ldots,N\}} fit\ j(t) \tag{3.13}$$

$$worst(t) = \max_{j\epsilon\{1,\ldots,N\}} fit\ j(t) \tag{3.14}$$

   Where,

   $fit\ j(t)$: the fitness value of the j^{th} agent at the iteration *t*

   best(t) : represents the best fitness at iteration *t*

   worst(t) : represents the worst fitness at iteration *t*

3. Gravitational constant (G) computation [7]:

$$G(t) = G_0 e^{\left(-\frac{\alpha}{T}\right)} \tag{3.15}$$

   G_0 and α are initialized at the beginning and will be reduced with the time to control the search accuracy. *T* is the total number of iterations [7].

4. Update mass (*M*). Give weighting in range [0,1] correspond to their fitness

$$m_i(t) = \frac{fitness_i(t) - worst(t)}{best(t) - worst(t)} \tag{3.16}$$

$$M_i\,(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)} \tag{3.17}$$

   Where $fitness_i(t)$ represent the fitness value of the function value of the agent *i* at time *t*, *worst(t)* and *best(t)* are defined as minimum fitness [7].

5. Acceleration of the i^th^ agent at iteration *t* is computed [7].

$$a_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} \tag{3.18}$$

Where,

M_{ii} : inertia mass of the i^th^ agent

$F_i^d(t)$: the total force acting on i^th^ agent

$$F_i^d(t) = \sum_{j \epsilon Kbest, j \neq i} rand_j F_{ij}^d(t) \tag{3.19}$$

Where,

Kbest : the set of first *K* agents with the best fitness value and biggest mass

Kbest will decrease linearly with the time and at the end there will be only one agent applying force to others. $F_{ij}^d(t)$ is computed as the following equation (3.20) [7].

$$F_{ij}^d(t) = G(t). \frac{M_{pi}(t) * M_{aj}(t)}{R_{ij}(t) + \varepsilon}.(x_j^d(t) - x_i^d(t)) \tag{3.20}$$

Where,

$F_{ij}^d(t)$: force acting on agent *i* from agent *j* at d^{th} dimension and t^{th} iteration

$R_{ij}^d(t)$: the Euclidian distance between two agents *i* and *j* at iteration *t*

G(t) : the computed gravitational constant at the same iteration

ε : a small constant

M_{aj} : the active gravitational masses

M_{pi} : the passive gravitational masses

Velocity and the position of the agents at the next iteration (t+1) are computed based on the following equations [7]:

$$v_i^d(t+1) = rand_i x v_i^d(t) + a_i^d(t) \tag{3.21}$$

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1) \tag{3.22}$$

6. Steps 2 to 6 are repeated until the iterations reach maximum limit. The best fitness value at the final iteration is computed as the global fitness while the position of the corresponding agent at specified dimensions is computed as the global solution of that problem.

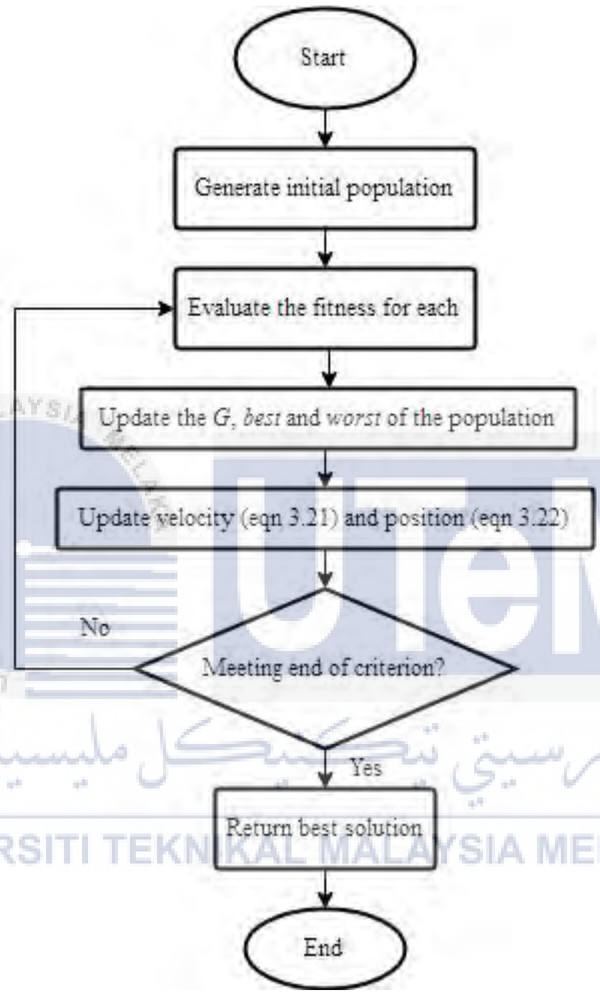

Figure 3.4: Gravitational Search Algorithm (GSA) Flowchart [28]

3.3.3 Improved Gravitational Search Algorithm (IGSA)

The accomplishment of the GSA relies on upon the two contradictory objectives, which are exploration and exploitation. The exploration is the ability of expanding global investigation of the search space, while the exploitation is the ability of finding the optima around a good solution [6]. During the process, exploration is used to avoid trapping in a local optimum. As the process continues, exploitation fades in to allow the found solution to be superior.

An improved gravitational search algorithm (IGSA) is introduced in [6] to overcome the weakness of the GSA in the searching process for the best solution. GSA fails to control the balance between exploration and exploitation where the more exploration will affect the premature convergence while the exploitation will affect on the convergence rate [29]. The second weakness was the best agent is still exploring the global space even it was at the best position [30]. IGSA was proposed to improve the searching behaviour and to avoid premature convergence by applying a popular logistic equation from [31]. The logistic equation is described as equation (3.23).

$$\phi(t+1) = \rho \times \phi(t) \times \big(1 - \phi(t)\big),\ 0 \leq \phi(1) \leq 1 \tag{3.23}$$

Where,

ϕ : chaotic value

ρ : control parameter between 0 to 4

t : iteration number

The new equation (3.24) for gravitational constant is obtained by multiplying equation (3.15) and (3.23) as follows [6]:

$$G(t) = \phi \times G_0 e^{(-\frac{\alpha}{T})} \tag{3.24}$$

In GSA, too much dependence on the random variables in the calculation will create less significant impact for the implementation of the gravitational theory on the search algorithm [6]. Random variable in the equation (3.19) is removed to avoid too much reliance on randomise exploration process. In GSA concept, the gravitational force depends on the masses and R_{ij} the Euclidian distance between two agents *i* and *j*. In IGSA, these two elements are used to get the decision parameter of λ in equation (3.25) [6].

$$\lambda_i^k = \begin{cases} 1, if\ M(k) > M(i)\ and\ R_{ik} \leq \tau \\ 0, otherwise, \end{cases} \tag{3.25}$$

Where τ is the maximum distance of the i^{th} agent to k^{th} agent and is set 30% of the i^{th} agent [6]. The new force equation (3.26) is obtained by multiplying the λ to the equation (3.20) as follows [6]:

$$F_{ij}^d(t) = \lambda_i^k . G(t). \frac{M_{pi}(t) * M_{aj}(t)}{R_{ij}(t) + \varepsilon} . (x_j^d(t) - x_i^d(t)) \tag{3.26}$$

Figure 3.5 below shown is the flowchart of the IGSA.

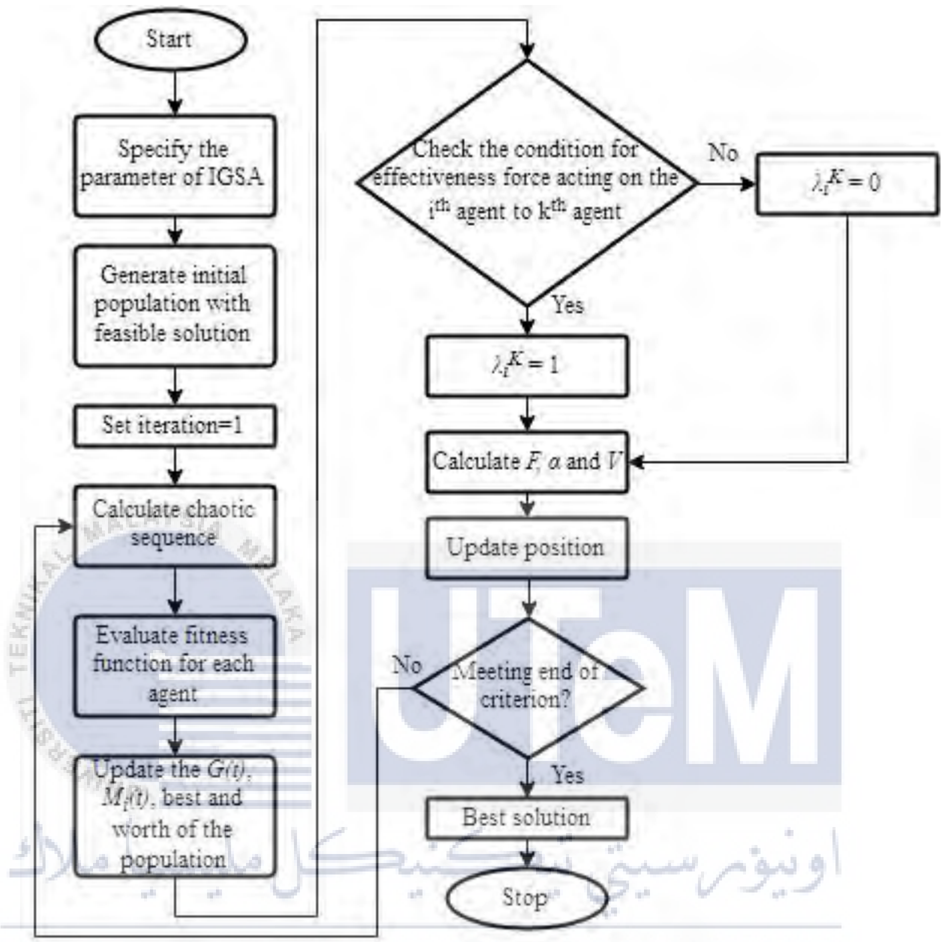

Figure 3.5: Improved Gravitational Search Algorithm (IGSA) Flowchart [6]

3.4 Application of Heuristic Methods in Costs of Operation Planning

The research is divided into five sections. In Chapter 1, a brief introduction about optimal placement and sizing of DG and the objectives and scopes of the project are identified. In Chapter 2, literature review on DG in distribution system, benefits of DG contribute to power system and methods to find the optimal placement and sizing of DG are presented. In Chapter 3, the methods to obtain the optimal placement and sizing of DG are presented in flowchart form. The objective function for this project are mentioned and all the problem formulations are in this section.

From the optimisation methods applied, the results of placement and sizing of DG are able to obtain. From that, the costs of operation planning are calculated based on the fitness value obtained from each optimisation methods according to the equations in the problem formulation section. The next chapter presents the analysis performed in the MATLAB environment based on the case study for IEEE 34-bus system and IEEE 69-bus system. The results are tabulated in the form of figures and tables. All data that have been simulate will be presented in this section.

Lastly, the conclusion chapter, this chapter concludes all the analysis that have been performed and suggestion will be made on the best method to optimise the placement and sizing of DG considering the costs of operation planning. Figure 3.6 shows the flowchart to illustrate the project flow and the Gantt chart can be referred to Appendix A.

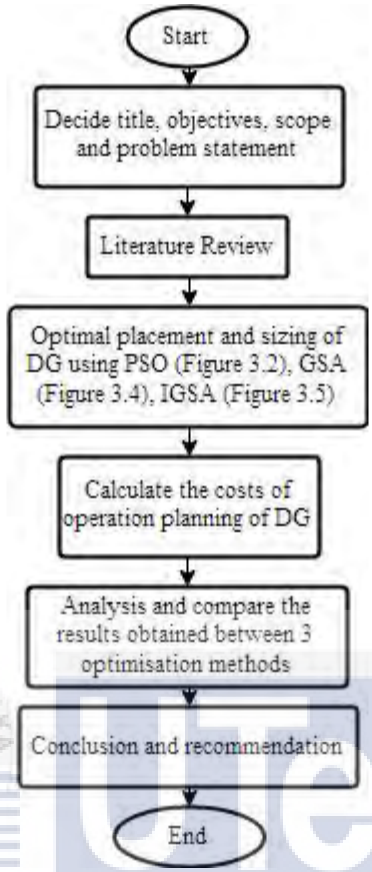

Figure 3.6: Overall Process of the Project

3.5 Test Systems

The heuristic methods are tested in IEEE 34-bus system and IEEE 69-bus system using MATLAB. The data and parameters for the bus system are indicated in [32], [33]. Single line diagram of both bus system is shown in Figure 3.7 and Figure 3.8 respectively. The voltage limit is set from 0.90 p.u to 1.05 p.u and for DG capacity is set from 1.2 MW to 2.0 MW that is about 40% range of the total connected load [34]. The base MVA is set to 100 MVA in this study. The total connected load for 34-bus system is 4.6MW and for 69-bus system is 3.8MW where the bus data can be referred in Appendix B and D. While the branch data can be referred in Appendix C and E for 34 and 69-bus system respectively.

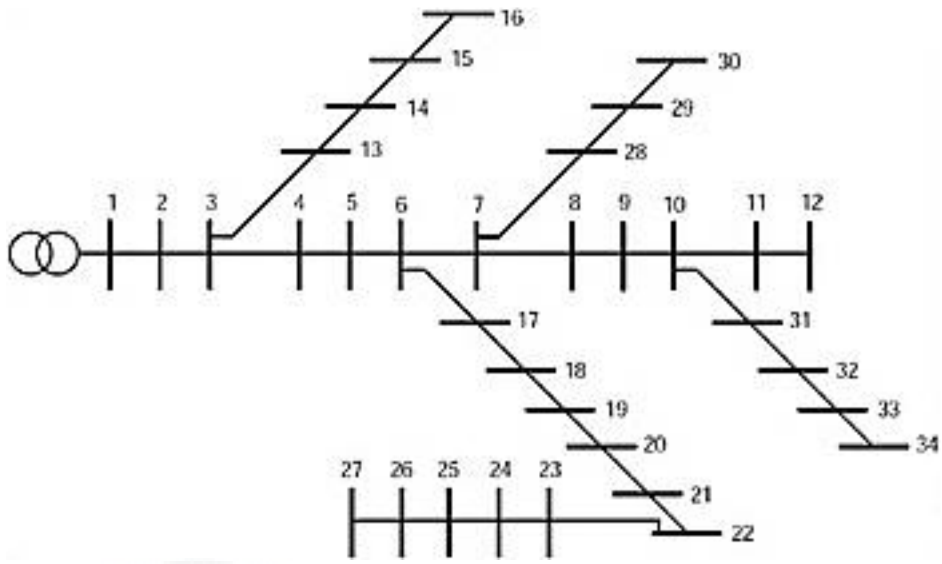

Figure 3.7: Single Line Diagram of IEEE 34-Bus System [33]

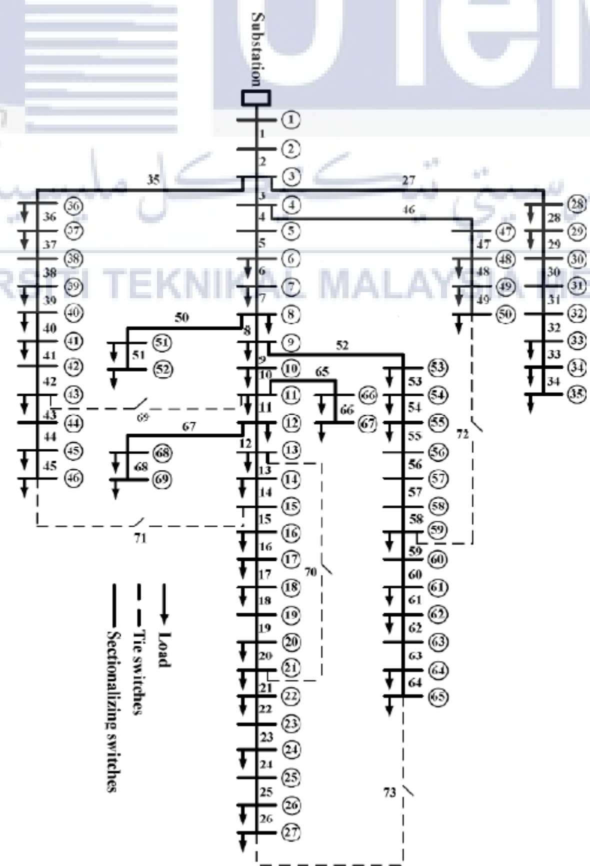

Figure 3.8: Single Line Diagram of IEEE 69-Bus System [32]

3.6 Costing for Photovoltaic (PV) System

The investment cost includes the PV module cost and Balance of System (BOS) cost [17]. BOS cost is difficult to be determine because it includes the labour cost, site preparation cost and other miscellaneous costs which are in a wide range of prices rely on upon the manufacturer and market. For case study purpose, the investment cost is assumed by referring the price in [17] where Monocrystalline is fixed to RM 14.50/W and for Thin-film is fixed to RM 14.00/W. The maintenance cost is 1% of the investment cost [35].

The FiT rate is set according the to the SEDA portal as shown in Figure 3.9 [36]. The efficiency for the Monocrystalline is 76.43% and for the Thin-film is 86.63% stated in [3]. To calculate the monthly energy output, kWh/month, the time for the PV to produce energy is set to 4 hours as for average in Malaysia the peak sun hours is between 11am to 3pm. In this research, the costs of operation planning are evaluated in one year. It will be inaccurate if the period becomes longer because the FiT rates will be varying and different for every year.

Description of Qualifying Renewable Energy Installation	FiT Rates (RM per kWh)
(a) Basic FiT rates having installed capacity of :	01-JAN-2016
(i) up to and including 4kW	0.8249
(ii) above 4kW and up to and including 24kW	0.8048
(iii) above 24kW and up to and including 72kW	0.6139
(iv) above 72kW and up to and including 1MW	0.5930
(v) above 1MW and up to and including 10MW	0.4651
(vi) above 10MW and up to and including 30MW	0.4162

Figure 3.9: FiT Rates for Solar PV [36]

3.7 Chapter Summary

In summary, this chapter presents all the problem formulation and process of heuristic methods. The details of flow and equations for each optimisation method can be obtained in this chapter. In addition, the application of heuristic methods in finding the Costs of Operation Planning is explained and showed in flowchart. Lastly, the data and parameters of IEEE 34-bus system and IEEE 69-bus system as well as the costing for the PV system are included in this chapter.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the results from PSO, GSA and IGSA are discussed. The placement and sizing of DG for IEEE 34-bus system and IEEE 69-bus system are recorded. The calculation for costs of operation planning for a year are tabulated in table form. Comparison for the costs of operation planning between Monocrystalline and Thin-film are recorded. Lastly, the correlation between the costs of operation planning and DG size are summarised and analysed.

4.2 IEEE 34-Bus System

All three optimisation methods are performed in the IEEE 34-bus system. The maximum iteration for the algorithm is set to 100 and was run for 30 times for more accurate data. The bus and branch data of the 34-bus system are attached in the Appendix B and C. Results from the optimisation methods are used to calculate the Costs of Operation Planning (C_p).

4.2.1 Optimisation Results

The convergence characteristics of the PSO, GSA and IGSA for one DG in 34-bus system is shown in Figure 4.1. This figure shows the best fitness value among 30 simulation runs using three different optimisation methods. From the figure, the fitness function improves as the number of iterations increases until it reaches a constant after certain number of iterations. In this 34-bus system, where one PV DG is installed, IGSA performs better than GSA and PSO and it gives the lowest best fitness function value of 0.03611. The fitness value for all 30 times simulation runs can be referred in Appendix F.

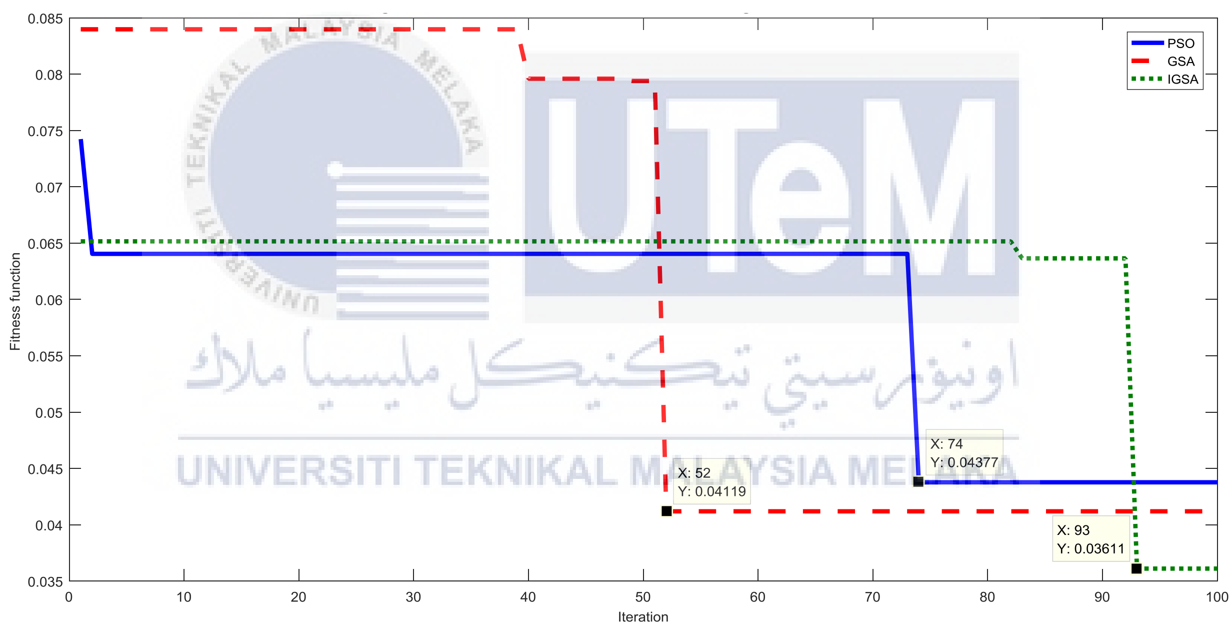

Figure 4.1: Convergence Characteristics of PSO, GSA and IGSA for One DG in 34-Bus System

Table 4.1 shows the performance of PSO, GSA and IGSA. The best candidates for PV DG placement using PSO, GSA and IGSA is at bus 9, bus 31 and bus 4 with the PV DG capacity 1.7520 MW, 1.8114 MW and 1.6689 MW, respectively. From the comparison, the IGSA technique has obtained the best optimal solution with the lowest fitness.

Table 4.1: Optimisation Results from PSO, GSA and IGSA in 34-Bus System

Case	Without DG	Installation with 1 DG		
Technique	-	PSO	GSA	IGSA
DG Size (MW)	-	1.7520	1.8114	1.6689
DG Location	-	9	31	4
DG Voltage (pu)	-	1.0141	0.9847	0.9862
Losses (kW)	224.90	43.77	41.19	36.11

4.2.2 Costs of Operation Planning

Table 4.2, 4.3 and 4.4 show the Costs of Power Loss (C_L) for 34-bus system from PSO, GSA and IGSA respectively. From the optimisation results obtained in Table 4.1, C_L can be calculated by equation (3.6) by assuming the time for the PV DG operates is 4 hours. Annual cost of power loss (C_L) for 34-bus system from PSO, GSA and IGSA optimisation methods are RM 29,803.27, RM 28,046.53 and RM 24,587.53 respectively using the FiT rates of RM 0.4651 from SEDA Portal for PV system. The lowest C_L calculated is from IGSA because from the optimisation result IGSA gives the best fitness value compared to PSO and GSA.

Table 4.2: Costs of Power Loss (C_L) in 34-Bus System from PSO

Month	Days	FiT Rate (RM)	Loss (kW)	Hours	C_L (RM)
Jan-16	31	0.4651	43.77	4	2524.32
Feb-16	29	0.4651	43.77	4	2361.46
Mar-16	31	0.4651	43.77	4	2524.32
Apr-16	30	0.4651	43.77	4	2442.89
May-16	31	0.4651	43.77	4	2524.32
Jun-16	30	0.4651	43.77	4	2442.89
Jul-16	31	0.4651	43.77	4	2524.32
Aug-16	31	0.4651	43.77	4	2524.32
Sep-16	30	0.4651	43.77	4	2442.89
Oct-16	31	0.4651	43.77	4	2524.32
Nov-16	30	0.4651	43.77	4	2442.89
Dec-16	31	0.4651	43.77	4	2524.32
			Annual C_L		29,803.27

Table 4.3: Costs of Power Loss (C_L) in 34-Bus System from GSA

Month	Days	FiT Rate (RM)	Loss (kW)	Hours	C_L (RM)
Jan-16	31	0.4651	41.19	4	2375.53
Feb-16	29	0.4651	41.19	4	2222.27
Mar-16	31	0.4651	41.19	4	2375.53
Apr-16	30	0.4651	41.19	4	2298.90
May-16	31	0.4651	41.19	4	2375.53
Jun-16	30	0.4651	41.19	4	2298.90
Jul-16	31	0.4651	41.19	4	2375.53
Aug-16	31	0.4651	41.19	4	2375.53
Sep-16	30	0.4651	41.19	4	2298.90
Oct-16	31	0.4651	41.19	4	2375.53
Nov-16	30	0.4651	41.19	4	2298.90
Dec-16	31	0.4651	41.19	4	2375.53
			Annual C_L		28,046.53

Table 4.4: Costs of Power Loss (C_L) in 34-Bus System from IGSA

Month	Days	FiT Rate (RM)	Loss (kW)	Hours	C_L (RM)
Jan-16	31	0.4651	36.11	4	2082.55
Feb-16	29	0.4651	36.11	4	1948.19
Mar-16	31	0.4651	36.11	4	2082.55
Apr-16	30	0.4651	36.11	4	2015.37
May-16	31	0.4651	36.11	4	2082.55
Jun-16	30	0.4651	36.11	4	2015.37
Jul-16	31	0.4651	36.11	4	2082.55
Aug-16	31	0.4651	36.11	4	2082.55
Sep-16	30	0.4651	36.11	4	2015.37
Oct-16	31	0.4651	36.11	4	2082.55
Nov-16	30	0.4651	36.11	4	2015.37
Dec-16	31	0.4651	36.11	4	2082.55
			Annual C_L		24,587.53

Table 4.5, 4.6 and 4.7 show Costs of Generation (C_{DG}) of Monocrystalline PV system from PSO, GSA and IGSA respectively for 12 months in 2016 with FiT rate RM 0.4651. From the optimisation result obtained in Table 4.1, the optimum size for DG are known and C_{DG} can be calculated by Equation (3.7). The efficiency for Monocrystalline PV System is 76.43% refer to [3] and by assuming the operating time by PV DG is 4 hours. Annual C_{DG} for Monocrystalline PV System in 34-Bus System from PSO, GSA and IGSA is RM 911,770.17, RM 942,682.92 and RM 868,523.53 respectively.

Table 4.5: Costs of Generation (C_{DG}) for Monocrystalline PV System in 34-Bus System from PSO

Month	Days	FiT Rate (RM)	DG Size (kW)	Hours	η Mono (%)	C_{DG} (RM)
Jan-16	31	0.4651	1752	4	0.7643	77,226.43
Feb-16	29	0.4651	1752	4	0.7643	72,244.08
Mar-16	31	0.4651	1752	4	0.7643	77,226.43
Apr-16	30	0.4651	1752	4	0.7643	74,735.26
May-16	31	0.4651	1752	4	0.7643	77,226.43
Jun-16	30	0.4651	1752	4	0.7643	74,735.26
Jul-16	31	0.4651	1752	4	0.7643	77,226.43
Aug-16	31	0.4651	1752	4	0.7643	77,226.43
Sep-16	30	0.4651	1752	4	0.7643	74,735.26
Oct-16	31	0.4651	1752	4	0.7643	77,226.43
Nov-16	30	0.4651	1752	4	0.7643	74,735.26
Dec-16	31	0.4651	1752	4	0.7643	77,226.43
					Annual C_{DG}	911,770.17

Table 4.6: Costs of Generation (C_{DG}) for Monocrystalline PV System in 34-Bus System from GSA

Month	Days	FiT Rate (RM)	DG Size (kW)	Hours	η Mono (%)	C_{DG} (RM)
Jan-16	31	0.4651	1811.4	4	0.7643	79,844.73
Feb-16	29	0.4651	1811.4	4	0.7643	74,693.46
Mar-16	31	0.4651	1811.4	4	0.7643	79,844.73
Apr-16	30	0.4651	1811.4	4	0.7643	77,269.09
May-16	31	0.4651	1811.4	4	0.7643	79,844.73
Jun-16	30	0.4651	1811.4	4	0.7643	77,269.09
Jul-16	31	0.4651	1811.4	4	0.7643	79,844.73
Aug-16	31	0.4651	1811.4	4	0.7643	79,844.73
Sep-16	30	0.4651	1811.4	4	0.7643	77,269.09
Oct-16	31	0.4651	1811.4	4	0.7643	79,844.73
Nov-16	30	0.4651	1811.4	4	0.7643	77,269.09
Dec-16	31	0.4651	1811.4	4	0.7643	79,844.73
					Annual C_{DG}	942,682.92

Table 4.7: Costs of Generation (C_{DG}) for Monocrystalline PV System in 34-Bus System from IGSA

Month	Days	FiT Rate (RM)	DG Size (kW)	Hours	η Mono (%)	C_{DG} (RM)
Jan-16	31	0.4651	1668.9	4	0.7643	73,563.47
Feb-16	29	0.4651	1668.9	4	0.7643	68,817.44
Mar-16	31	0.4651	1668.9	4	0.7643	73,563.47
Apr-16	30	0.4651	1668.9	4	0.7643	71,190.45
May-16	31	0.4651	1668.9	4	0.7643	73,563.47
Jun-16	30	0.4651	1668.9	4	0.7643	71,190.45
Jul-16	31	0.4651	1668.9	4	0.7643	73,563.47
Aug-16	31	0.4651	1668.9	4	0.7643	73,563.47
Sep-16	30	0.4651	1668.9	4	0.7643	71,190.45
Oct-16	31	0.4651	1668.9	4	0.7643	73,563.47
Nov-16	30	0.4651	1668.9	4	0.7643	71,190.45
Dec-16	31	0.4651	1668.9	4	0.7643	73,563.47
					Annual C_{DG}	868,523.53

Table 4.8, 4.9 and 4.10 show Costs of Generation (C_{DG}) of Thin-film PV system from PSO, GSA and IGSA respectively for 12 months in 2016 with FiT rate RM 0.4651. From the optimisation result obtained in Table 4.1, the optimum size for DG are known and C_{DG} can be calculated by Equation (3.7). The efficiency for Thin-film PV System is 86.63% refer to [3] and by assuming the operating time by PV DG is 4 hours. Annual C_{DG} for Thin-film PV System in 34-Bus System from PSO, GSA and IGSA is RM 1,033,450.86, RM 1,068,489.09 and RM 984,432.73 respectively.

Table 4.8: Costs of Generation (C_{DG}) for Thin-film PV System in 34-Bus System from PSO

Month	Days	FiT Rate (RM)	DG Size (kW)	Hours	η TF (%)	C_{DG} (RM)
Jan-16	31	0.4651	1752	4	0.8663	87,532.72
Feb-16	29	0.4651	1752	4	0.8663	81,885.45
Mar-16	31	0.4651	1752	4	0.8663	87,532.72
Apr-16	30	0.4651	1752	4	0.8663	84,709.09
May-16	31	0.4651	1752	4	0.8663	87,532.72
Jun-16	30	0.4651	1752	4	0.8663	84,709.09
Jul-16	31	0.4651	1752	4	0.8663	87,532.72
Aug-16	31	0.4651	1752	4	0.8663	87,532.72
Sep-16	30	0.4651	1752	4	0.8663	84,709.09
Oct-16	31	0.4651	1752	4	0.8663	87,532.72
Nov-16	30	0.4651	1752	4	0.8663	84,709.09
Dec-16	31	0.4651	1752	4	0.8663	87,532.72
					Annual C_{DG}	1,033,450.86

Table 4.9: Costs of Generation (C_{DG}) for Thin-film PV System in 34-Bus System from GSA

Month	Days	FiT Rate (RM)	DG Size (kW)	Hours	η TF (%)	C_{DG} (RM)
Jan-16	31	0.4651	1811.4	4	0.8663	90,500.44
Feb-16	29	0.4651	1811.4	4	0.8663	84,661.70
Mar-16	31	0.4651	1811.4	4	0.8663	90,500.44
Apr-16	30	0.4651	1811.4	4	0.8663	87,581.07
May-16	31	0.4651	1811.4	4	0.8663	90,500.44
Jun-16	30	0.4651	1811.4	4	0.8663	87,581.07
Jul-16	31	0.4651	1811.4	4	0.8663	90,500.44
Aug-16	31	0.4651	1811.4	4	0.8663	90,500.44
Sep-16	30	0.4651	1811.4	4	0.8663	87,581.07
Oct-16	31	0.4651	1811.4	4	0.8663	90,500.44
Nov-16	30	0.4651	1811.4	4	0.8663	87,581.07
Dec-16	31	0.4651	1811.4	4	0.8663	90,500.44
					Annual C_{DG}	1,068,489.09

Table 4.10: Costs of Generation (C_{DG}) for Thin-film PV System in 34-Bus System from IGSA

Month	Days	FiT Rate (RM)	DG Size (kW)	Hours	η TF (%)	C_{DG} (RM)
Jan-16	31	0.4651	1668.9	4	0.8663	83,380.91
Feb-16	29	0.4651	1668.9	4	0.8663	78,001.50
Mar-16	31	0.4651	1668.9	4	0.8663	83,380.91
Apr-16	30	0.4651	1668.9	4	0.8663	80,691.21
May-16	31	0.4651	1668.9	4	0.8663	83,380.91
Jun-16	30	0.4651	1668.9	4	0.8663	80,691.21
Jul-16	31	0.4651	1668.9	4	0.8663	83,380.91
Aug-16	31	0.4651	1668.9	4	0.8663	83,380.91
Sep-16	30	0.4651	1668.9	4	0.8663	80,691.21
Oct-16	31	0.4651	1668.9	4	0.8663	83,380.91
Nov-16	30	0.4651	1668.9	4	0.8663	80,691.21
Dec-16	31	0.4651	1668.9	4	0.8663	83,380.91
					Annual C_{DG}	984,432.73

Table 4.11 summarised the Costs of Operation Planning (C_P) which includes investment cost (C_I), maintenance cost (C_M), power loss cost (C_L) and generation cost (C_{DG}). For the case study, the investment cost for Monocrystalline is fixed to RM 14.50/W and for Thin-film is fixed to RM 14.00/W. From the optimisation results obtained in Table 4.1, the DG size for Monocrystalline and Thin-film PV systems in 34-bus are known for all three methods. From the DG size, the C_I can be determined while C_M is 1% from C_I as mentioned earlier in the case study section. Thus, the C_P can be calculated using equation (3.5). The annual C_P for Monocrystalline PV in 34-bus system from PSO, GSA and IGSA is RM 24,776,073.10, RM 25,613,316.61 and RM 23,597,104.50 respectively. The annual C_P for Thin-film PV in 34-bus system from PSO, GSA and IGSA is RM 23,769,632.41, RM 24,572,753.44 and RM 22,638,400.80 respectively. Thin-film PV system with IGSA gives the best and lowest C_P among others which is RM 22,638,400.80. The first reason is the losses after installation of DG in the 34-bus system is the lowest compared to PSO and GSA. The second reason is the price of the Thin-film is cheaper than Monocrystalline thus resulting in a lower cost of investment and maintenance. Also, the Thin-film has higher efficiency than Monocrystalline, which results in higher C_{DG} and considering overall costs included, the C_P of Thin-film is the lowest.

Table 4.11: Summary for Costs of Operation Planning (C_P) in 34-Bus System

	Monocrystalline			**Thin-film**		
	PSO	**GSA**	**IGSA**	**PSO**	**GSA**	**IGSA**
Investment Cost, C_I (RM)	25,404,000.00	26,265,300.00	24,199,050.00	24,528,000.00	25,359,600.00	23,364,600.00
Maintenance Cost, C_M (RM)	254,040.00	262,653.00	241,990.50	245,280.00	253,596.00	233,646.00
Power Loss Cost, C_L (RM)	29,803.27	28,046.53	24,587.53	29,803.27	28,046.53	24,587.53
Generation Cost, C_{DG} (RM)	911,770.17	942,682.92	868,523.53	1,033,450.86	1,068,489.09	984,432.73
Total Costs of Operation Planning, C_P (RM)	**24,776,073.10**	**25,613,316.61**	**23,597,104.50**	**23,769,632.41**	**24,572,753.44**	**22,638,400.80**

4.3 IEEE 69-Bus System

IEEE 69-bus system is used as the second case study in this research. Similar to IEEE 34-bus system, iterations for the algorithm is set to 100 and run for 30 times to obtained the best results. The bus and branch data of the 69-bus system are attached in the Appendix D and E.

4.3.1 Optimisation Results

The convergence characteristics of the PSO, GSA and IGSA for one DG in 69-bus system is shown in Figure 4.2. This figure shows the best fitness value among 30 simulation runs using three different optimisation methods. From the figure, the fitness function improves as the number of iterations increases until it reaches a constant after certain number of iterations. In this 69-bus system, where one PV DG is installed, IGSA performs better than GSA and PSO and it gives the lowest best fitness function value of 0.02373. The fitness value for all 30 times simulation runs can be referred in Appendix F.

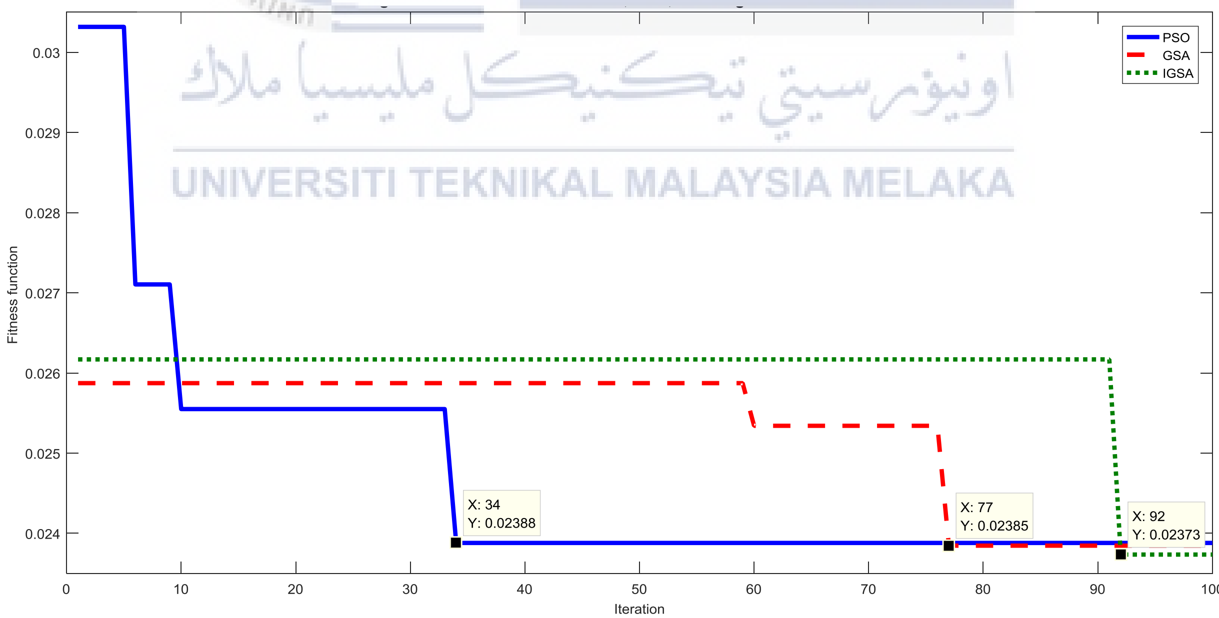

Figure 4.2: Convergence Characteristics of the PSO, GSA and IGSA for One DG in 69-Bus System

Table 4.12 shows the performance of PSO, GSA and IGSA. The best candidates for PV DG placement using PSO, GSA and IGSA is at bus 59, bus 63 and bus 51 with the PV DG capacity 1.0121 MW, 1.0178 MW and 0.9902 MW, respectively. From the comparison, the IGSA technique has obtained the best optimal solution with the lowest fitness.

Table 4.12: Optimisation Results from PSO, GSA and IGSA in 69-Bus System

Case	Without DG	Installation with 1 DG		
Technique	-	PSO	GSA	IGSA
DG Size (MW)	-	1.5793	1.4725	1.2879
DG Location	-	59	63	51
DG Voltage (pu)	-	1.0121	1.0178	0.9902
Losses (kW)	229.80	23.88	23.85	23.73

4.3.2 Costs of Operation Planning

Table 4.13, 4.14 and 4.15 show the Costs of Power Loss (C_L) for 69-bus system from PSO, GSA and IGSA respectively. From the optimisation results obtained in Table 4.12, C_L can be calculated by equation (3.6) by assuming the time for the PV DG operates is 4 hours. Annual C_L for 69-bus system from PSO, GSA and IGSA optimisation methods are RM 16,260.04, RM 16,239.62 and RM 16,157.91 respectively using the FiT rates of RM 0.4651 from SEDA Portal for PV system. The lowest C_L calculated is from IGSA because from the optimisation result IGSA gives the best fitness value compared to PSO and GSA.

Table 4.13: Costs of Power Loss (C_L) in 69-Bus System from PSO

Month	Days	FiT Rate (RM)	Loss (kW)	Hours	C_L (RM)
Jan-16	31	0.4651	23.88	4	1377.22
Feb-16	29	0.4651	23.88	4	1288.36
Mar-16	31	0.4651	23.88	4	1377.22
Apr-16	30	0.4651	23.88	4	1332.79
May-16	31	0.4651	23.88	4	1377.22
Jun-16	30	0.4651	23.88	4	1332.79
Jul-16	31	0.4651	23.88	4	1377.22
Aug-16	31	0.4651	23.88	4	1377.22
Sep-16	30	0.4651	23.88	4	1332.79
Oct-16	31	0.4651	23.88	4	1377.22
Nov-16	30	0.4651	23.88	4	1332.79
Dec-16	31	0.4651	23.88	4	1377.22
			Annual C_L		16,260.04

Table 4.14: Costs of Power Loss (C_L) in 69-Bus System from GSA

Month	Days	FiT Rate (RM)	Loss (kW)	Hours	C_L (RM)
Jan-16	31	0.4651	23.85	4	1375.49
Feb-16	29	0.4651	23.85	4	1286.75
Mar-16	31	0.4651	23.85	4	1375.49
Apr-16	30	0.4651	23.85	4	1331.12
May-16	31	0.4651	23.85	4	1375.49
Jun-16	30	0.4651	23.85	4	1331.12
Jul-16	31	0.4651	23.85	4	1375.49
Aug-16	31	0.4651	23.85	4	1375.49
Sep-16	30	0.4651	23.85	4	1331.12
Oct-16	31	0.4651	23.85	4	1375.49
Nov-16	30	0.4651	23.85	4	1331.12
Dec-16	31	0.4651	23.85	4	1375.49
			Annual C_L		16,239.62

Table 4.15: Costs of Power Loss (C_L) in 69-Bus System from IGSA

Month	Days	FiT Rate (RM)	Loss (kW)	Hours	C_L (RM)
Jan-16	31	0.4651	23.73	4	1368.57
Feb-16	29	0.4651	23.73	4	1280.27
Mar-16	31	0.4651	23.73	4	1368.57
Apr-16	30	0.4651	23.73	4	1324.42
May-16	31	0.4651	23.73	4	1368.57
Jun-16	30	0.4651	23.73	4	1324.42
Jul-16	31	0.4651	23.73	4	1368.57
Aug-16	31	0.4651	23.73	4	1368.57
Sep-16	30	0.4651	23.73	4	1324.42
Oct-16	31	0.4651	23.73	4	1368.57
Nov-16	30	0.4651	23.73	4	1324.42
Dec-16	31	0.4651	23.73	4	1368.57
			Annual C_L		16,157.91

Table 4.16, 4.17 and 4.18 show Costs of Generation (C_{DG}) of Monocrystalline PV system from PSO, GSA and IGSA respectively for 12 months in 2016 with FiT rate RM 0.4651. From the optimisation result obtained in Table 4.12, the optimum size for DG are known and C_{DG} can be calculated by Equation (3.7). The efficiency for Monocrystalline PV System is 76.43% refer to [3] and by assuming the operating time by PV DG is 4 hours. Annual C_{DG} for Monocrystalline PV System in 69-Bus System from PSO, GSA and IGSA is RM 821,894.19, RM 766,313.68 and RM 670,244.75 respectively.

Table 4.16: Costs of Generation (C_{DG}) for Monocrystalline PV System in 69-Bus System from PSO

Month	**Days**	**FiT Rate (RM)**	**DG Size (kW)**	**Hours**	**η Mono (%)**	**C_{DG} (RM)**
Jan-16	31	0.4651	1579.3	4	0.7643	69,613.99
Feb-16	29	0.4651	1579.3	4	0.7643	65,122.76
Mar-16	31	0.4651	1579.3	4	0.7643	69,613.99
Apr-16	30	0.4651	1579.3	4	0.7643	67,368.38
May-16	31	0.4651	1579.3	4	0.7643	69,613.99
Jun-16	30	0.4651	1579.3	4	0.7643	67,368.38
Jul-16	31	0.4651	1579.3	4	0.7643	69,613.99
Aug-16	31	0.4651	1579.3	4	0.7643	69,613.99
Sep-16	30	0.4651	1579.3	4	0.7643	67,368.38
Oct-16	31	0.4651	1579.3	4	0.7643	69,613.99
Nov-16	30	0.4651	1579.3	4	0.7643	67,368.38
Dec-16	31	0.4651	1579.3	4	0.7643	69,613.99
					Annual C_{DG}	821,894.19

Table 4.17: Costs of Generation (C_{DG}) for Monocrystalline PV System in 69-Bus System from GSA

Month	Days	FiT Rate (RM)	DG Size (kW)	Hours	η Mono (%)	C_{DG} (RM)
Jan-16	31	0.4651	1472.5	4	0.7643	64,906.35
Feb-16	29	0.4651	1472.5	4	0.7643	60,718.84
Mar-16	31	0.4651	1472.5	4	0.7643	64,906.35
Apr-16	30	0.4651	1472.5	4	0.7643	62,812.60
May-16	31	0.4651	1472.5	4	0.7643	64,906.35
Jun-16	30	0.4651	1472.5	4	0.7643	62,812.60
Jul-16	31	0.4651	1472.5	4	0.7643	64,906.35
Aug-16	31	0.4651	1472.5	4	0.7643	64,906.35
Sep-16	30	0.4651	1472.5	4	0.7643	62,812.60
Oct-16	31	0.4651	1472.5	4	0.7643	64,906.35
Nov-16	30	0.4651	1472.5	4	0.7643	62,812.60
Dec-16	31	0.4651	1472.5	4	0.7643	64,906.35
					Annual C_{DG}	766,313.68

Table 4.18: Costs of Generation (C_{DG}) for Monocrystalline PV System in 69-Bus System from IGSA

Month	Days	FiT Rate (RM)	DG Size (kW)	Hours	η Mono (%)	C_{DG} (RM)
Jan-16	31	0.4651	1287.9	4	0.7643	56,769.36
Feb-16	29	0.4651	1287.9	4	0.7643	53,106.82
Mar-16	31	0.4651	1287.9	4	0.7643	56,769.36
Apr-16	30	0.4651	1287.9	4	0.7643	54,938.09
May-16	31	0.4651	1287.9	4	0.7643	56,769.36
Jun-16	30	0.4651	1287.9	4	0.7643	54,938.09
Jul-16	31	0.4651	1287.9	4	0.7643	56,769.36
Aug-16	31	0.4651	1287.9	4	0.7643	56,769.36
Sep-16	30	0.4651	1287.9	4	0.7643	54,938.09
Oct-16	31	0.4651	1287.9	4	0.7643	56,769.36
Nov-16	30	0.4651	1287.9	4	0.7643	54,938.09
Dec-16	31	0.4651	1287.9	4	0.7643	56,769.36
					Annual C_{DG}	670,244.75

Table 4.19, 4.20 and 4.21 show Costs of Generation (C_{DG}) of Thin-film PV system from PSO, GSA and IGSA respectively for 12 months in 2016 with FiT rate RM 0.4651. From the optimisation result obtained in Table 4.12, the optimum size for DG are known and C_{DG} can be calculated by Equation (3.7). The efficiency for Thin-film PV System is 86.63% refer to [3] and by assuming the operating time by PV DG is 4 hours. Annual C_{DG} for Thin-film PV System in 69-Bus System from PSO, GSA and IGSA is RM 931,580.45, RM 868,582.42 and RM 759,692.56 respectively.

Table 4.19: Costs of Generation (C_{DG}) for Thin-film PV System in 69-Bus System from PSO

Month	Days	FiT Rate (RM)	DG Size (kW)	Hours	η TF (%)	C_{DG} (RM)
Jan-16	31	0.4651	1579.3	4	0.8663	78,904.36
Feb-16	29	0.4651	1579.3	4	0.8663	73,813.75
Mar-16	31	0.4651	1579.3	4	0.8663	78,904.36
Apr-16	30	0.4651	1579.3	4	0.8663	76,359.05
May-16	31	0.4651	1579.3	4	0.8663	78,904.36
Jun-16	30	0.4651	1579.3	4	0.8663	76,359.05
Jul-16	31	0.4651	1579.3	4	0.8663	78,904.36
Aug-16	31	0.4651	1579.3	4	0.8663	78,904.36
Sep-16	30	0.4651	1579.3	4	0.8663	76,359.05
Oct-16	31	0.4651	1579.3	4	0.8663	78,904.36
Nov-16	30	0.4651	1579.3	4	0.8663	76,359.05
Dec-16	31	0.4651	1579.3	4	0.8663	78,904.36
					Annual C_{DG}	931,580.45

Table 4.20: Costs of Generation (C_{DG}) for Thin-film PV System in 69-Bus System from GSA

Month	Days	FiT Rate (RM)	DG Size (kW)	Hours	η TF (%)	C_{DG} (RM)
Jan-16	31	0.4651	1472.5	4	0.8663	73,568.46
Feb-16	29	0.4651	1472.5	4	0.8663	68,822.10
Mar-16	31	0.4651	1472.5	4	0.8663	73,568.46
Apr-16	30	0.4651	1472.5	4	0.8663	71,195.28
May-16	31	0.4651	1472.5	4	0.8663	73,568.46
Jun-16	30	0.4651	1472.5	4	0.8663	71,195.28
Jul-16	31	0.4651	1472.5	4	0.8663	73,568.46
Aug-16	31	0.4651	1472.5	4	0.8663	73,568.46
Sep-16	30	0.4651	1472.5	4	0.8663	71,195.28
Oct-16	31	0.4651	1472.5	4	0.8663	73,568.46
Nov-16	30	0.4651	1472.5	4	0.8663	71,195.28
Dec-16	31	0.4651	1472.5	4	0.8663	73,568.46
					Annual C_{DG}	868,582.42

Table 4.21: Costs of Generation (C_{DG}) for Thin-film PV System in 69-Bus System from IGSA

Month	Days	FiT Rate (RM)	DG Size (kW)	Hours	η TF (%)	C_{DG} (RM)
Jan-16	31	0.4651	1287.9	4	0.8663	64,345.54
Feb-16	29	0.4651	1287.9	4	0.8663	60,194.22
Mar-16	31	0.4651	1287.9	4	0.8663	64,345.54
Apr-16	30	0.4651	1287.9	4	0.8663	62,269.88
May-16	31	0.4651	1287.9	4	0.8663	64,345.54
Jun-16	30	0.4651	1287.9	4	0.8663	62,269.88
Jul-16	31	0.4651	1287.9	4	0.8663	64,345.54
Aug-16	31	0.4651	1287.9	4	0.8663	64,345.54
Sep-16	30	0.4651	1287.9	4	0.8663	62,269.88
Oct-16	31	0.4651	1287.9	4	0.8663	64,345.54
Nov-16	30	0.4651	1287.9	4	0.8663	62,269.88
Dec-16	31	0.4651	1287.9	4	0.8663	64,345.54
					Annual C_{DG}	759,692.56

Table 4.22 summarised the Costs of Operation Planning (C_P) which includes investment cost (C_I), maintenance cost (C_M), power loss cost (C_L) and generation cost (C_{DG}). For the case study, the investment cost for Monocrystalline is fixed to RM 14.50/W and for Thin-film is fixed to RM 14.00/W. From the optimisation results obtained in Table 4.12, the DG size for Monocrystalline and Thin-film PV systems in 69-bus are known for all three methods. From the DG size, the C_I can be determined while C_M is 1% from C_I as mentioned earlier in the case study section. Thus, the C_P can be calculated using equation (3.5). The annual C_P for Monocrystalline PV in 69-bus system from PSO, GSA and IGSA is RM 22,323,214.35, RM 20,854,229.94 and RM 18,207,208.66 respectively. The annual C_P for Thin-film PV in 69-bus system from PSO, GSA and IGSA is RM 21,415,981.59, RM 20,006,985.20 and RM 17,467,371.35 respectively. Thin-film PV system with IGSA gives the best and lowest C_P among others which is RM 17,467,371.35. The first reason is the losses after installation of DG in the 69-bus system is the lowest compared to PSO and GSA. The second reason is the price of the Thin-film is cheaper than Monocrystalline thus resulting in a lower cost of investment and maintenance. Also, the Thin-film has higher efficiency than Monocrystalline, which results in higher C_{DG} and considering overall costs included, the C_P of Thin-film is the lowest.

Table 4.22: Summary for Costs of Operation Planning (C_P) in 69-Bus System

	Monocrystalline			**Thin-film**		
	PSO	**GSA**	**IGSA**	**PSO**	**GSA**	**IGSA**
Investment Cost, C_I (RM)	22,899,850.00	21,390,400.00	18,674,550.00	22,110,200.00	20,652,800.00	18,030,600.00
Maintenance Cost, C_M (RM)	228,998.50	213,904.00	186,745.50	221,102.00	206,528.00	180,306.00
Power Loss Cost, C_L (RM)	16,260.04	16,239.62	16,157.91	16,260.04	16,239.62	16,157.91
Generation Cost, C_{DG} (RM)	821,894.19	766,313.68	670,244.75	931,580.45	868,582.42	759,692.56
Total Costs of Operation Planning, C_P (RM)	**22,323,214.35**	**20,854,229.94**	**18,207,208.66**	**21,415,981.59**	**20,006,985.20**	**17,467,371.35**

4.4 Results Comparison of Test Systems

Table 4.23 shows the performance of PSO, GSA and IGSA. For both bus system, the IGSA technique has obtained the best optimal solution with the lowest fitness. After installation of DG in the bus system, the power loss has significantly drop compared to system without installation of DG as shown in Figure 4.3. This is because the installation of additional generation, DG has significant impact in terms of reduction of total power loss.

Table 4.23: Performance of PSO, GSA and IGSA in 34 and 69-Bus System

Bus System	Techniques	Worst fitness	Average fitness	Best fitness	Standard deviation	Average elapsed time
34	PSO	0.0757	0.0667	0.0438	0.0063	38.6864
	GSA	0.0775	0.0663	0.0412	0.0093	26.9951
	IGSA	0.0903	0.0663	0.0361	0.0094	42.2088
69	PSO	0.0704	0.0311	0.0239	0.0091	43.7886
	GSA	0.0518	0.0335	0.0238	0.0085	39.4227
	IGSA	0.0430	0.0301	0.0237	0.0052	45.5565

In Figure 4.3, before the DG installation for 34-bus system and 69-bus system, the losses are 224.90 and 229.80, respectively in kW. After the installation of DG with the optimisation methods applied, the losses for both bus system have significantly decreases. In comparison for both bus system, the losses in 69-bus system are lower compare to 34-bus system after applying the optimisation methods. This also results in the power loss cost (C_L) is lower in 69-bus system.

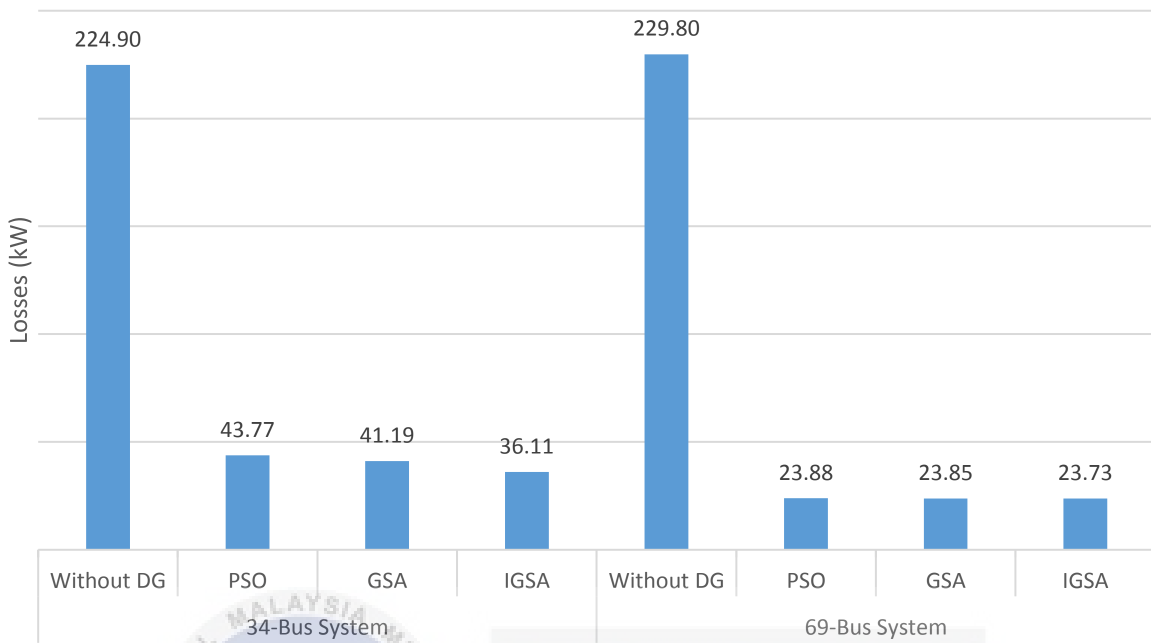

Figure 4.3: Power Losses Before and After Installation of DG in 34-Bus System and 69-Bus System

It is noted that the DG size of Figure 4.4 is larger than Figure 4.5. This is because the total connected load of 34-bus system is higher than 69-bus system referring Appendix B and Appendix D. By relating the Costs of Operation Planning (C_P) with the optimal DG size, it shows that the C_P decreases when the DG size is smaller. Therefore, to obtain a better C_P, a smaller PV DG size is preferred.

The optimal sizing of PV DG obtained in 34-bus system shows in Table 4.1 are larger size compare to 69-bus system shows in Table 4.12 for all three optimisation methods. The larger sizing of PV DG and the higher losses in 34-bus system result in higher investment cost (C_I), maintenance cost (C_M), power loss cost (C_L) and generation cost (C_{DG}). In additional, the C_{DG} is mainly depend on the performance efficiency of the type of PV. Thin-film PV which has higher performance efficiency than Monocrystalline PV is having higher C_{DG}. But it is an advantage to have higher C_{DG} in the C_P as it is a good income and generating more power for the distribution system.

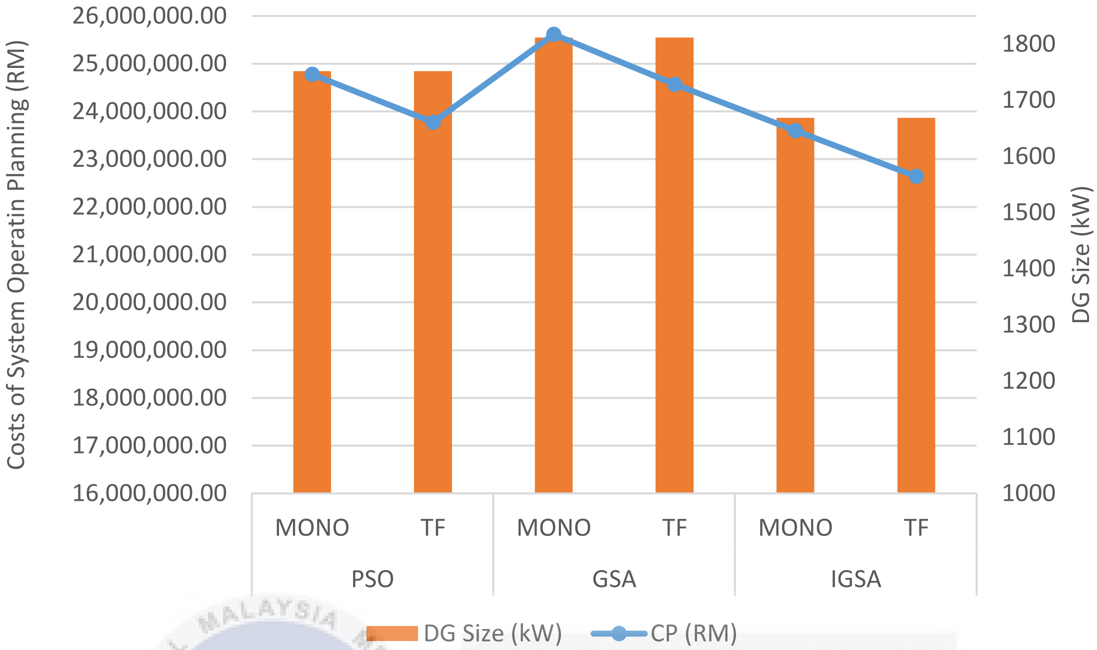

Figure 4.4: Correlation between Costs of Operation Planning (C_P) and DG Size in 34-Bus System

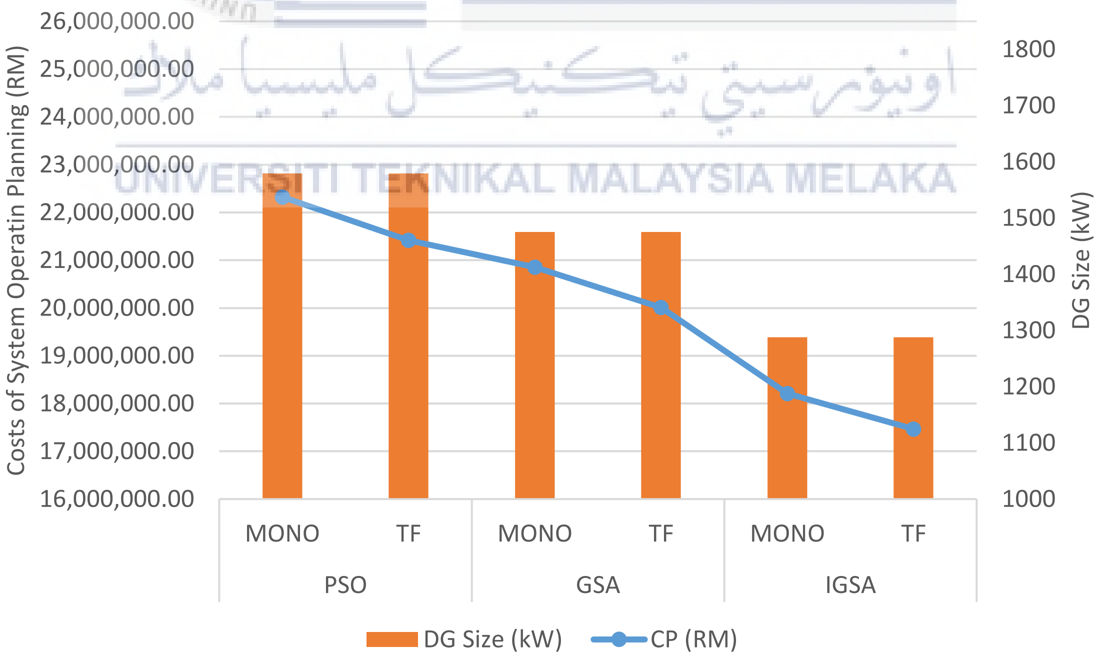

Figure 4.5: Correlation between Costs of Operation Planning (C_P) and DG Size in 69-Bus System

4.5 Chapter Summary

In summary, this chapter presents all the optimisation results performed by PSO, GSA and IGSA. The convergence characteristics of proposed method IGSA is compared with the PSO and GSA and it shows that the proposed method IGSA is performed better in finding the optimal placement and sizing of DG. IGSA obtained the best fitness value in both 34-bus system and 69-bus system. From the optimisation methods, the optimal placement and sizing of DG are able to obtain and based on the optimal results, the investment cost (C_I), maintenance cost (C_M), power loss cost (C_L) and generation cost (C_{DG}) are calculated and tabulated. Lastly, the total annual Costs of Operation Planning (C_P) in 2016 are compared between each case and the results show that the Thin-film PV DG with IGSA optimisation is the best type of PV DG to be installed in both 34-bus system and 69-bus system.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, the optimal placement and sizing of Photovoltaic DG in 34-bus system is at bus 4 with 1.6689 MW, while in 69-bus system is at bus 51 with 1.2879 MW. The first objective is achieved by using the optimisation method and proposed IGSA is effective in finding optimum size and location of DG in a power distribution system compare to PSO and GSA. The objective function is to minimise power loss and costs of operation planning, C_P. The power losses after the installation of DG in the power system has significantly reduces due to the power generation are nearer to the load. The attainment of effectiveness of IGSA in finding optimal placement and sizing of DG is the measure of second objective. From the analysis, the total Costs of Operation Planning, C_P of Thin-film PV system are cheaper than Monocrystalline PV system based on the investment cost, maintenance cost, power losses cost and generation cost. Thus, Thin-film PV system is preferable to be installed as DG in the IEEE 34-bus system and IEEE 69-bus system as the costs of operation planning are cheaper in both bus systems and this attained the last objective of this study. The results show that by using proposed IGSA method, the Costs of Operation Planning, C_P obtained is the lowest compared to the PSO and GSA.

5.2 Recommendation

In future research work, instead of only determining which algorithm gives the best fitness value and convergence rate, the total voltage harmonic distortion (THDv) can be also considered after the installation of DG in the power system. Besides, apart from Photovoltaic type DG, others renewable type of DG such as wind power and hydroelectricity can be include in the study, compare which is the most suitable and not only in Malaysia.

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APPENDIX A

Gantt Chart

Month / Tasks	FYP 1				FYP 2					
	September	October	November	December	January	February	March	April	May	June
Briefing										
Preliminary Research										
Introduction										
Literature Review										
Methodology										
Analysis										
Submission of Draft Report										
Presentation FYP 1										
Report Writing										
Presentation FYP 2										
Project Finalize and Checking										

APPENDIX B

Bus Data for IEEE 34-Bus System

Bus_i	Type	Pd	Qd	Ps	Gs	Area	Vm	Va	basekV	Zone	Vmax	Vmin
1	3	0	0	0	0	1	1	0	11	1	1.05	0.9
2	1	0.23	0.1425	0	0	1	1	0	11	1	1.05	0.9
3	1	0	0	0	0	1	1	0	11	1	1.05	0.9
4	1	0.23	0.1425	0	0	1	1	0	11	1	1	0.9
5	1	0.23	0.1425	0	0	1	1	0	11	1	1	0.9
6	1	0	0	0	0	1	1	0	11	1	1.05	0.9
7	1	0	0	0	0	1	1	0	11	1	1.05	0.9
8	1	0.23	0.1425	0	0	1	1	0	11	1	1.05	0.9
9	1	0.23	0.1425	0	0	1	1	0	11	1	1.05	0.9
10	1	0	0	0	0	1	1	0	11	1	1.05	0.9
11	1	0.23	0.1425	0	0	1	1	0	11	1	1.05	0.9
12	1	0.137	0.084	0	0	1	1	0	11	1	1.05	0.9
13	1	0.072	0.045	0	0	1	1	0	11	1	1.05	0.9
14	1	0.072	0.045	0	0	1	1	0	11	1	1.05	0.9
15	1	0.072	0.045	0	0	1	1	0	11	1	1.05	0.9
16	1	0.0135	0.0075	0	0	1	1	0	11	1	1.05	0.9
17	1	0.23	0.1425	0	0	1	1	0	11	1	1.05	0.9
18	1	0.23	0.1425	0	0	1	1	0	11	1	1.05	0.9
19	1	0.23	0.1425	0	0	1	1	0	11	1	1.05	0.9
20	1	0.23	0.1425	0	0	1	1	0	11	1	1.05	0.9
21	1	0.23	0.1425	0	0	1	1	0	11	1	1.05	0.9
22	1	0.23	0.1425	0	0	1	1	0	11	1	1.05	0.9
23	1	0.23	0.1425	0	0	1	1	0	11	1	1.05	0.9
24	1	0.23	0.1425	0	0	1	1	0	11	1	1.05	0.9
25	1	0.23	0.1425	0	0	1	1	0	11	1	1.05	0.9
26	1	0.23	0.1425	0	0	1	1	0	11	1	1.05	0.9

27	1	0.137	0.085	0	0	1	1	0	11	1	1.05	0.9
28	1	0.075	0.048	0	0	1	1	0	11	1	1.05	0.9
29	1	0.075	0.048	0	0	1	1	0	11	1	1.05	0.9
30	1	0.075	0.048	0	0	1	1	0	11	1	1.05	0.9
31	1	0.057	0.0345	0	0	1	1	0	11	1	1.05	0.9
32	1	0.057	0.0345	0	0	1	1	0	11	1	1.05	0.9
33	1	0.057	0.0345	0	0	1	1	0	11	1	1.05	0.9
34	1	0.057	0.0345	0	0	1	1	0	11	1	1.05	0.9

APPENDIX C

Branch Data for IEEE 34-Bus System

fbus	rbus	r	x	b	rateA	rateB	rateC	ratio	angle	status	angmin	angmax
1	2	0.09669	0.03966	0	9900	0	0	0	0	1	-360	360
2	3	0.08863	0.03636	0	9900	0	0	0	0	1	-360	360
3	4	0.1359	0.03772	0	9900	0	0	0	0	1	-360	360
4	5	0.1359	0.03772	0	9900	0	0	0	0	1	-360	360
5	6	0.12355	0.03429	0	9900	0	0	0	0	1	-360	360
6	7	0.25983	0.04462	0	9900	0	0	0	0	1	-360	360
7	8	0.17322	0.02975	0	9900	0	0	0	0	1	-360	360
8	9	0.25983	0.04462	0	9900	0	0	0	0	1	-360	360
9	10	0.17322	0.02975	0	9900	0	0	0	0	1	-360	360
10	11	0.10826	0.01859	0	9900	0	0	0	0	1	-360	360
11	12	0.08661	0.01487	0	9900	0	0	0	0	1	-360	360
3	13	0.12991	0.02231	0	9900	0	0	0	0	1	-360	360
13	14	0.17322	0.02975	0	9900	0	0	0	0	1	-360	360
14	15	0.08661	0.01487	0	9900	0	0	0	0	1	-360	360
15	16	0.0433	0.00743	0	9900	0	0	0	0	1	-360	360
6	17	0.14826	0.04115	0	9900	0	0	0	0	1	-360	360
17	18	0.1359	0.03772	0	9900	0	0	0	0	1	-360	360
18	19	0.17181	0.03909	0	9900	0	0	0	0	1	-360	360
19	20	0.15619	0.03553	0	9900	0	0	0	0	1	-360	360
20	21	0.15619	0.03553	0	9900	0	0	0	0	1	-360	360
21	22	0.21652	0.03719	0	9900	0	0	0	0	1	-360	360
22	23	0.21652	0.03719	0	9900	0	0	0	0	1	-360	360
23	24	0.25983	0.04462	0	9900	0	0	0	0	1	-360	360
24	25	0.17322	0.02975	0	9900	0	0	0	0	1	-360	360
25	26	0.10826	0.01859	0	9900	0	0	0	0	1	-360	360
26	27	0.08661	0.01487	0	9900	0	0	0	0	1	-360	360

7	28	0.12991	0.02231	0	9900	0	0	0	0	1	-360	360
28	29	0.12991	0.02231	0	9900	0	0	0	0	1	-360	360
29	30	0.12991	0.02231	0	9900	0	0	0	0	1	-360	360
10	31	0.12991	0.02231	0	9900	0	0	0	0	1	-360	360
31	32	0.17322	0.02975	0	9900	0	0	0	0	1	-360	360
32	33	0.12991	0.02231	0	9900	0	0	0	0	1	-360	360
33	34	0.08661	0.01487	0	9900	0	0	0	0	1	-360	360

APPENDIX D

Bus Data for IEEE 69-Bus System

Bus_i	Type	Pd	Qd	Ps	Gs	Area	Vm	Va	basekV	Zone	Vmax	Vmin
1	3	0	0	0	0	1	1	0	12.66	1	1.05	0.9
2	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
3	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
4	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
5	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
6	1	0.0026	0.0022	0	0	1	1	0	12.66	1	1.05	0.9
7	1	0.0404	0.03	0	0	1	1	0	12.66	1	1.05	0.9
8	1	0.075	0.054	0	0	1	1	0	12.66	1	1.05	0.9
9	1	0.03	0.022	0	0	1	1	0	12.66	1	1.05	0.9
10	1	0.028	0.019	0	0	1	1	0	12.66	1	1.05	0.9
11	1	0.145	0.104	0	0	1	1	0	12.66	1	1.05	0.9
12	1	0.145	0.104	0	0	1	1	0	12.66	1	1.05	0.9
13	1	0.008	0.0055	0	0	1	1	0	12.66	1	1.05	0.9
14	1	0.008	0.0055	0	0	1	1	0	12.66	1	1.05	0.9
15	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
16	1	0.0455	0.03	0	0	1	1	0	12.66	1	1.05	0.9
17	1	0.06	0.035	0	0	1	1	0	12.66	1	1.05	0.9
18	1	0.06	0.035	0	0	1	1	0	12.66	1	1.05	0.9
19	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
20	1	0.001	0.0006	0	0	1	1	0	12.66	1	1.05	0.9
21	1	0.114	0.081	0	0	1	1	0	12.66	1	1.05	0.9
22	1	0.0053	0.0035	0	0	1	1	0	12.66	1	1.05	0.9
23	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
24	1	0.028	0.02	0	0	1	1	0	12.66	1	1.05	0.9
25	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
26	1	0.014	0.01	0	0	1	1	0	12.66	1	1.05	0.9
27	1	0.014	0.01	0	0	1	1	0	12.66	1	1.05	0.9

28	1	0.026	0.0186	0	0	1	1	0	12.66	1	1.05	0.9
29	1	0.026	0.0186	0	0	1	1	0	12.66	1	1.05	0.9
30	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
31	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
32	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
33	1	0.014	0.01	0	0	1	1	0	12.66	1	1.05	0.9
34	1	0.0195	0.014	0	0	1	1	0	12.66	1	1.05	0.9
35	1	0.006	0.004	0	0	1	1	0	12.66	1	1.05	0.9
36	1	0.026	0.01855	0	0	1	1	0	12.66	1	1.05	0.9
37	1	0.026	0.01855	0	0	1	1	0	12.66	1	1.05	0.9
38	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
39	1	0.024	0.017	0	0	1	1	0	12.66	1	1.05	0.9
40	1	0.024	0.017	0	0	1	1	0	12.66	1	1.05	0.9
41	1	0.0012	0.001	0	0	1	1	0	12.66	1	1.05	0.9
42	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
43	1	0.006	0.0043	0	0	1	1	0	12.66	1	1.05	0.9
44	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
45	1	0.03922	0.0263	0	0	1	1	0	12.66	1	1.05	0.9
46	1	0.03922	0.0263	0	0	1	1	0	12.66	1	1.05	0.9
47	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
48	1	0.079	0.0564	0	0	1	1	0	12.66	1	1.05	0.9
49	1	0.3847	0.2745	0	0	1	1	0	12.66	1	1.05	0.9
50	1	0.3847	0.2745	0	0	1	1	0	12.66	1	1.05	0.9
51	1	0.0405	0.0283	0	0	1	1	0	12.66	1	1.05	0.9
52	1	0.0036	0.0027	0	0	1	1	0	12.66	1	1.05	0.9
53	1	0.00435	0.0035	0	0	1	1	0	12.66	1	1.05	0.9
54	1	0.0264	0.019	0	0	1	1	0	12.66	1	1.05	0.9
55	1	0.024	0.0172	0	0	1	1	0	12.66	1	1.05	0.9
56	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
57	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
58	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9

59	1	0.1	0.072	0	0	1	1	0	12.66	1	1.05	0.9
60	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
61	1	1.244	0.888	0	0	1	1	0	12.66	1	1.05	0.9
62	1	0.032	0.023	0	0	1	1	0	12.66	1	1.05	0.9
63	1	0	0	0	0	1	1	0	12.66	1	1.05	0.9
64	1	0.227	0.162	0	0	1	1	0	12.66	1	1.05	0.9
65	1	0.059	0.042	0	0	1	1	0	12.66	1	1.05	0.9
66	1	0.018	0.013	0	0	1	1	0	12.66	1	1.05	0.9
67	1	0.018	0.013	0	0	1	1	0	12.66	1	1.05	0.9
68	1	0.028	0.02	0	0	1	1	0	12.66	1	1.05	0.9
69	1	0.028	0.02	0	0	1	1	0	12.66	1	1.05	0.9

APPENDIX E

Branch Data for IEEE 69-Bus System

fbus	rbus	r	x	b	rateA	rateB	rateC	ratio	angle	status	angmin	angmax
1	2	0.000312	0.000749	0	9900	0	0	0	0	1	-360	360
2	3	0.000312	0.000749	0	9900	0	0	0	0	1	-360	360
3	4	0.000936	0.002247	0	9900	0	0	0	0	1	-360	360
4	5	0.015668	0.018352	0	9900	0	0	0	0	1	-360	360
5	6	0.228464	0.116355	0	9900	0	0	0	0	1	-360	360
6	7	0.23789	0.121161	0	9900	0	0	0	0	1	-360	360
7	8	0.0922	0.029338	0	9900	0	0	0	0	1	-360	360
8	9	0.030774	0.015668	0	9900	0	0	0	0	1	-360	360
9	10	0.511236	0.168976	0	9900	0	0	0	0	1	-360	360
10	11	0.116854	0.038639	0	9900	0	0	0	0	1	-360	360
11	12	0.44407	0.146754	0	9900	0	0	0	0	1	-360	360
12	13	0.642946	0.212235	0	9900	0	0	0	0	1	-360	360
13	14	0.651685	0.215356	0	9900	0	0	0	0	1	-360	360

14	15	0.660424	0.218227	0	9900	0	0	0	0	1	-360	360
15	16	0.122722	0.040574	0	9900	0	0	0	0	1	-360	360
16	17	0.233708	0.077278	0	9900	0	0	0	0	1	-360	360
17	18	0.002934	0.000998	0	9900	0	0	0	0	1	-360	360
18	19	0.204494	0.067603	0	9900	0	0	0	0	1	-360	360
19	20	0.131461	0.043071	0	9900	0	0	0	0	1	-360	360
20	21	0.213233	0.070474	0	9900	0	0	0	0	1	-360	360
21	22	0.008739	0.002871	0	9900	0	0	0	0	1	-360	360
22	23	0.099313	0.032833	0	9900	0	0	0	0	1	-360	360
23	24	0.216167	0.071473	0	9900	0	0	0	0	1	-360	360
24	25	0.467415	0.154494	0	9900	0	0	0	0	1	-360	360
25	26	0.192821	0.063732	0	9900	0	0	0	0	1	-360	360
26	27	0.108115	0.035705	0	9900	0	0	0	0	1	-360	360
3	28	0.002746	0.006742	0	9900	0	0	0	0	1	-360	360
28	29	0.03995	0.09769	0	9900	0	0	0	0	1	-360	360
29	30	0.248315	0.082085	0	9900	0	0	0	0	1	-360	360

30	31	0.04382	0.014482	0	9900	0	0	0	0	1	-360	360
31	32	0.219101	0.072409	0	9900	0	0	0	0	1	-360	360
32	33	0.52372	0.17578	0	9900	0	0	0	0	1	-360	360
33	34	1.066167	0.352434	0	9900	0	0	0	0	1	-360	360
34	35	0.920099	0.304182	0	9900	0	0	0	0	1	-360	360
3	36	0.002746	0.006742	0	9900	0	0	0	0	1	-360	360
36	37	0.03995	0.09769	0	9900	0	0	0	0	1	-360	360
37	38	0.06573	0.076779	0	9900	0	0	0	0	1	-360	360
38	39	0.018976	0.022159	0	9900	0	0	0	0	1	-360	360
39	40	0.001124	0.001311	0	9900	0	0	0	0	1	-360	360
40	41	0.454619	0.531149	0	9900	0	0	0	0	1	-360	360
41	42	0.193508	0.226155	0	9900	0	0	0	0	1	-360	360
42	43	0.025593	0.029838	0	9900	0	0	0	0	1	-360	360
43	44	0.005743	0.007241	0	9900	0	0	0	0	1	-360	360
44	45	0.067977	0.085705	0	9900	0	0	0	0	1	-360	360
45	46	0.000562	0.000749	0	9900	0	0	0	0	1	-360	360

4	47	0.002122	0.005243	0	9900	0	0	0	0	1	-360	360
47	48	0.053121	0.130025	0	9900	0	0	0	0	1	-360	360
48	49	0.180899	0.442634	0	9900	0	0	0	0	1	-360	360
49	50	0.051311	0.125531	0	9900	0	0	0	0	1	-360	360
8	51	0.057928	0.029526	0	9900	0	0	0	0	1	-360	360
51	52	0.207178	0.069538	0	9900	0	0	0	0	1	-360	360
9	53	0.108614	0.055306	0	9900	0	0	0	0	1	-360	360
53	54	0.126717	0.064544	0	9900	0	0	0	0	1	-360	360
54	55	0.177403	0.090325	0	9900	0	0	0	0	1	-360	360
55	56	0.175593	0.089451	0	9900	0	0	0	0	1	-360	360
56	57	0.992509	0.333146	0	9900	0	0	0	0	1	-360	360
57	58	0.489201	0.16417	0	9900	0	0	0	0	1	-360	360
58	59	0.189888	0.062797	0	9900	0	0	0	0	1	-360	360
59	60	0.241011	0.073159	0	9900	0	0	0	0	1	-360	360
60	61	0.316792	0.161361	0	9900	0	0	0	0	1	-360	360

61	62	0.060799	0.030961	0	9900	0	0	0	0	1	-360	360
62	63	0.090512	0.046067	0	9900	0	0	0	0	1	-360	360
63	64	0.443508	0.225905	0	9900	0	0	0	0	1	-360	360
64	65	0.649812	0.330961	0	9900	0	0	0	0	1	-360	360
11	66	0.125593	0.038139	0	9900	0	0	0	0	1	-360	360
66	67	0.002934	0.000873	0	9900	0	0	0	0	1	-360	360
12	68	0.461548	0.152559	0	9900	0	0	0	0	1	-360	360
68	69	0.002934	0.000998	0	9900	0	0	0	0	1	-360	360

APPENDIX F

Fitness Value For 30 Times Simulation Runs

34-Bus System			69-Bus System		
PSO	GSA	IGSA	PSO	GSA	IGSA
0.0640	0.0775	0.0646	0.0239	0.0285	0.0317
0.0438	0.0462	0.0621	0.0371	0.0296	0.0259
0.0757	0.0685	0.0683	0.0321	0.0476	0.0273
0.0658	0.0690	0.0653	0.0266	0.0328	0.0267
0.0683	0.0697	0.0661	0.0267	0.0364	0.0364
0.0520	0.0711	0.0610	0.0269	0.0256	0.0293
0.0648	0.0652	0.0361	0.0258	0.0256	0.0293
0.0607	0.0637	0.0903	0.0248	0.0251	0.0289
0.0706	0.0705	0.0573	0.0280	0.0265	0.0334
0.0707	0.0646	0.0629	0.0343	0.0353	0.0303
0.0674	0.0719	0.0658	0.0277	0.0292	0.0254
0.0700	0.0705	0.0697	0.0283	0.0452	0.0250
0.0644	0.0618	0.0765	0.0256	0.0293	0.0334
0.0712	0.0694	0.0668	0.0269	0.0256	0.0338
0.0731	0.0482	0.0689	0.0458	0.0279	0.0242
0.0683	0.0645	0.0654	0.0313	0.0284	0.0380
0.0675	0.0636	0.0672	0.0331	0.0448	0.0262
0.0680	0.0673	0.0667	0.0299	0.0262	0.0294
0.0678	0.0772	0.0741	0.0342	0.0461	0.0237
0.0679	0.0412	0.0675	0.0324	0.0264	0.0275
0.0659	0.0670	0.0870	0.0417	0.0238	0.0411
0.0690	0.0677	0.0669	0.0273	0.0303	0.0263
0.0609	0.0682	0.0694	0.0240	0.0330	0.0294
0.0671	0.0864	0.0604	0.0249	0.0455	0.0245
0.0698	0.0717	0.0518	0.0255	0.0324	0.0268
0.0723	0.0507	0.0648	0.0343	0.0326	0.0402
0.0731	0.0684	0.0643	0.0261	0.0258	0.0430
0.0626	0.0647	0.0716	0.0258	0.0518	0.0298
0.0667	0.0686	0.0647	0.0309	0.0495	0.0296
0.0710	0.0732	0.0669	0.0704	0.0373	0.0265