An-Najah National University
Faculty of Graduate Studies

Optimal Sizing and Placement of Distributed Generation Using an Improved Particle Swarm Optimization (IPSO) Method for Power Loss Reduction and Voltage Stability Improvement

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This Thesis is Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Electrical Power Engineering, Faculty of Graduate Studies, An-Najah National University, Nablus-Palestine.
2018

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Dedication

To my father, my mother, brothers, sisters and family in law.

To my husband, my daughters.

To all my friends and colleagues.

Acknowledgment

I would like to thank my research supervisors Dr. Tamer Khatib and Dr. Maher Khammash. My thanks are also given to Electrical Power Engineering Master Program members at An-Najah National University and all people who has helped me in conducting this research.

الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

Optimal Sizing and Placement of Distributed Generation Using an Improved Particle Swarm Optimization (IPSO) for Power loss Reduction and Voltage Stability Improvement

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Declaration

The work provided in this thesis, unless otherwise referenced is the researcher's own work and has not been submitted elsewhere for any other degree or qualification.

Student's name: **اسم الطالب:**

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List of Abbreviations

ABC	Artificial Bee Colony
ACS	An Ant colony System Algorithm
AIS	Artificial Immune System
CHP	Combine Heat and Power
CIGRE	International Council on large Electric system
DE	Differential Evolution
DG	Distributed Generation
DP	Dynamic Programming
EHV	Extra High Voltage
FA	Firefly Algorithm
FC	Fuel Cell
GA	Genetic Algorithm
GSA	Gravitational Search Algorithm
HAS	Harmony Search Algorithm
HS	Harmony Search
HV	High Voltage
IEEE	Institute of Electric and Electronic Engineering
IEPSO	Improved Evolutionary Particle Swarm optimization
IGSA	Improved Gravitational Search Algorithm
IPSO	Improved Particle Swarm Optimization
KCL	Kirchhoff Current Law
KW	Kilo -Watt
LP	Linear Programming
LEA	Local Escape Algorithm
MT	Micro – Turbine
MW	Mega – Watt

MVA	Mega Volt Ampere
Mvar	Mega Volt Ampere Reactive
NLP	Nonlinear Programming
ODGP	Optimal Distributed Generation Placement
OSG	On- Site Generation
OO	Ordinal Optimization
P	Active Power
PFDE	Pareto Frontier Differential Evolution
PSO	Particle Swarm Optimization
PV	Photo Voltaic
PVDG	Photo Voltaic Generation Placement
pu	Per Unit System
Q	Reactive Power
SA	Simulated Annealing
SAIDI	System Average Interruption Duration Index
SAVDM	System Average Voltage Dip Magnitude
SQP	Sequential Quadratic Programming
THD	Total Harmonic Distortion
T.L	Transmission Line
TS	Tabu Search
UHV	Ultra High Voltage
VSM	Voltage Stability
WP	Work Package
WT	Wind Turbine

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Abstract

The integration of distributed generation (DG) units in power distribution networks has become very important field in recent years. The aim of the optimal DG planning is to provide the best locations and sizes of DGs to optimize electrical distribution network operation taking into account DG capacity constraints. In this thesis an improved particle swarm optimization method (IPSO) is proposed to optimally choose suitable DG unit in accordance to DG size and location so as to improve voltage profile and reduce active power losses. IEEE 34 distribution bus system is used as a case study for this research. A new equation of weight inertia is proposed so as to improve the performance of conventional PSO algorithm. This development is done by controlling the inertia weight which affects the updating velocity of particles in the algorithm. Maltab codes are developed for electric power system, improved PSO algorithm and power flow analysis so as to conduct the research. Results show that the applied conventional PSO algorithm successfully finds the optimal size and location of the desired DG unit with a capacity of 1.6722 MW at bus number 10. This makes the voltage magnitude equals to 1.0055 pu and improves the status of the power system in general. The minimum value of fitness losses using the applied algorithm is 0.0406 while average elapse time is 78.6212 s. In addition to that, the applied PSO algorithm reduces the active power losses by 31.61%. As a comparison, conventional PSO algorithm that is based on linear inertia weight equations consumes 78.6212 s and 69.0836 s to provide the optimum solution. In the meanwhile, the proposed algorithm consumes 62.2325 s to provide the optimum solution

Chapter one
Introduction

1.1 Background

Electric energy represents a big percentage of the total energy consumption all over the world. Currently this consumption represents a 12% of total energy consumption, while, electrical power demand will be increased with the rapid growing of worldwide population and loads. As expected, by 2025 this percentage will be increased to be a 34% of the total consumption [ElNozahy and Salama, 2013].

Electric energy is produced from many resources. Most of this energy is produced by conventional energy resources such as coal, oil and gas [Mehta, 2005]. However, burning fossil fuel to generate electricity produces greenhouse gas emissions which have a big rule in global warming .Thus, these emissions must be reduced to prevent the global warming problem from aggravate. In the meanwhile, research shows that by 2050 the reduction of these emissions worldwide must be 80% of 1990 levels [Meinshausen et.al, 2009].

To protect the environment from these emissions the dependency on fossil fuel to generate electricity must be reduced. This can be achieved by searching for alternative resources to produce electricity such as renewable energy resources like sun, wind and hydropower [Zahedi, 2011].

On the other hand, it is noted that the power demand has increased which in turn increases electrical energy production almost to its capacity limits. In

addition to that, power utilities must have a reserve margin of existing power generation at a sufficient level. Thus, the fast growing of electrical power demand make the transmission systems reaching their maximum capacity. Therefore, the utilities that are responsible of power grid have to invest a lot of money to expand their capacity to meet the demanded power and to prevent the interruption of electricity [Math and Fainan, 2011]. Moreover, one of the issues that degrades the performance of power system is the voltage level. If the power is transferred for far distance, a voltage drop will occur and power losses increase. In addition, there are other issues such as harmonics which reduce power quality [Math and Fainan, 2011].

Following that, many solutions were suggested to solve these problems, one of these solutions is distributed generation (DG) [Bindeshwar and Janmejay, 2017]. DG units are grid connected units which are located near customers and deliver power to the grid regardless of its capacity or type. The introduction of DG to the power system has either positive and negative impacts depending on the power grid properties and DGs characteristics [Bindeshwar and Janmejay, 2017]. DG units have many benefits that can improve the power system such as micro turbine which depend on fossil fuel and renewable energy resources like PVs. [Bindeshwar and Janmejay, 2017].

The fundamental way of power system operation depends on centralized plants whereas power flows at a unidirectional way from generation toward distribution. In the meanwhile, the introduction of DG to the power system changes the nature of the system from passive networks to active networks.

Active networks imply power flow in a bidirectional way due to the distributed resources along the network [Master, 2002].

Several benefits can be obtained from DG such as voltage support, improve power quality, loss reduction, support transmission and distribution infrastructure and increase system reliability.

Installing DGs to the power system may be depending on the weakest busses but this is not an optimal solution always as it may cause negative impacts on the power system such as higher power losses, voltage fluctuation problem and reduction of system stability. However, DGs have drawbacks like reverse power flow which lead to malfunction of protection devices, power quality problems because of harmonics which are a normal result of electronic converters that are being used, reliability problem especially when renewable resources are used [Bindeshwar and Janmejay, 2017].

Thus, before installing a DG unit in power system appropriate planning of power system is required considering several aspects such as the number, capacity and the location of DGs units [Bindeshwar and Janmejay, 2017].

1.2 Problem Statements

The electrical power system has many problems such as the shortage of supply with load growing, active power losses and voltage drop due to distances and huge amount of power transferred [Stevenson, 1982]. The introduction of Micro grid concept to the power system by using distributed generation will prevent these problems by improving power grid performance [Lasseter and Paigi, 2004].

By choosing the optimal size and location of DG, power losses can be reduced and voltage profile can be improved without deterioration of the power system. There are a lot of methods that can be used for optimally choosing DG size and location, such as artificial intelligent (AI) and conventional linear methods. These methods have advantages and shortcoming. However, artificial intelligent based methods are considered the best due to their robustness and simple implementation [Paliwal et.al., 2012].

One of AI methods that this research work on is particle swarm optimization (PSO) method. PSO is based on inelegance which can be applied into scientific and engineering researches. It has no overlapping and mutation process because the search depends on speed of particle. So PSO can be considered as a simple optimization method. But one of shortcoming of PSO is the high computing time[Bai, 2010]. In this research PSO is used for optimal size and location of DG to achieve proper planning and improvement. However, the convergence rate of PSO can still be improved so as to achieve more accurate size and place of the DG in a faster time [Devi and Geethanjali, 2014].

1.3 Research Objectives

In this research a number of objectives are listed based on the aforementioned problem statement as follows,

1. To model an IEEE 34 bus system using Matlab with several weak buses.
2. To find the optimum size and placement of DG units in this power network using PSO method.
3. To propose an improved PSO method for optimum sizing and placement of DG units in the adapted power network.
4. To conduct a comparison between the two methods so as to show the superiority of the proposed method.

1.4 Research Methodology

In this thesis, the research work is conducted based on a defined research methodology. This research methodology is consisted of a number of work packages (WP) and tasks as listed below,

WP.1: Modeling of IEEE 34 bus-bar power system.

T1.1 Develop a Matlab code for IEEE 34 bus-bar power system

T1.2 Conduct a power flow analysis of IEEE 34 bus-bar power system

T1.3. Modify the loading of the IEEE 34 bus-bar power system so as to simulate a weak power system that needs distribution generation based solution.

WP.2: Optimal sizing of DG units in power system using PSO.

T.2.1 Develop a PSO code using Matlab environment.

T.2.2 Conduct an optimal sizing of DG units in power system using PSO methodology.

T.2.3 Analysis of the new power system in terms of power losses and voltage profile.

WP.3: Optimal sizing of DG units in the electric power system using improved particle swarm optimization method (IPSO).

T.3.1 Improve PSO algorithm by modifying algorithm weight calculation methodology.

T.3.2 Conduct an optimal sizing of DG units in power system using IPSO method.

T.3.3 Analysis of the new power system in terms of power losses and voltage profile

WP.6: Conduct a comparison between PSO and IPSO.

WP.7: Thesis writing.

WP.8 writing a research paper that contains the results obtained from the research.

1.5 Significance of Research

1- A developed PSO algorithm for optimal sizing of DG in power system

2- A method for improving the performance of power systems using DGs units which in turn reduces the power losses and improves the voltage level of IEEE 34 test bus system.

Chapter Two

Literature Review

2.1 Distributed Generation.

Conventional electrical power system usually consists of generation, transmission and distribution. Electricity power generation station is a large station which produces electricity to cover the demand of loads. In the meanwhile, the produced energy is delivered to the distribution side via transmission lines.

The responsibility of each part of the power grid can be held by several companies, namely generation’s company, transmission’s company and finally distribution’s company. Electricity production, transmission and delivery should be done at acceptable reliability and voltage quality for all customers at minimum price. Moreover, in case of any problem at any side of the power grid, all sides of the power grid are affected.

On the other hand, energy end-users are currently demanding more energy in accordance to the growth which leads to many challenges in terms of electrical power aspects. Therefore, new power generation technologies are being developed such as distributed generation (DG). There are many reasons for developing these new methods of power production, the first reason is enabling new electricity production to the electricity market, which will consequently increase the competition between market players. Such a practice will increase production capacity and reduce the electricity price [Math and Fainan, 2011]. In the meanwhile, the second reason is the reduction of carbon dioxide emission that is resulted from conventional energy resources and leads to global warming [Meinshausen et.al., 2009]. Thirdly, there is currently a small margin between consumption and available production, thus, the rapid growth of energy demand will make this margin smaller. Therefore, to increase this margin, additional conventional power stations must be introduced to the power grid and this will be a costly solution and will cause many changes to the grid [Borbely and Kreidel, 2001]. Consequently, new production methods of electric energy such as distributed generation (DG) can significantly help.

DG units are small units that can be used for producing electric energy ranging from less than one kW to tens of MW from different resources. These units can be considered as decentralized energy resources which can be connected at distributed system or customer side that is close to the end user [El-Khattam and Salama, 2004].

According to Institute of Electric and Electronic Engineering (IEEE) DGs is defined as the generation of electricity by facilities sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in the power system. In the meanwhile, the International Council on large Electric system (CIGRE) working group defines DGs as not centrally planned, not centrally dispatched energy generation units that are connected to the distributed network in the range of 50 – 100 MW. In general DGs can be classified with respect to the rating as micro DGs

(1 – 5 kW), small DGs (5 kW – 5 MW), medium DGs (5 MW – 50 MW) and large DGs (50 MW

50MW– 300 MW)[Thomas et.al., 2001].

DG units are usually located near load or end users or close to the distribution stage of the power grid [Thomas et.al., 2001]. The appropriate location and capacity of DGs depends on many factors such as the capacity of distribution system, system's voltage level and system's power quality [Thomas et.al., 2001].

2.2 Types of Distributed Generation

It is very important to know the type and the technology of DGs as this helps in choosing the suitable type based on grid's situation. Here, it is worth to mention that not all DGs depend on renewable energy resources as there are types that can be considered as conventional based DGs. DG types and technologies can be classified as below,

1- Traditional generators which are combustion based engines such as micro–turbines (MT). These turbines convert kinetic energy which comes from heat to electric energy. The types of fuel that generate the heat by combustion are in general gas, oil or coal [El-Khattam and Salama, 2004].

2- Non – traditional generators which are in general based on clean energy [El-Khattam and Salama, 2004]. These generators can be classified either as electrochemical devices such as fuel cell (FC) or renewable energy resources such as photovoltaic (PV) and wind turbine (WT) power systems.

3- Storage devices like Batteries, Flywheels and ultra-capacitors.

2.2.1 Micro –Turbines

Micro–Turbine (MT) is one type of DGs that depends on combustion. It can be considered as a traditional type. MTs are small combustion turbines with the volume of (0.4 – 1 m3) and 20 kw–500 kW. They can be operated using natural gas, propane or oil. The simple form of MT consists of compressor, combustion, recuperator, small turbine and generators [Suter, 2001]. There are a lot of advantages for MT as they can be replaced at any site because they are small so they are useful if there is a space limitation [El-Khattam and Salama, 2004]. Moreover, they have lower emission in comparison to other combustion generators. The efficiency of such a technology is about 80% when waste heating recovery is used [El-Khattam and Salama, 2004]. In addition, they can be started up easily and need less maintenance because of their simple design [Suter, 2001]. The cost of MT is low as compared to other DGs technology[Del Monaco, 2001]. Finally, the interfaces between MTs and between the load or grid are power electronics devices which give the system more flexibility in control [Lasseter, 2001].

2.2.2 Electrochemical devices (FC)

Fuel cell (FC) is an electrochemical cell that converts chemical energy into electricity by electrochemical reaction of hydrogen with oxygen or other oxidizing materials. A fuel processor is used to convert the source fuel to a hydrogen-rich fuel stream which is needed for the electrochemical reaction. FC consists of two oxidant electrodes that are separated by an electrolyte member. These cells generate electric power and thermal energy. FC can be considered as a storage device when it has a continuous source of fuel [El-Khattam and Salama, 2004].

FC and batteries differ from each other whereas FC requiring continuous source of fuel and oxygen to maintain the chemical reaction. In the meanwhile, with battery, the chemical energy comes from chemicals that are already existing in the battery [Ellis et.al., 2001].

FC has high efficiency (60%) as compared to diesel or gas based engines. In addition, FC works silently which makes it suitable to be used in buildings and hospitals [Rahman, 2001]. On the other hand, it depends on hydrogen as fuel not like conventional fuels [Farooque and Maru, 2001]. Finally, FC does not require a lot of maintenance.

On the other hand, FC has some disadvantages whereas hydrogen is very expensive as it's difficult to be extracted, handled and stored. FC is also flammable due to the hazard materials utilized that come from hydrogen. In addition, from the electrical point of view, as a result of aging, FC internal impedance slowly increases and therefore, power electronic interface is required so as to regulate the output voltage [Farooque and Maru, 2001].

2.2.3 Photovoltaic Systems (PV)

Photovoltaic system is one of renewable systems. It is a system that depends on sun energy to generate electricity. The basic unit of a PV system is a solar cell. This cell may be square or round shape and it consists of doped silicon crystal. From solar cells, a PV module or PV panel is formed, and these modules are formed is an array to generate electricity [Math and Fainan, 2011].

Solar energy is absorbed by the cell where light photons force cell electrons to flow and consequently cause the photocurrent phenomena. Each cell provides 2 to 4 A with a voltage value of 0.5V. PV modules are usually connected in series or in parallel to provide a specific voltage and current.

PV systems come as standalone systems, roof-top mounted or buildings integrated systems with capacities ranging from a few to several tens of kW.

It also comes as a large utility of power station with a capacity of hundreds of MWs [Olga et.al, 2010].

PV panels give clean and free energy and so they are environmen friendly. Operational and maintenance costs of PV panels are low as compared to the operational and maintenance costs of other renewable energy systems. PV panels have no moving parts as the only moving part is used for sun tracking so they are totally silent. The cost of solar panels is affordable and it is currently being degraded with time [Priscila et.al., 2017].

On the other hand, PV system has some disadvantages where during nights, cloudy and rainy weather there is no electricity which decreases the reliability of the system. Moreover, the output power of these systems is DC and must be converted to AC to suit power system and thus, additional equipment are required such as electronic converter. In addition, for a continuous supply of energy, storage system is required which increases the cost of system. The efficiency of these systems is low (14%-25%) as compared to other renewable energy systems. Although the cost of PV panels is low, land space is needed and this increases the cost of the system [Priscila et.al., 2017].

2.2.4 Wind –Turbine (WT)

Electricity can be generated from several types of energies. One of these energies is the kinetic energy which comes from wind. Wind turbines collect the wind energy and convert it to kinetic energy. A wind turbine is usually consisted of a main part which is called blade. The blades come in many sizes at vertical and horizontal axis. The wind rotates the blades and then blades rotate the shaft of a generator which produces electricity. These systems can be in small sizes that may be used to charge batteries. In the meanwhile, wind power systems can come in large sizes (Wind farm). A wind farm can be considered as a source of intermittent renewable energy [Fainan, 2011].

Wind energy is free and does not affect the environment. In the meanwhile, wind turbines do not need a large area because they can be mounted at tall towers. The area under these towers can be used for other purposes such as agriculture.

However, wind turbines have some drawbacks. For example, the speed of wind is always fluctuating and thus, the output power of the wind turbine is not constant depending on the wind speed. The view of wind turbine is not interesting for all and might be visually disturbing. Moreover, there is some pollution when turbine blades are manufactured. Finally, the motion of the turbine blades cause unwanted noise[Fainan, 2011].

2.2.5 Storage devices :

It is a device that is used to store energy at low load demand and it is used when the demand is higher than the power supply. Storage devices can be batteries, flywheels, Ultra-capacitors and fuel cells. In general, storage devices come as standalone systems but sometimes they are incorporated with DGs to supply power at peak load demand.

2.3 Impact of Distributed Generation Units on the Electrical Power System

Inserting DGs to electrical power systems has many benefits. These benefits can be classified according to different aspects such as economical and operational aspects.

From economical point of view, DGs can be installed locally anywhere near the loads to supply loads without needing new transmission and distribution line [Barker and De Mello, 2000]. The capacity of DG can be controlled in a flexible and easy way. Economically, the waste heat of DGs can be used for heating and cooling in a combine heat and power (CHP) process. Thus, the efficiency of the overall system can be increased [Ilic, 2001]. Moreover, DGs can supply the exact customer load demand. The price of electricity can be reduced because DGs supply power to the grid which will reduce the needed power from the power plant and consequently reduce power losses [Coles and Beck, 2001]. On the other hand, from operational point of view, DGs have positive impact on the distribution system in terms of voltage profile and power quality issues.

The power losses in distributed power systems can be reduced when using DGs because of the reduction of the power flow in transmission lines. In addition, voltage profile can be improved based on the amount of power delivered to the network from DGs [Hadjsaid et.al., 1999]. DGs can be used effectively in load management programs. In addition, they can help in improvement of system continuity and reliability because DGs can be used on site as a standby source to supply electricity at emergency and system outages [Coles and Beck, 2001 - Xu and Girgis, 2001]. DGs can be installed on medium and/or low voltage distribution networks [Silvestri et.al., 1999].

In general, DGs are used in the network to improve power grid performance. However, there are some negative impacts of DGs. Large DG units have greater effect on the power system. When the DGs power flows through the system, the system’s voltage will rise and be improved. However, a problem happens when the output power of the DG unit fluctuates which in turn causes voltage flicker [Honghai et.al., 2011].

In addition to that, DG units may have negative impact on the protection scheme of the electrical power system. An electrical power system without DGs has a radial configuration with a unidirectional power flow. But when DGs is introduced to the system, the distribution network is converted from passive to active power system. This will lead to a change in fault current calculation and duration. In passive unidirectional networks, the current flows in one direction, but with DGs, the current flows in two directions (bidirectional power flow) not only from the substation to the load but in a reverse direction as well. Thus, the setting of protection devices must be changed in accordance to the new situation with DGs. This means that networks with DGs need more complex control and management [Hua and LuYuping, , 2008].

In the meanwhile, DG may have negative impact on grid’s stability. Inserting DGs to the power system will change the traditional power system topology because of the large number of electronic devices that contains capacitors and inductors. These devices will have voltages and current with frequencies that are not synchronized with grid’s frequency which may affect network’s power quality negatively. These undesired frequencies called harmonics and will increase losses and heat up the transmission lines [Honghai et.al., 2011].

2.4 Optimal Sizing and Placement of Distributed Generation Into the Electrical Power System

Inserting DGs to any electrical power system must be planned and studied well. Poor planning of DG placement in electrical power systems may lead to several problems. For example, DGs decrease the power losses in a power system, but at the same time may cause more harmonics in the system. Harmonics create currents with new frequencies which increase losses and heat up power lines. Based on that, optimal sizing of DG units should be considered.

Similarly, the location of DGs may be chosen in accordance to the voltage level of the buses. They may be installed at the weakest bus or at the most critical one to improve network’s voltage. Installing DGs in this way will improve the voltage level of the near buses but not the whole system’s voltage. Thus, optimization methods should be used to choose the optimum location and size of DG units. Therefore, the installation of DGs in electrical power systems should be subject to electrical networks operating constraints, DG operation constraints, and investment constraints [Pavlos et.al., 2013].

In general, the objective function of this optimization process can be single or multi-objective function. The main single objective-function is minimization of the total power loss of the system, minimization of energy losses, minimization of system’s average interruption duration index, minimization of cost, minimization of voltage deviations, maximization of DG capacity, maximization of profit, maximization of benefit/cost ratio and maximization of voltage limit loadability (the maximum loading that can be supplied by the power distribution system while the voltages at all nodes are within acceptable limits). Multi-objective function formulation can be done using weights. This multi-objective function can be divided into single objective functions using the weighted sum of individual objectives [Pavlos et.al., 2013].

In general DGs can be installed in the power system using optimization method considering different numbers of DG units as single DG installation or multiple DG installation. Therefore, there are some variables that must be determined such as location, size, technology (wind, solar, biomass, fuel cell and diesel generator) and number of DG units. These variables can be considered individually or as group in the optimization problem.

The most common constrains in the optimization process that used in power flow problems are equality constrains, such as bus voltages or voltage drop limit, line or transformer overloading or capacity. Other constrains can be considered such as total harmonic distortion, voltage distortion limits, short circuit level limits, reliability constrains, power generation limits, DG penetration limits, maximum number of DGs, budget limits, DG with constant power factor, limited bused for DG installation and discrete size of DG units [Pavlos et.al., 2013].

2.4.1 Optimization Methods

As mentioned previously, DG installation needs much of planning to choose the suitable size and location of the DG unit. There are a lot of optimization methods which differ in basics, computing time and applications that can be used for this purpose. The three major methods of DG optimization are analytical methods, numerical methods and heuristic techniques based methods [Vasileios et.al., 2016].

1- Analytical Method

On a radial feeder when the load is uniformly distributed, analytical method can be used. The analytical method is known as "2/3 rule " which suggests to install 2/3 of the capacity of the incoming generation at 2/3 of the length of the line[Willis, 2000]. This method is not effective for non-uniformly distributed loads. In [Acharya et.al., 2006] analytical approaches are used to determine the optimal location for placing DG in both radial and networked systems to minimize power losses. The proposed approaches are not iterative algorithms. Therefore, there is no convergence problems involved and results could be obtained very quickly.

2- Numerical Methods

Numerical methods usually involve heuristics and visualization tools to facilitate the search of optimum solution. In contrast to mathematical modeling approaches, the solving algorithm of these methods is not clear. In general, numerical methods are formulated from graphical and tabular forms [Wai Lip et.al., 2017]. Numerical methods have many solving algorithms such as Gradient Search [Rau and Wan,1994], Linear programming (LP) [Keane and O'Malley, 2005], Sequential Quadratic Programming (SQP) [AlHajri et.al., 2010], Nonlinear Programming (NLP) [Atwa and El-Saadany, 2011], Dynamic Programming (DP) [Khalesi et.al., 2011], Ordinal Optimization (OO) and Exhaustive Search [Jabrb and Pal, 2009].

3- Heuristic Methods

These methods apply an iterative generation process which can acts as a lead for its subordinate heuristic to find the optimal or near optimal solution for the optimization problem.

These methods combine concepts derived from artificial intelligence such as Genetic Algorithm (GA) [Kim et.al., 1998], Tabu Search (TS) [Nara et.al., 2001], Particle Swarm Optimization (PSO) [El-Zonkoly, 2011], Ant colony system (ACS) algorithm [Wang and Singh, 2008], Artificial Bee Colony (ABC) [Abu-Mouti and El-Hawary, 2011], Differential Evolution (DE) [Arya et.al., 2012], Harmony Search (HS) [Rao et.al, 2013] and Practical Heuristic Algorithms [Hamedi and Gandomkar, 2012].

2.5 State of Art of Optimal Sizing of DG in Electrical Power Systems

In general there are many researchers who have utilized heuristic techniques to find the optimum size and place of DG units in electrical power system. In [Daud et.al., 2016] the researchers had applied PSO, Gravitational Search Algorithm (GSA) and Improved Gravitational Search Algorithm (IGSA) to find the optimal size and place of a DG unit based on IEEE 69-bus radial distribution system. Moreover, they have conducted a comparison between these heuristic optimization techniques. The proposed objective function was to minimize the real power losses, voltage deviation, average voltage Total Harmonic Distortion (THDv) and System Average Voltage Dip Magnitude (SAVDM). According to the results, the size of Photo Voltaic Distributed Generation (PVDG) as a percentage of the total load considering an optimal placement and sizing of a single PVDG was 50.6% , 13.6% , 24.6 % using GSA, PSO and IGSA algorithms respectively. Moreover, PSO algorithm achieve minimum value of total active power losses. In the meanwhile, IGSA algorithm has achieved the minimum value of voltage deviation. On the other hand, the sizes of PVDGs as a percentage of the total load when optimal placement and sizing of two PVDGs were 79% , 50% , 71% using GSA, PSO and IGSA respectively. Here, with IGSA minimum value of total losses was achieved while the minimum voltage deviation was achieved using GSA.

In [Hasan et.al., 2008] a method for optimal placement of a DG unit was proposed. In this method the place of installation of DG in distribution networks was implemented based on an iterative algorithm method. This method locates the most sensitive buses for voltage collapse .The case study used was a typical 34-bus test system. As a result, this method showed high efficiency in improving voltage profile, reduction of power losses and also an increase in power transfer capacity, maximum loading and voltage stability. The total active power losses were reduced by 38.79% and power transfer capacity was increased by 20.31%.

In [Al Abri et.al., 2012] a method of DG units allocation is proposed to improve voltage stability margin. It takes into account the probabilistic nature of loads and renewable DG. The model that was used as a load is IEEE-RTS system and the renewable DG resource is modeled by using three years of historical data (solar irradiance and wind speed). The candidate buses were selected based on the sensitivity of bus voltages. Simulation results indicated that DG size and location can have positive impacts on the voltage stability margin. Therefore, the method can be used to improve system’s voltage and to help in preventing any violation of system’s limits such as voltage and feeders current.

In [Haiyan et.al., 2006] the author introduced interfaces between DGs and distribution network and the impact of DGs on the voltage stability of static system by using voltage stability index. According to the results, the level of voltage stability in distribution systems can be improved by installing conventional capacitors and regulators, which are less expensive than DGs. However, DGs can supply active power to serve load besides injecting reactive power into the distribution networks.

In [Aman et.al., 2013] an approach was presented based on multi-objective function for optimal DG placement taking into account maximizing voltage level and minimizing power losses. The research was conducted by finding the weakest bus in accordance to voltage. PSO algorithm was used to solve the proposed multi-objective function. The proposed algorithm was tested on 12-bus, 30-bus, 33-bus and 69-bus radial distribution test systems. In this work there was a comparison between PSO with existing analytical and grid search algorithm. PSO was found to be better in performance as compared to the other two methods. Results showed that power system losses have been reduced, system loading factor also has been increased, system voltage profile has been improved, line stability has been increased and Bus voltage stability has also been increased.

In [Masoud et.al., 2013] a method was proposed for optimal placement of DGs to maximize VSM and minimize power losses at the same time using dynamic programming search method to find the global optimal solution. A typical distribution test system was used as a case study. As a result, the DG reactive limits affected the number of DG, their locations and size.

In [Masoud, 2013] a multi-objective function was proposed as a basic for placing and sizing of DG units. Number of DGs and power losses were assumed to be minimized. In the meanwhile, voltage stability margin was assumed to be maximized. The objective functions were formulated using the same scale in order to prevent problems that usually happen in weighting multi-objective methods. DG reactive power and power system constrains were taken into account as well. The method that was used for sizing and placement was a nonlinear programming (NLP) method. It was claimed that DG units were utilized more efficiently by placing them not at the end buses of radial branches.

In [Moradi et.al., 2014] multiple DG sizing and location issues were studied using a constrained nonlinear programming optimization method. The voltage stability index, active power losses and voltage profile were considered as objective functions to be optimized. This problem was solved by a developed Pareto Frontier Differential Evolution (PFDE) method. The efficiency of the proposed method has been illustrated through 33-buses and 69-buses radial distribution networks. The obtained results were compared with results of using single objective weighted sum method in GA/PSO, GA and PSO. According to the results, PFDE has a higher convergence speed than GA/PSO, GA and PSO.

In [Neeraj et.al., 2017] the researchers have used an improved PSO for optimal allocation of distributed energy resources such as shunt capacitors and distributed generation in radial distribution network to maximize annual savings. The idea was conducted by reducing the charges for annual energy losses, peak power losses and substation capacity release against the annual charges that is used to purchase distributed energy resources while maintaining better node voltage profiles and feeder current profiles. The proposed method was applied on IEEE-33 bus system and 69-bus test distribution system. As a result, the proposed IPSO performed better than the standard PSO model. The performance of the proposed IPSO was improved by suggesting a Local Escape Algorithm (LEA) and GSA algorithm. In this research LEA utilized inherent inability of PSO to deal with continuous decision variables and thus avoids several local trappings. In the meanwhile, GSA virtually squeezes the problem search space though it maintains adequate diversity.

In [Prakash and Lakshminarayana, 2016] particle optimization method was used for multi DG placement for losses reduction and voltage profile improvement. The proposed method was tested on IEEE-33 bus system and IEEE-69 bus. Maximum penetration of DG was considered as 100%, while, the maximum number of DG’s was considered to be three. MATLAB environment was used to run load flow and to calculate power losses so as to find optimal location and optimal size of DG units. DGs that have been used have two types, whereas one type injects real power only, while, the other type injects real and reactive power. As a result, PSO algorithm reduced the power losses and improved voltage profile.

In [Lucian et.al, 2014] the researchers have studied the effect of distributed generation on the electrical power system. As a result, DG has advantages and disadvantages on the power system. DG has significant impact on reduction of power losses, and improving voltage profile. However, flicker, harmonics, short circuit level, islanding, reliability and network protection were considered as very important issues that appear when using DGs.

In [Engin et.al., 2015] the threshold penetration level of distributed generation was studied. As a case study, the penetration level was assumed to be 4% and 2% of IEEE-30 and IEEE-57 bus systems, respectively. For IEEE 30 system, bus 26 was the most problematic bus in terms of voltage profile, while, bus 57 was found to be the most problematic bus for IEEE-57. For this reason, some measures were suggested for these buses in order to increase DG penetration. In addition, multiple-DG penetration was assumed to be better than the single-DG penetration for voltage profile because of the fact that the penetration level can be increased up to 4.4% without any measure.

In [Jamil and Sharique Anees, 2016] an analytical approach was used to find the optimal size and location of solar photovoltaic in a primary distribution network based on multiple locations. The proposed approach was tested on IEEE 33 and IEEE 69 bus system. It is found that the power loss reduction was 57%, while, the voltage profile was improved from

0.943908 to 0.977294 pu for IEEE 33 bus system. In the meanwhile, a reduction of 29% of power losses was also achieved and the voltage levels were improved from 0.94882 to 0.95727 for IEEE 69 bus system. As a result of the comparison, the placement of multiple DG is more significant and economical as compared to single DG placement.

Chapter Three

Optimal Sizing and Placement of Distributed Generation Using Improved PSO

3.1 Introduction

The electrical distribution network is usually considered as the final destination of the power flow in the power grid where end-users are located. In general, a reliable electrical distribution network implies that the energy demand of the end-users is covered properly without any shortages. However, nowadays electrical distribution networks are facing many reliability challenges. One of these challenges is the fluctuation of electricity at these areas because of the rapidly growing energy demand, power losses and voltage drop at transmission lines.

Introducing DGs to the electrical distribution networks can mitigate these challenges by reducing the electrical power transferred over the transmission lines [Barker and De Mello, 2000]. However, inserting a DG to the electrical power system needs proper planning so as to get the desired benefits. This planning implies proper sizing and placement of DG in the electrical power system with proper control strategy [Dondi et.al., 2002].

The proper sizing and allocation of DGs in the electrical power system can be achieved by optimization techniques. Recently such a nonlinear optimization problem is solved using many techniques such as analytical, heuristic and meta-heuristic techniques [Pesaran et.al., 2017]. Each one of these techniques has advantages and disadvantages. A summary of the advantages and disadvantages of these techniques can be found in Chapter two of this thesis.

In this thesis, meta-heuristic optimization technique is used. Meta-heuristic optimization is defined as an iterative generation process which guides a group of solutions by combining intelligent concepts for exploration and exploitation of the search space [Osman and Kelly, 1996]. Meta heuristic optimization techniques are more suitable for problem solving due to their robustness and simplicity [Paliwal et.al., 2012].

There are many techniques in the literature that can be considered as a meta-heuristic optimization algorithm [Christian and Andrea, 2003]. Examples of these optimization techniques are simulated annealing (SA) [Kirkpatrick et.al., 1983], particle swarm optimization (PSO) [Kennedy and Eberhart, 1995] and ant colony optimization (ACO) [Dorigo et.al., 1996]. In the meanwhile, researchers have used more than one method to form a hybridized optimization method to overcome the shortcoming of individual ones. Firefly algorithm (FA) [Yang, 2009], artificial immune system (AIS) [Alamos et.al., 1986], harmony search algorithm (HAS) [Geem et.al., 2001] and artificial bee colony (ABC) [Karaboga and Akay, 2009] can be considered as meta heuristic optimization methods due to the implied randomization method in the initialization process.

In this thesis PSO algorithm as well as an improved version of PSO algorithm are used as optimization methods.

3.2 Adapted Electrical Power Network

Electrical power grid is a network that is used to deliver electricity from producers to consumers. It consists of a number of generation stations that have resources to generate electrical power. The electrical power is transferred efficiently to the demand side via transmission lines. To transfer

electrical power for large distances, the voltage level must be stepped up using transformer to high levels. Finally, the power reaches distribution networks and is delivered to the customers [Stevenson, 1982].

Based on the voltage level, the electrical grid can be divided into several categories. At the generation side, the voltage may be in the range of 13.8 to 24 kV or higher such as 18 to 24 kV. Then generated power stepped up and transferred with minimum losses via transamination lines that have a voltage in the range of 115 to 765 kV [Stevenson, 1982].

After that, high voltages are stepped down to be in the range of 34.5 to 138 kV. These levels are used sometimes by industrial customers such as factories. Then, at distribution power substation, the voltage level is stepped down further to be in the range of 34.5 to 4 kV. In the final stage, secondary distribution power substations step down the voltage to 0.4 kV so as to be utilized by normal end-users [Stevenson, 1982].

The transmission lines that are used to transfer power may be overhead transmission lines or undergrounded cables. The most popular one is the overhead transmission lines, but nowadays there is a big attention toward undergrounded cables. Underground cables have an advantage in heavily populated areas and submarine applications [Short, 2006].

The electrical power grid has many topologies or structures which depend on loads and generation nature, reliability requirements and economic aspects. Distribution networks can be in a form of radial network, mesh network or loop network. Radial network is the simplest form which has a tree of properties where the generated power is exported by several lines to reach customers destination. This topology is simple however, if a single failure occurs the entire branches of the network are affected [Short, 2006].

The other topology is mesh network which is more reliable because each load has more than one line of supply. With this case, if any line fails, the power can be rerouted. Finally, Loop or ring network is a topology that is fed by more than one feeder whereas in case of any fault at any feeder other feeders can replace the failure [Short, 2006].

The electrical power network can be modeled as a circuit that consists of a source, load and transmission line (T.L). This circuit is called one line diagram. The source is usually described as a rotating machine, while, T.L are described using parameters such as resistance, inductance and capacitance. Finally, loads can be described as an impedance or apparent power consumer. These parts of the network are grouped together by busses or nodes which have many types according to their purposes such as slack or swing bus, voltage controlled buses or generation buses and load buses. Slack buses are used to balanced active power (P) and reactive power (Q) for the network. Meanwhile, generation buses provide the network with constant active power at constant voltage. Finally load buses represent the loads which are connected to the network [Saadat, 1999].

In general a load flow analysis is used to study the performance of an electrical network. This analysis has a great importance for planning future expansion and helps in determining the best operation of the system. The most important information that can be got from load flow analysis are voltage and phase angle for each bus as well as real and reactive power for each line. In a load flow analysis, slack bus's voltage and phase angle are

known while, real and reactive power are calculated. Meanwhile, load bus's active and reactive powers are known and the voltage and phase are calculated. Finally, generations bus's active power and voltage magnitude are known, while, reactive power and phase angle must be determined [Stevenson, 1982].

Load flow analysis is usually done based on an iterative numerical solution. There are many methods that can be used for such a purpose such as Gauss– Seidel method, Newton–Raphson method and Fast–Decoupled method [Stevenson, 1982].

Currently, there are many softwares that can be used to conduct a load flow analysis such as ETAP, POWER WORLD simulator, MATLAB and PScad. By using these softwares many studies can be done such as load flow calculation, fault calculation and others.

In this thesis, one of IEEE power systems is adapted and coded using MATLAB, then the load flow analysis is conducted based on Newton-Raphson method. The adapted network consists of 34 buses whereas one of these buses is a generation bus, while, the others are load buses. The total generation in the adapted network is 5.89 MW and 3.52 MVAr. Meanwhile, the total load demand of the adapted network is 5.56 MW and 3.42 MVAr.

3.3 Newton–Raphson Based Power Flow Analysis Method

The equations that describe the power flow in a network are nonlinear. Following that, an iterative method is needed to solve these non–linear equations such as Newton–Raphson method. This method starts based on initial assumption for all variables which are unknown, like voltage magnitude and phase angle of load buses. After that a Taylor series is used while, higher order terms are neglected, for each power balanced equation so as to form a linear equation [Stevenson, 1982].

Newton–Raphson method for solving load flow analysis is usually preferred because it has some advantages. This method has a quadratic convergence which means higher order of convergence. Moreover, the method is efficient and practical for large system because of the low number of iterations required for solving the problem independently [Saadat, 1999].

The calculation of the load flow analysis starts by describing Kirchhoff Current Law (KCL) which stats that the sum of currents flowing into a node is equal to the sum of currents that are coming out of this node as shown in figure 3.1,

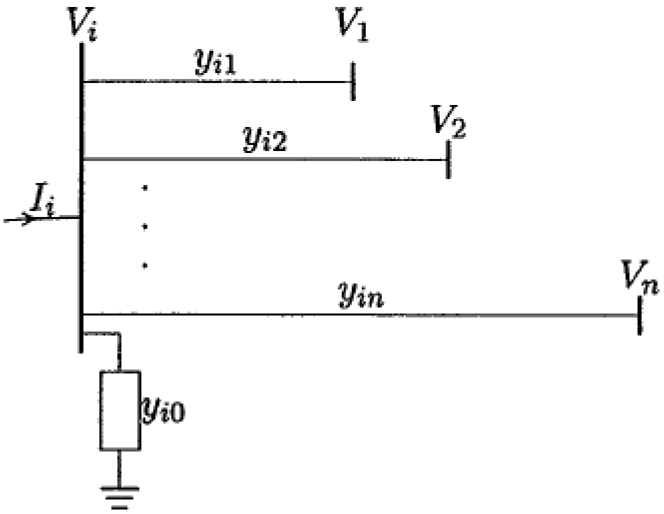

Figure 3.1: A typical bus of the power system [Saadat, 1999].

The current flow out from bus i can be described in the equation below,

$$I_i = \sum_{j=1}^{n} Y\,ij\,Vj = \sum_{j=1}^{n} |Y\,ij|\ |Vj\,| < \theta\,ij + \delta j \tag{1}$$

where:

I_i: current injected from bus i in pu.

$Y\,ij$: mutual admittance between bus i and j in pu.

$V\,j$: voltage of bus j in pu.

$\theta\,ij$: angle of mutual admittance between bus i and j in radian.

δj: voltage angle of bus j in radian.

In the meanwhile, real and reactive power injection are described using the equation below,

$$P_i - jQ_i = V_i^* I_i \tag{2}$$

where:

Pi: active power injected from bus i in pu.

Qi: reactive power injected from bus i in pu.

V_i: voltage of bus i in pu.

I_i: current injected from bus i in pu.

Substituting for Ii yields,

$$Pi - jQi = (|Vi < -\delta i|)\sum_{j=1}^{n}|Yij||Vj| < \theta ij + \delta j \tag{3}$$

where:

δi: voltage angle of bus i in radian.

By converting the second part of equation (3) into rectangular form, we get two equations containing real and reactive power as below,

$$P_i = \sum_{j=1}^{n}|Vi|\,|Vj|\,|Yij|\,\cos(\theta ij - \delta i + \delta j) \tag{4}$$

$$Q_i = -\sum_{j=1}^{n}|Vi|\,|Vj|\,|Yij|\,\sin(\theta ij - \delta i + \delta j) \tag{5}$$

Then, converting equations (4) and (5) into iterative form gives,

$$P_i^{[K]} = \sum_{j=1}^{n}\left|V_i^{[k]}\right|\left|V_j^{[k]}\right|\left|Y_{ij}\right|\cos\left(\theta_{ij} - \delta_i^{[k]} + \delta_j^{[k]}\right) \tag{6}$$

$$Q_i^{[K]} = \sum_{j=1}^{n}\left|V_i^{[k]}\right|\left|V_j^{[k]}\right|\left|Y_{ij}\right|\sin\left(\theta_{ij} - \delta_i^{[k]} + \delta_j^{[k]}\right) \tag{7}$$

where:

$P_i^{[K]}$: active power injected from bus i at itteration K in pu.

$Q_i^{[K]}$: reactive power injected from bus i at itteration K in pu.

$\left|V_i^{[k]}\right|$: voltage magnitude of bus i at itteration K in pu.

$\left|V_j^{[k]}\right|$: voltage magnitude of bus j at itteration K in pu.

$\left|Y_{ij}\right|$: mutual admittance magnitude between bus i and j in pu.

θ_{ij}: angle of mutual admittance between bus i and j.

$\delta_i^{[k]]}$: phase angle of bus i at iteration K in radian.

$\delta_j^{[k]}$: phase angle of bus j at iteration K in radian.

After that, a matrix C can be formulated for the system as below,

$$C = \begin{bmatrix} P_{inj}^{sch} \\ Q_{inj}^{sch} \end{bmatrix} \tag{8}$$

$$x^{[k]} = \begin{bmatrix} \delta^{[k]} \\ V^{[k]} \end{bmatrix} \tag{9}$$

where:

P_{inj}^{sch}: scheduald injected active power in pu.

Q_{inj}^{sch}: scheduald injected reactive power in pu.

$\delta^{[k]}$: the unknown phase angle.

$V^{[k]}$: the unknown voltage magnitude.

$$\mathrm{f}\,(\,x^{[k]}) \;=\begin{bmatrix} P_{inj}\left(x^{[k]}\right) \\ Q_{inj}\left(x^{[k]}\right) \end{bmatrix} \tag{10}$$

Using given values P_{inj} and Q_{inj}, the unknown values as in equation (9) can be determined by forming jacobian matrix. Jacobian Matrix gives the linearized releationship between small changes in voltage angle $\Delta\delta_i^{[K]}$and voltage magnitude $\Delta\left|V_i^{[K]}\right|$ with small changes in real and reactive power $\Delta P_i^{[K]}$ and $\Delta Q_i^{[K]}$. The elements of the jacobian matrix of (6) and (7) equations are apartially derived and can be evaluated at $\Delta\delta_i^{[K]}$ and $\Delta\left|V_i^{[K]}\right|$ as below,

$$ {}^{df(\,x)}\!/_{dx} \;\Longrightarrow\; \begin{bmatrix} \Delta\, P \\ \Delta\, Q \end{bmatrix} = \begin{bmatrix} {}^{\partial P}\!/_{\partial\delta} & {}^{\partial P}\!/_{\partial|V|} \\ {}^{\partial Q}\!/_{\partial\delta} & {}^{\partial Q}\!/_{\partial|V|} \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \tag{11}$$

$$\begin{bmatrix} \Delta P_1 \\ \Delta P_{n-1} \\ \vdots \\ \Delta Q_1 \\ \Delta Q_{n-m} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_1}{\partial\delta_1} & \cdots & \frac{\partial P_1}{\partial\delta_{n-1}} & \frac{\partial P_1}{\partial|V_1|} & \cdots & \frac{\partial P_1}{\partial|V_{n-m}|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial P_{n-1}}{\partial\delta_1} & \cdots & \frac{\partial P_{n-1}}{\partial\delta_{n-1}} & \frac{\partial P_{n-1}}{\partial|V_1|} & \cdots & \frac{\partial P_{n-1}}{\partial|V_{n-m}|} \\ \frac{\partial Q_1}{\partial\delta_1} & \cdots & \frac{\partial Q_1}{\partial\delta_{n-1}} & \frac{\partial Q_1}{\partial|V_1|} & \cdots & \frac{\partial Q_1}{\partial|V_{n-m}|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial Q_{n-m}}{\partial\delta_1} & \cdots & \frac{\partial Q_{n-m}}{\partial\delta_{n-1}} & \frac{\partial Q_{n-m}}{\partial|V_1|} & \cdots & \frac{\partial Q_{n-m}}{\partial|V_{n-m}|} \end{bmatrix} \begin{bmatrix} \Delta\delta_1 \\ \vdots \\ \Delta\delta_{n-1} \\ \Delta|V_1| \\ \vdots \\ \Delta|V_{n-m}| \end{bmatrix} \tag{12}$$

The matrices in equation (12) can be written in a short form as following,

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J1 & J2 \\ J3 & J4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \tag{13}$$

For voltage-controlled buses, the voltage magnitudes are known. Therfore, if m buses of a system are voltage-controlled, m equations involves ΔQ and

$\Delta|V|$ and thus, the corresponding columns of the jaconian matrix are eliminated. Accodingly there are $n-1$ real power constrains and $n-1-m$ reactive power constrains, and the jacobian matrix of order $(2n-2-m)\times(2n-2-m)$. $J1$ is of order $(n-1)\times(n-1)$, $J2$ is of order $(n-1)\times(n-1-m)$, $J3$ is of order $(n-1-m)\times(n-1)$, and $J4$ is of order $(n-1-m)\times(n-1-m)$.

The first derevitive of real power (equation (6)) which is refered to the voltage angle can be used to form the diagonal and off-diagonal of $J1$ as below,

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{j\neq i}|V_i||V_j||Y_{ij}|\sin(\theta_{ij}-\delta_i+\delta_j) \tag{14}$$

$$\frac{\partial P_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}|\sin(\theta_{ij}-\delta_i+\delta_j)i\neq j \tag{15}$$

In the meanwhile, the first derevitive of the real power (equation (6)) refered to the voltage magnitude that can be used to form the diagonal and off-diagonal of $J2$ as below,

$$\frac{\partial P_i}{\partial |V_i|} = 2*|V_i||Y_{ii}|\cos\theta_{ii} + \sum_{i\neq j}|V_j||Y_{ij}|\cos(\theta_{ij}-\delta_i+\delta_j) \tag{16}$$

$$\frac{\partial P_i}{\partial |V_j|} = |V_i||Y_{ij}|\cos(\theta_{ij}-\delta_i+\delta_j)\,i\neq j \tag{17}$$

Similarlly,the first derevitive of reactive power (equation (7)) refered to the voltage angle can be used to form the diagonal and off-diagonal of $J3$ as follows,

$$\frac{\partial Q_i}{\partial \delta_i} = \sum_{j \neq i} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \tag{18}$$

$$\frac{\partial Q_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}| \cos\left(\theta_{ij} - \delta_i + \delta_j\right) i \neq j \tag{19}$$

Also, the first derevitive of reactive power (equation (7)) can be written refering to the voltage magnitude which can be used to form the diagonal and off-diagonal of $J4$ as below,

$$\frac{\partial Q_i}{\partial |V_i|} = -2 * |V_i||Y_{ii}| \sin \theta_{ii} + \sum_{i \neq j} |V_j||Y_{ij}| \sin\left(\theta_{ij} - \delta_i + \delta_j\right) \tag{20}$$

$$\frac{\partial Q_i}{\partial |V_j|} = -|V_i||Y_{ij}| \sin\left(\theta_{ij} - \delta_i + \delta_j\right) i \neq \mathrm{j} \tag{21}$$

Power mismatch is the difference between scheduled and calculated power. The calculated power can be found using equation (6), (7) and the estimated values.

Active power mismatch is calcualted as below,

$$\Delta P_i^{[k]} = P_i^{sch} - P_i^{[k]} \tag{22}$$

where:

$\Delta P_i^{[k]}$: changes in active power at itteration K.

P_i^{sch}: scheduald active power at bus i.

$P_i^{[k]}$: calculated injected active power from bus i at itteratioin k.

Similarlly, reactive power mismatch is calcualted as follows,

$$\Delta\, Q_i^{[k]} \;=\; Q_i^{sch} - \; Q_i^{[k]} \tag{23}$$

where:

$\Delta\, Q_i^{[k]}$: changes in reactive power at itteration K.

Q_i^{sch}: scheduald reactive power at bus i.

$Q_i^{[k]}$: calculated injected reactive power from bus i at itteratioin k.

After solving equation (12), the new estimates for the voltages and phase angle can be used it in the next itteration as below,

$$\delta_i^{[K+1]} \;=\; \delta_i^{[k]} \;+\; \Delta\delta_i^{[k]} \tag{24}$$

$$\left|V_i^{[k+1]}\right| = \left|V_i^{[k]}\right| + \;\Delta\; \left|V_i^{[k]}\right| \tag{25}$$

The main steps of Newton-Raphson load flow method that is done per each itteration are illustratred in Figure 3.2. The final solution can be expressed as bus’s voltage magnitude and phase angle.

The algorithm illustarted in figure 3.2 can be summrized in the following steps [Saadat, 1999]:

1- Initilization: for load buses the active and reactive power are known, the voltage and angle must be estimated. For the slack bus the voltage and angle are known so set the voltage magnitude 1 and angle 0°.

2- Calculate power mismatch: calculate P and Q injection for load buses using the given values and the estimated values of voltage magnitudes and phase angles, while, for generator bus, P injection is calcualed. After that power mismatch ΔP and ΔQ can be found.

3- Jacoubian matrix is formed using the partial derevitive equations which are in terms of voltage magnitude and angle.

4- Then, matrix form of equations are solved using one of these two methods:

- inversing the Jacobian matrix and multiplying it by the power mismatch.
- using Gaussian elemination for the jacoubian matrix so as to find $\Delta\delta$ and $\Delta|V|$ values.

5- New estimated values are found for voltage magnitude and angle.

6- These steps are repeated until the power mismatch is less than the specified accurcy as illustrated below.

$$\left|\Delta P_i^{[k]}\right| \leq \epsilon \qquad (26)$$

$$\left|\Delta Q_i^{[k]}\right| \leq \epsilon \qquad (27)$$

where:

ϵ: the accurcy is used to determine the final solution.

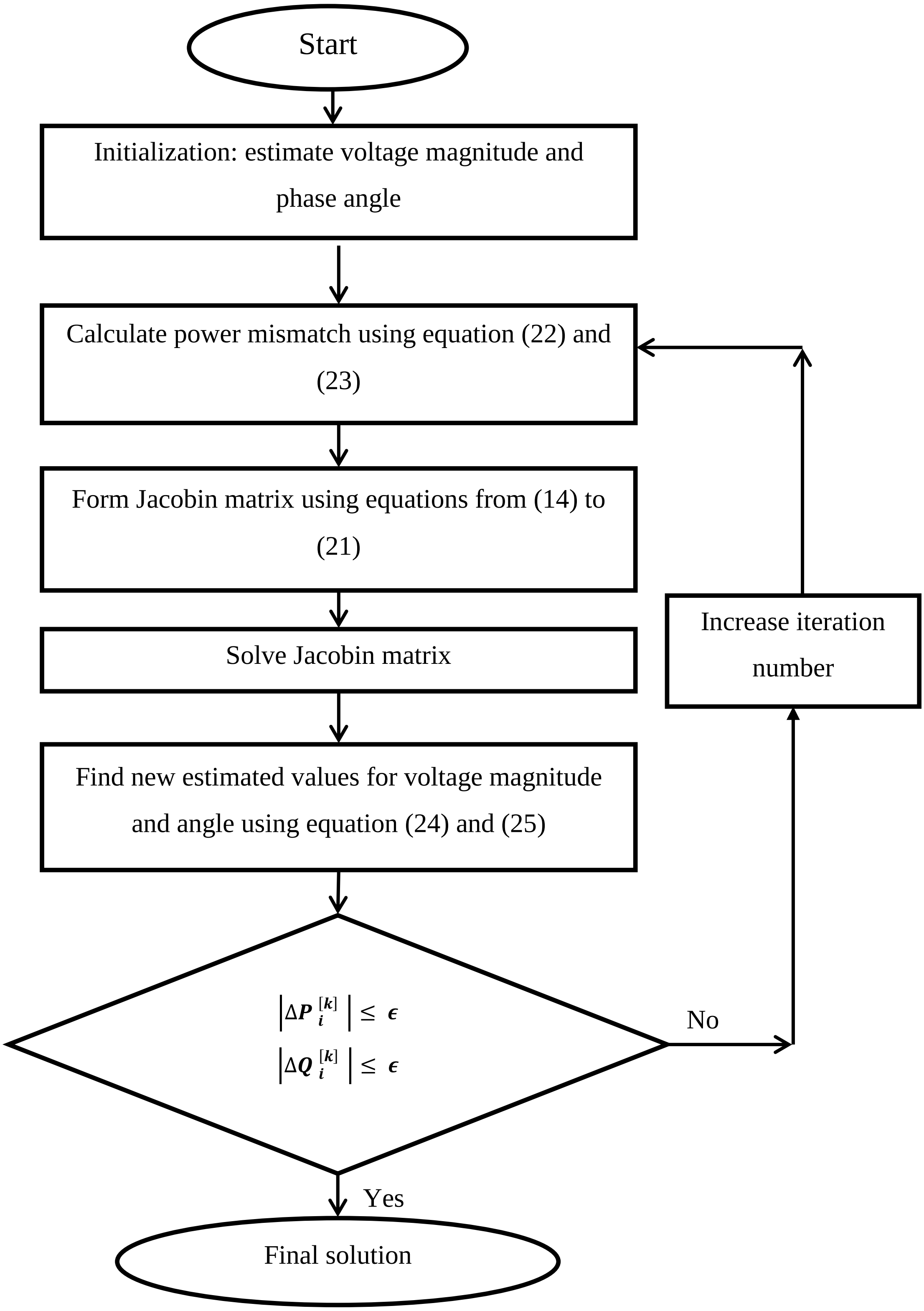

Figure 3.2: Newton-Raphson load flow chart.

fter calculating the voltage magnitude and phase angle for each bus, the power flowing in the line and power losses can be calculated. Before calculating the power losses, some assumptions must be taken into consideration which are the addmittance of transmission line and transformers.

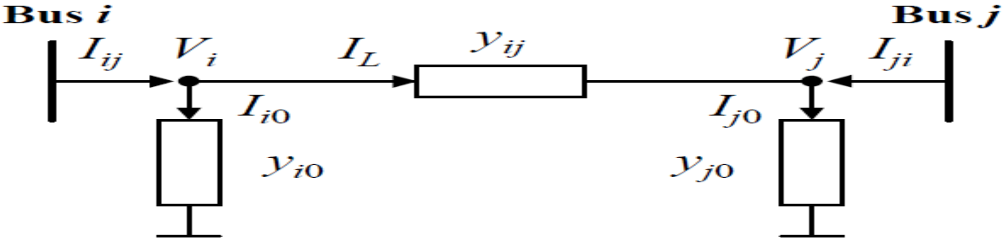

Figure 3.3: Small power network of two buses[Saadat, 1999].

As in figure 3.3 the power that is leaving bus i and flowing to bus j can be found by calculating the flowing current from bus i to bus j as below,

$$I_{ij} = I_L + I_{i0} = y_{ij}\left(V_i - V_j\right) + y_{i0} V_i \tag{28}$$

where:

I_{ij}: the current flow from bus i to bus j.

$$S_{ij} = V_i I_{ij}^* = V_i^2\left(y_{ij} + y_{i0}\right) - V_i y_{ij}^* V_j^* \tag{29}$$

where:

S_{ij}: apperant power flow from bus i to bus j.

Also the power flows from bus j to bus i can be found by calculating the flowing current from bus j to bus i as follows,

$$I_{ji} = -I_L + I_{j0} = y_{ij}\left(V_j - V_i\right) + y_{j0}\,V_j \qquad (30)$$

where:

I_{ji}: the current flow from bus j to bus i.

$$S_{ji} = V_j\,I_{ji}^* = V_j^2\left(y_{ij} + y_{j0}\right)^* - V_j\,y_{ij}^* V_i^* \qquad (31)$$

where:

S_{ji}: apperant power flow from bus i to bus j.

By substracting equation (31) from (29), the power losses can be calculated as follows,

Power losses : $S_{Loss\,ij} = S_{ij} + S_{ji}$ (32)

3.4 Particle Swarm Optimization Method (PSO)

One of the Meta heuristic optimization methods that are utilized for optimal sizing and placement of DG is PSO. PSO can be considered as a computational method that reaches optimal solution for a problem by iteratively updating solution depending on some constrains [Pesaran et.al., 2017].

PSO is a randomly population based optimization method that was developed by Kennedy and Eberhart in 1995 [Kennedy, 1997]. The main idea of it depends on food searching behavior of birds, fish and insects with no leader that is looking for food's place which is the optimal solution. For example, swarms are flying in an organized manner that is based on communication between them without any collision. They update their position and velocity according to the previous case until reaching the optimal solution [Palupi Rini et.al., 2011].

Exploration and Exploitation are two terms that declare the operation of the optimization. When the searching algorithm tries to explore different regions in search space for the optimum, the process is called Exploration. On the other hand, when the searching algorithm tries to concentrate toward a specific region in order to refine a candidate solution, the process is called Exploitation. Using these two concepts the particles in a swarm tries to find optimum solution with the help of their memory by storing data such as their own best position and the global best position for the whole swarm in the memory [Ghalia, 2008].

In PSO each particle in the search space has (solution and fitness), velocity and its own best position and it has a global best position.

The Individual member of the swarm called particle. Each particle has its own dimensional coordinate position and the particles perform the swarm. Fitness is the function (objective function) that is used as an interface between the optimum problem and the physical one and determines the accuracy of the solution. In the search space there are two terms that are updated at each iteration. The first one is the position in the search space that the fitness function returns as best one for a specific position P_{best}t. Meanwhile, the second one is the position in the search space that the fitness function returns as best one for the whole swarm G_{best}. Also upper and lower bounds of the velocity for the movement of the particles in the search space can be considered as constrains V_{Max}, V_{Min}[Abugri and Karam, 2015].

In PSO, each particle is represented in a d-dimensional space, where $\mathrm{x_i} = \left(\mathrm{x_i^1}, \mathrm{x_i^2}, \ldots, \mathrm{x_i^n}\right)$, $\mathrm{V_i} = \left(\mathrm{v_i^1}, \mathrm{v_i^2}, \ldots, \mathrm{v_i^n}\right)$ represents the position and velocity of the $\mathrm{i^{th}}$ particle, respectively.

At each iteration, the velocity must be updated which in turn used to update the position as shown in the equation below,

$$v_{i+1} = \omega V_i + c_1 r_1 (P_{best} - x_i) + c_2 r_2 (G_{best} - x_i) \tag{33}$$

where:

r_1 and r_2: two random variables in the range of zero to one.

c_1 and c_2: positive constants which determine how far the PSO particles move toward P_{best} and G_{best}.

ω: the inertia weight.

ωV_iinertia keeps the particle movements at same direction.

$c_1 r_1 (P_{best} - x_i)$: personal influence which improves the individuals.

$c_2 r_2 (G_{best} - X_i)$: social influence which makes the particle moves toward the best neighbor s direction.

By using equation (33) the position of each particle can be updated as below,

$$x_{i+1} = v_{i+1} + X_i \tag{34}$$

The convergence is controlled by inertia weight (ω) which is chosen at suitable way so as to give a good balance between global and local exploration. Here, if $\omega \geq 1$, the velocities increase with time and PSO diverges, while, if $1 > \omega > 0$, PSO converges.

The algorithm shown in figure 3.4 illustrate PSO method and can be summarized by the following steps [Kennedy and Eberhart, 1995]:

1- Initialization: at this stage the configuration is introduced, such as configuration of the distributed network, candidates for DG sizing and location, initial population that is established randomly, number of iterations and finally the objective function as well as random value of velocity and position should be introduced.

2- Calculation of the fitness function (f(x)): after the program starts in the search space, the fitness function calculates the summation of each particle.

3- P_{best}, G_{best}t for all population are calculated at each iteration. The lowest fitness value for the current iteration is called P_{best}. Also the current value of P_{best} is compared with the one of previous iteration and recorded as G_{best}.

4- The new velocity and position are calculated using equations (33) and (34) for the next iteration.

5- At this point, the new position is updated again.

6- Here, if the condition acheived the specified accuracy, then the algorithm gets back to step 2.

7- Finally, the optimum value or the desired output is set as G_{best}.

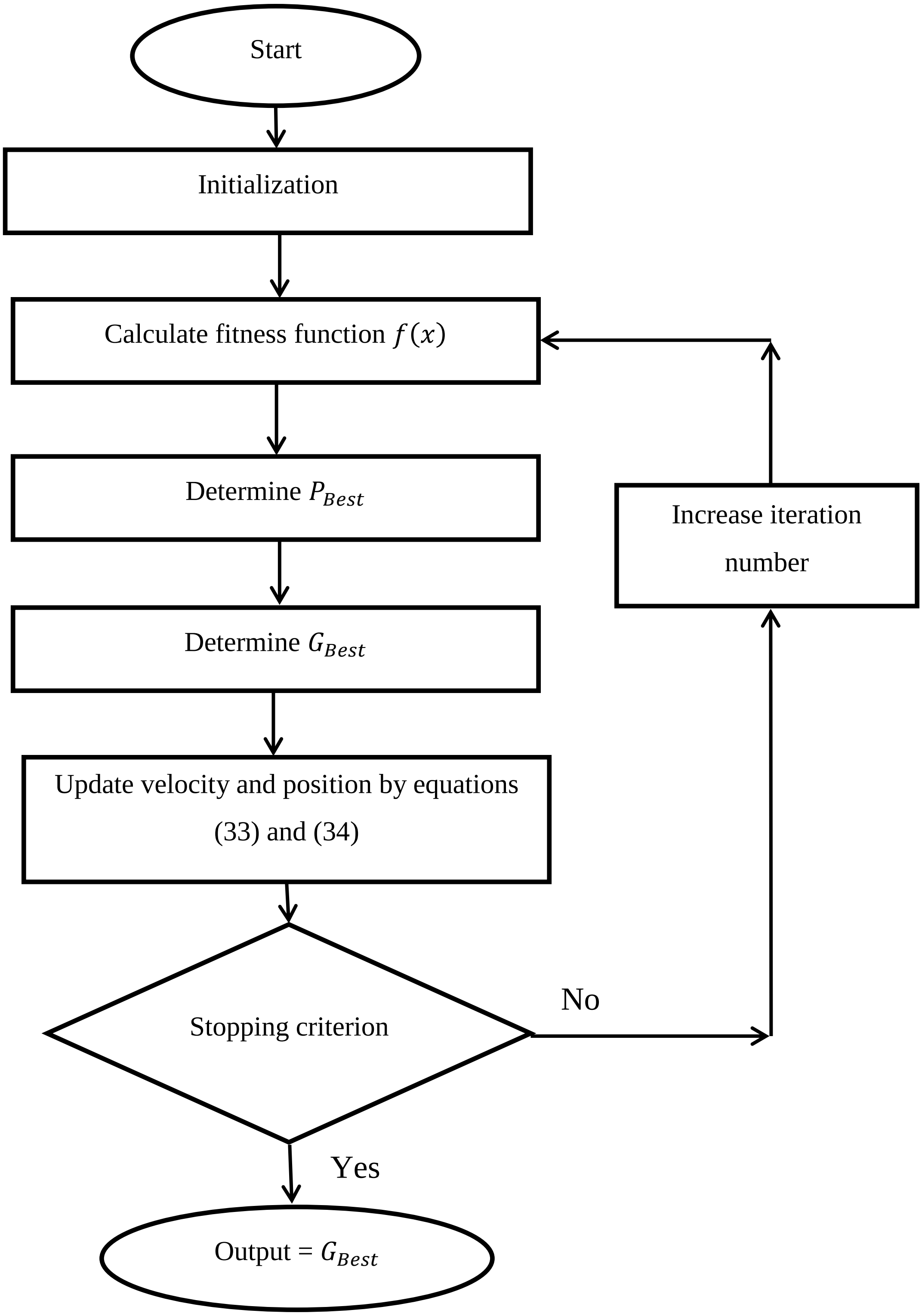

Figure 3.4: Standard PSO algorithm.

3.5 Improved Particle Swarm Optimization Method (IPSO):

PSO solves many optimization problems efficiently but in fact there is no optimization algorithm that can be considered as a perfect one. According to research, there are some problems that PSO fails to solve because of having particles that are trapped at local optimum solution not global one. In addition, PSO has three main constants which are inertia weight ω, c_1, c_2. Any change in these three constants will affect the performance of the algorithm. These parameters need to be adjusted and sometimes if the adjustment is inaccurate, it leads to a diverged solution.

Inertia weigh ω plays a key role in the process of providing balance between exploration and exploitation process. Also, it determines the contribution of the previous velocity of each particle with the current velocity. The basic PSO has no inertia constant [Kennedy and Eberhart, 1995]. Following that the concept of inertia weight was introduced as constant value by [Shi and Eberhart], they state that a large inertia weight facilities a global search while small inertia weight facilities a local search [Liang and Kang, 2016]. It also has a great influence optimization performance. High value of ω is useful to improve the convergence speed of the algorithm, while the low ω improves the convergence precision of the algorithm [Shi and Eberhart, 2002].

In order to improve PSO a time variant inertia weight has been introduced by many researchers which helps to come out quickly from a region where the velocity becomes stagnant [Ojha and Das, 2012].

There are many different strategies that have been proposed to change inertia weight, which can be divided into two categories, linear strategy [Shi and Eberhart, 1999] and nonlinear strategy [Shi and Eberhart, 2001]. The linear strategy suggests that inertia weight with the number of iterations increased can be decrease linearly as in equation (35), which can ensure early larger ω value so as to accelerate convergence and smaller value ω so as to avoid falling into local optimum. By comparing with linear strategy, nonlinear strategy not only suggests ω in the initial stage in a better way, but it also reduces time needed to get the optimum solution. Moreover, with nonlinear inertia strategy, all particles can be quickly spread all over the search space so as to determine the approximate range of global extremes. Therefore, nonlinear strategy can obtain better performance than linear strategy [Liang and Kang, 2016].

In this research, linear strategies will be used in conventional PSO algorithm. Meanwhile, an improved version of PSO which offers improvement in quality solution and computational time is proposed by controlling the inertia weight ω by using exponentially time varying weight.

The linear equation of inertia weight used in conventional PSO algorithm can be described as below [Falco et.al., 2007],

$$\omega = \omega_{max} -((\omega_{max} - \omega_{min}) \times \left(\frac{iter}{maxiter}\right)) \qquad (35)$$

In the meanwhile, the linear equation that is used in[Obaidy and Ayesh, 2008] can be described as below,

$$\omega = (\omega - 0.4\ ) * \left(\frac{(maxiter - iter\ )}{maxiter}\right) + 0.4 \qquad (36)$$

where:

ω_{max}: the maximum weight.

ω_{min}: the minimum weight.

$iter$: the current iteration number.

$maxiter$: maximum number of iterations.

ω : the constant weight suggested value is 0.9.

The equations (35) and (36) offer a linear decreasing inertia weight. This inertia weight linearly decreases with respect to time. Generally for initial stages of the search process, large inertia weight is recommended to enhance the global exploration (searching new area). Meanwhile, for last stages, the inertia weight is reduced for local exploration (fine tuning of the current search area).

As an addition to linear strategies, equation (36) can be used as a time varying inertia weight which decreases exponentially with time. By starting from maximum toward minimum weight, the exponential inertia weight reduces computational time in PSO and improves convergence.

$$\omega = \omega_{max} \times \; e^{\left(\left(\frac{(maxiter - iter)}{maxiter}\right) - 1\right)} - \omega_{min} \tag{36}$$

where:

ω_{max}: the maximum weight.

ω_{min}: the minimum weight.

$iter$: the current iteration number.

$maxiter$: maximum number of iterations.

In this research this equation is used in the PSO algorithm so as to provide an improved version of PSO method.

Chapter Four
Results and Discussion

4.1 Introduction

In this research an improved PSO optimization algorithm is proposed for optimal placement and sizing of DGs in electrical power systems. IEEE 34 bus network is used as a case study to perform this research. Power flow analysis is utilized so as to study the performance of the adapted electrical power system before and after placing the optimally sized DG unit. Thus, in this chapter power flow analysis of the adapted system with and without DG units that are placed and sized based on conventional PSO algorithm as well as the proposed improved PSO algorithm are presented.

4.1.1 Power Flow Analysis of IEEE 34 Bus System Without DG:

The adapted electrical network consists of 34 buses with one generation bus, 29 load buses and 33 branches. IEEE 34 bus network has a radial configuration as can be seen in figure 4.1.

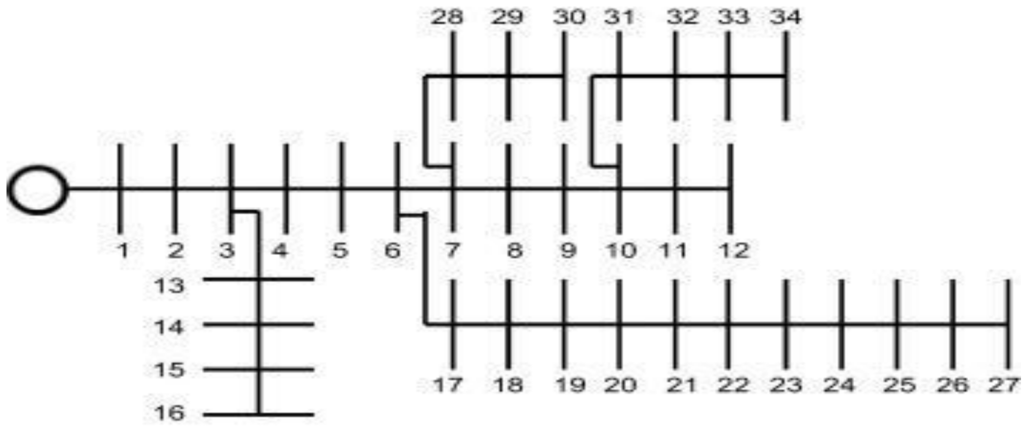

Figure 4.1: One line diagram of IEEE 34 bus system.

The adapted testing system is studied in terms of active and reactive power losses, voltage magnitudes and phase angles before any DGs installation using power flow analysis. Load flow analysis is performed for this network with MATPOWER 6.0 package. The solution of the load flow mathematical problem is done based on Newton-Raphson method. The coded network using MATLAB can be seen in Appendix A.

As a result, the total generation of the network is 5.89MW (P_g) and 3.52 MVAr (Q_g). In the meanwhile, the total loads of the network are 5.56 MW (P_d) and 3.42 MVAr (Q_d) distributed over 29 load buses. Figure 4.2 shows the results of the conducted load flow analysis in terms of voltage magnitudes and angles (see Appendix B). From the figure, the buses that are far from the power source have low voltage magnitude as compared to the buses that are located near generation source. The buses which are in the range of bus 19 to bus 27 have the lowest voltage magnitude as compared to other buses. All of these buses have voltage magnitude below 0.95 pu. Phase angles for all buses seem good and there are no instability problems. Anyway it is assumed that any DG placement at buses 19 to 27 can support this power system in a positive way. Moreover, active and reactive power losses are determined from the conducted power flow analysis (see Appendix C). Figure 4.3 shows a summary of the active and reactive power losses for each branch. The total losses in the whole network is 0.329 MW (P_{losses}) which is 5.58% of the total active power generation, while the reactive power losses are 0.10 MVAr (Q_{losses}), which is 2.84% of the total reactive power generation.

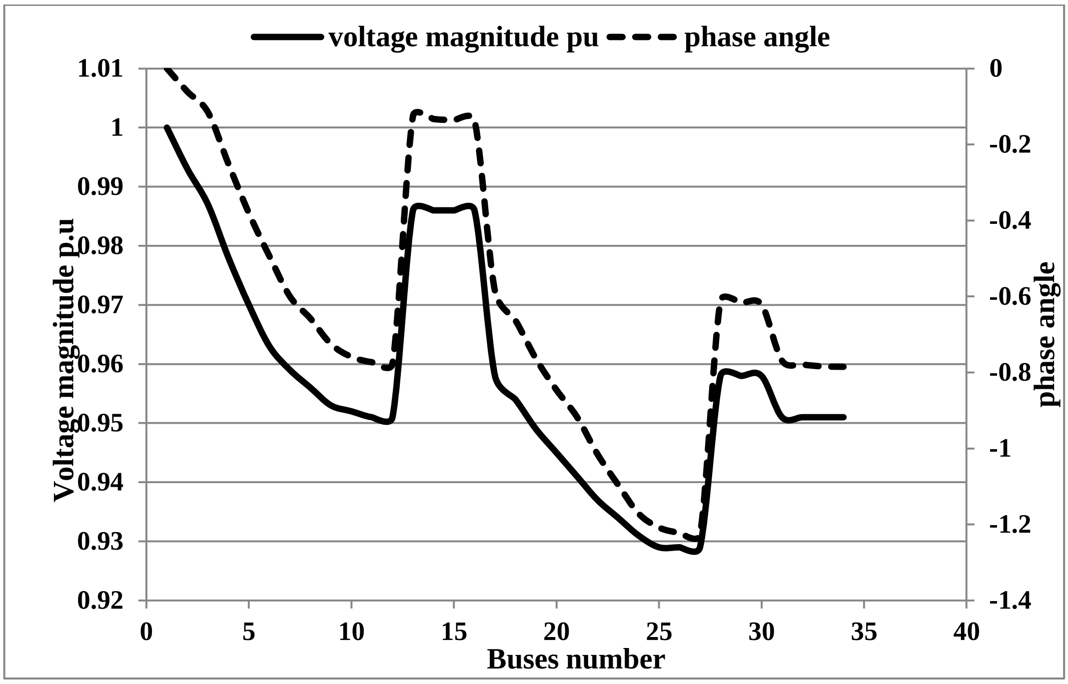

Figure 4.2: voltage magnitude and phase for the power system angle before DG installation.

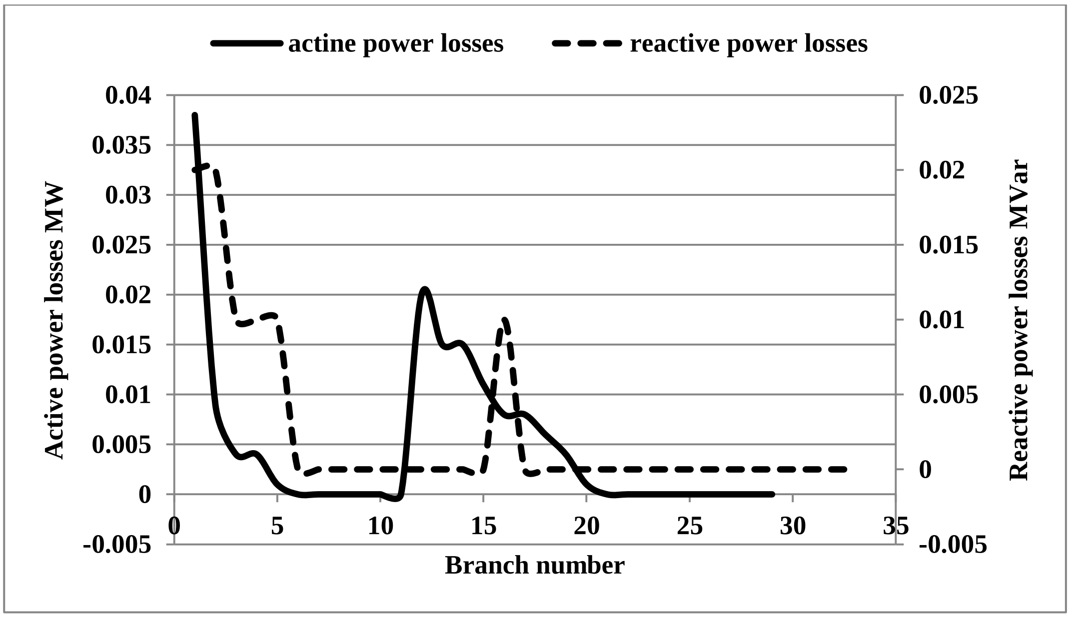

Figure 4.3: Active and reactive power losses for the system before DG installation.

4.2 Results for Optimal Placement and Sizing of DG Using Conventional PSO Method

In this research MATLAB software is used to apply the conventional particle swarm optimization algorithm for optimal placement and sizing of DG in the power system.

A mfile called mainPSO_34 is used as main code (see Appendix D). This mfile has an iterative loop which is called “PSO codes 100 times”. In the meanwhile, Newton-Raphson code and other codes from MATPOWER package are used namely runpf.m, newtonpf.m, case34balanced.m and etc.(see Appendix E) as supportive codes for the main code.

In the used PSO code, 50 particles are generated to find the size and location of one DG unit which has three dimensions. In the used PSO code constants are used to update the velocity of the algorithm such as inertia weight which has 0.9 and 0.4 as maximum and minimum value respectively as recommended by [Xin et.al., 2009]. In addition, c_1 and c_2 are positive constant used in the algorithm whereas these constants are assumed to be equal to 2 as recommended by [Kennedy, 1997].

The applied DG supplies active power only while, the maximum penetration level allowed is assumed to be 41.15% of the total generation. Some boundaries are achieved according to DG capacity, voltage and location of the DG unit. The capacity of the DG is assumed to be in the range of 1.2 - 2 MW. According to the location of the generation load buses which are located between buses 2 and 34 are considered as a possible location for the DG unit. A constraint is considered for the bus voltage magnitude, they should be in the range from 0.9 up to 1.05 pu.

In conventional PSO algorithm, a linear inertia equation is usually used [Kennedy, 1997]. Inertia weight starts from a maximum value of weight and decreases linearly toward the minimum value of the weight as shown in figure 4.4.

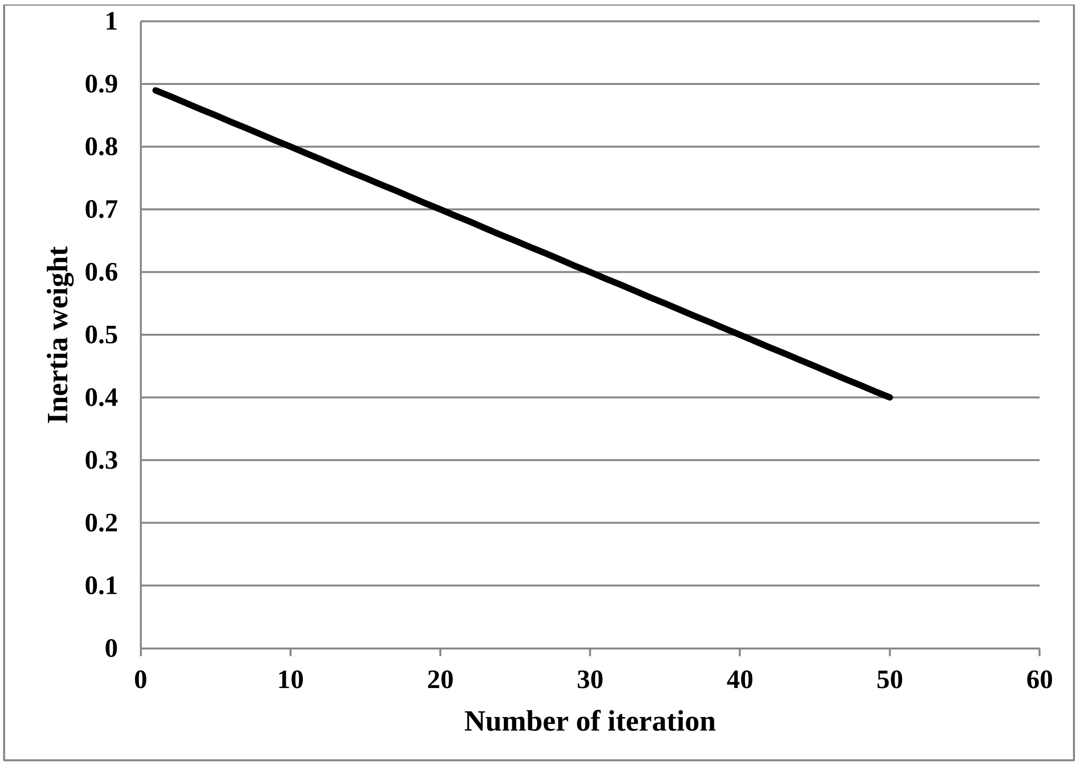

Figure 4.4: Inertia weight using linear equation.

Figure 4.5 shows the applied convetional PSO algorithm. The algorithm can be summrized in the following steps:

1- Insert a PV unit at each bus in IEEE34 bus system.

2- Assume initial parameters of PSO code such as number of iteration, number of DG units, PSO parameters and upper boundary and lower one.

3- Randomly create the 1st particle position and then start forming the search space.

4- Return the load flow result from Matpower codes using Newton Raphson load flow method.

5- Check bus voltage constraints and if they are achieved continue, otherwise repeat the load flow analysis.

6- Reset G_{Best} and compare the current P_{Best} with the fitness. If P_{Best} is less than the fitness, P_{Best} is updated, otherwise P_{Best} remains the same.

7- Compare the current G_{Best} with P_{Best}. If G_{Best} is less than the P_{Best}, G_{Best} is updated, otherwise G_{Best} remains the same.

8- Update particles velocity and position.

9- Check upper and lower bounds.

10- Sort the result according to the obtained optimum solution.

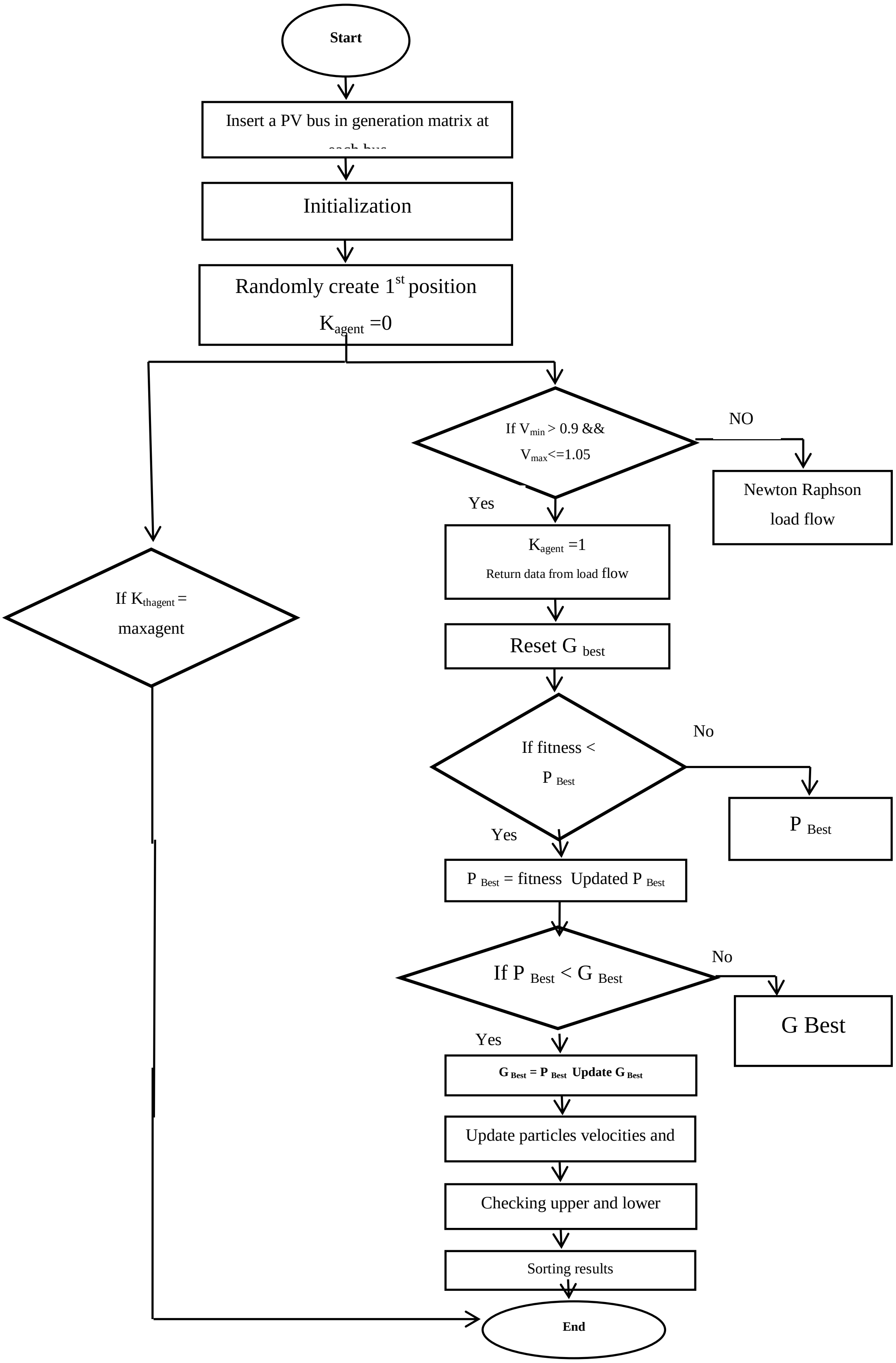

Figure 4.5: PSO algorithm according to the PSO cod.

According to figure 4.6, a DG unit with a size of 1.6722 MW can be installed at bus number 10 which makes the voltage magnitude 1.0055 pu. The minimum value of fitness losses is 0.0406 while average elapse time is 78.6212 s (see Appendix F). Also the convergence characteristic of the optimum choice is shown in figure 4.7.

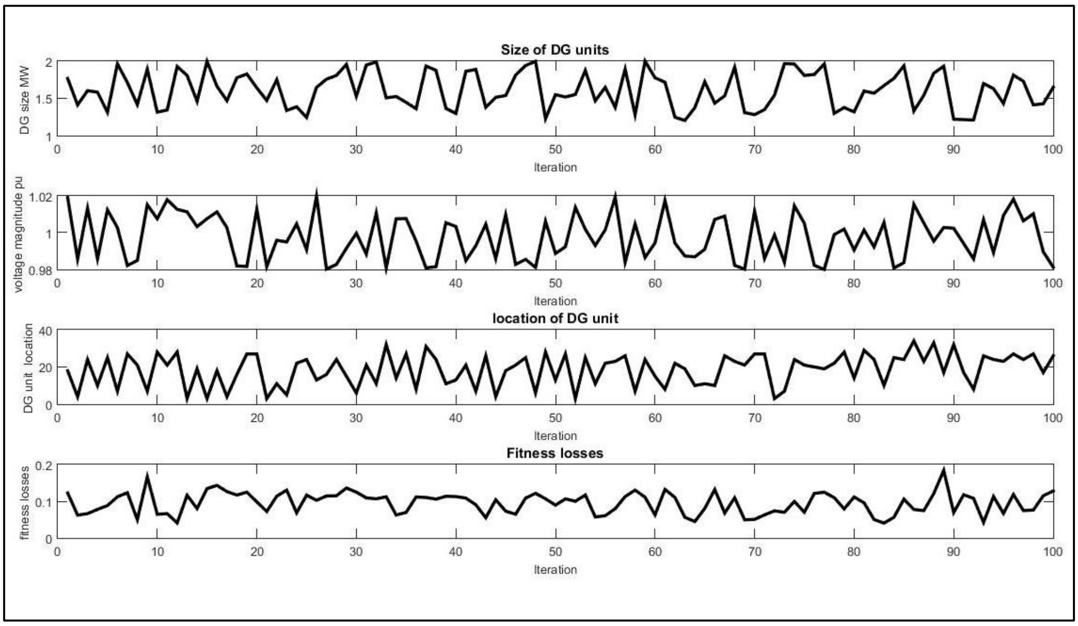

Figure 4.6: The result of conventional PSO algorithm.

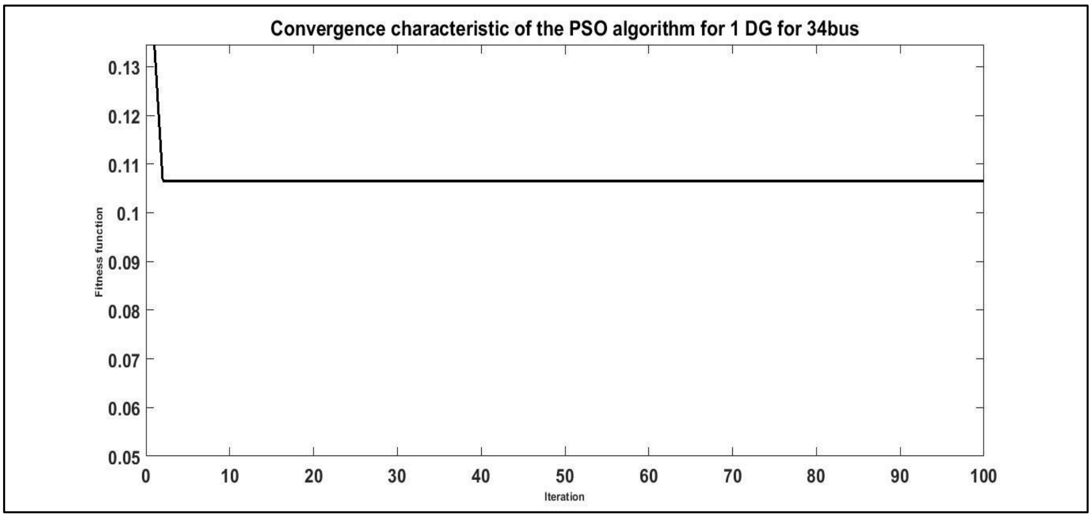

Figure 4.7: The convergence characteristic of the optimum iteration using conventional PSO.

After getting the optimum results from PSO optimization method, a power flow analysis study is conducted again for the network considering the newly installed DG unit.

As a result of installing the newly optimized DG unit in the power system, the total generation in the network is 5.79MW, and 3.48 MVAr. Meanwhile, the total loads are 5.56 MW and 3.42 MVAr distributed over 29 load buses. It is noted that, the total generation of the whole system does not change before and after DG installation. However, the individual sharing of generated power from the main source is reduced which consequently reduces the active power losses.

As shown in figure 4.8 the voltage magnitudes of the buses are improved without affecting phase angles in terms of any instability (see Appendix G).

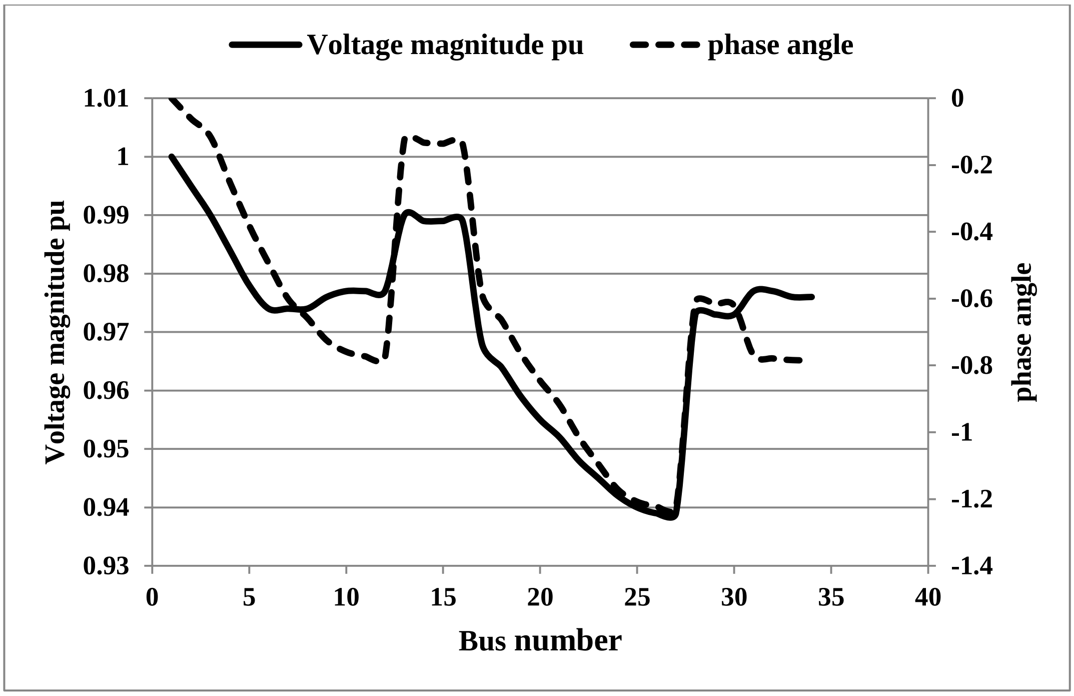

Figure 4.8: voltage magnitudes and phase angles after a DG installation.

Figure 4.9 shows branch losses after DG installation whereas these losses are reduced. See Appendix H for more details about branch losses.

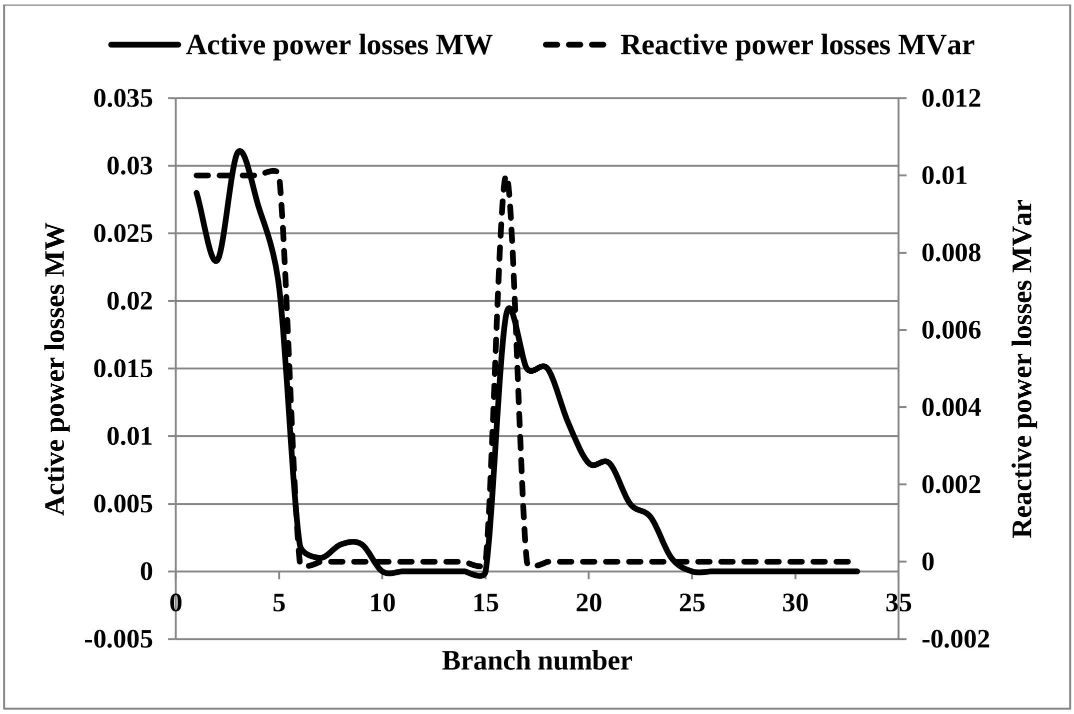

Figure 4.9: Active and reactive power losses after a DG installation.

Table 4.1 shows a comparison of the performance of the network before and after inserting the DG. As noted from figure 4.9 the branches' active and reactive power losses are decreased. The total power losses in this network after DG unit is installed are 0.225 MW and 0.06 MVAr. It is noted that the active power losses are reduced by 31.61%.

Table 4.1: comparison between network status before and after DG installation.

	Before DG installation	After DG installation
Total active power generation MW	5.89	5.79
Total reactive power generation MVar	3.52	3.48
Total active power losses MW	0.329	0.225
Total reactive power losses Mvar	0.1	0.06
Power factor	0.8584	0.7639
Bus voltages pu	0.929 – 1.000	0.939 – 1.000

It is noted from figure 4.10 that voltage profile is improved after a DG installation. All loads get the demanded power from the main source in the network before DG installation. In the meanwhile, after installing the DG at bus 10 with a size of 1.6722 MW, the power flow is changed in terms of direction as the installed DG helps in powering loads that are located near it and consequently it reduces the amount of power demanded from main source. As a result, losses in the system are decreased and the voltage profile is improved . But the power factor is reduced after DG installation as shown in table 4.10 because the power generated from main source is reduced but reactive power remains the same. This problem can be solved using power factor correction method such as capacitor banks.

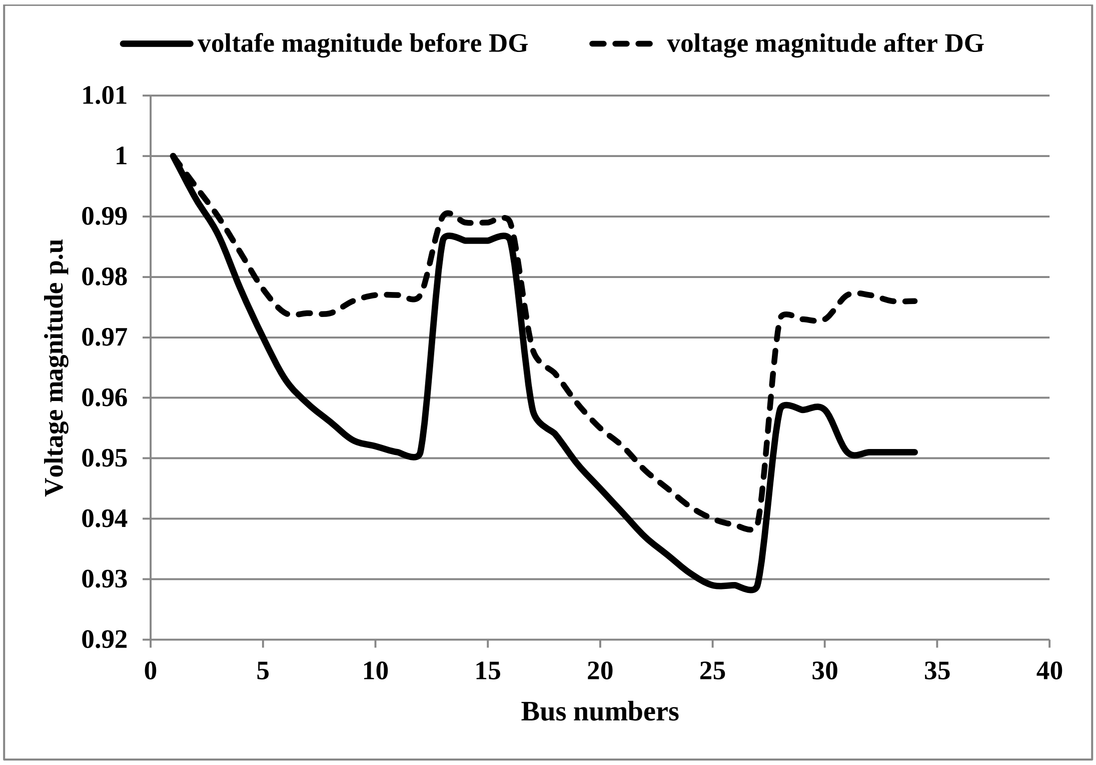

Figure 4.10: Bus voltage magnitudes before and after DG installation.

4.3 Results for Installing DG Using the Improved Particle Swarm Optimization (IPSO)

As mentioned earlier, an improved PSO algorithm is used to reduce the elapse time by using new proposed weight equation. This equation has a non-linear pattern. Figure 4.11 shows the pattern of the inertia weight decreasing exponentially using the proposed non-linear equation. In addition another equation of weight that is presented in [Obaidy and Ayesh, 2008] is used so as to show the superiority of the proposed research.

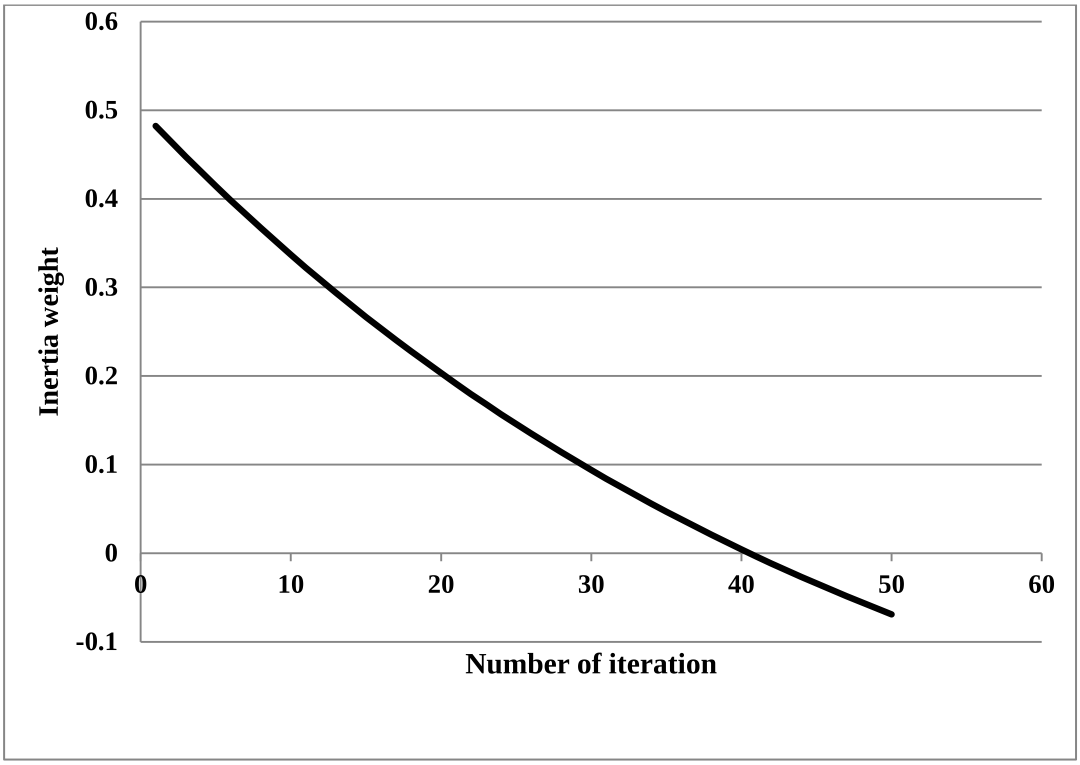

Figure 4.11: Inertia weight using non-linear equation.

Figure 4.12 and 4.13 show the results of the new proposed algorithm based on the new nonlinear equation (codes are shown in Appendix I and J).

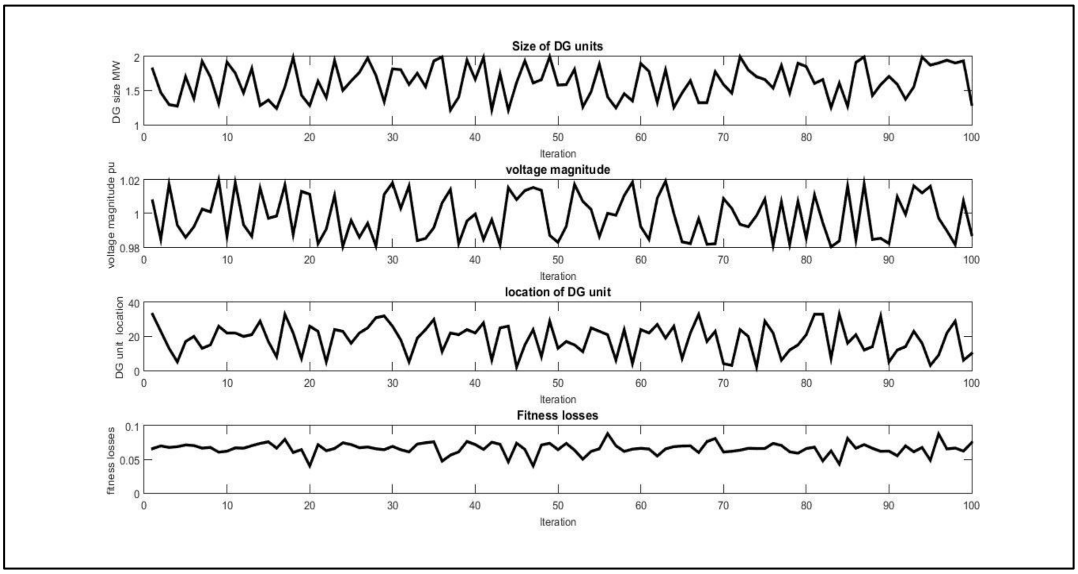

Figure 4.12: Result of proposed improved PSO algorithm .

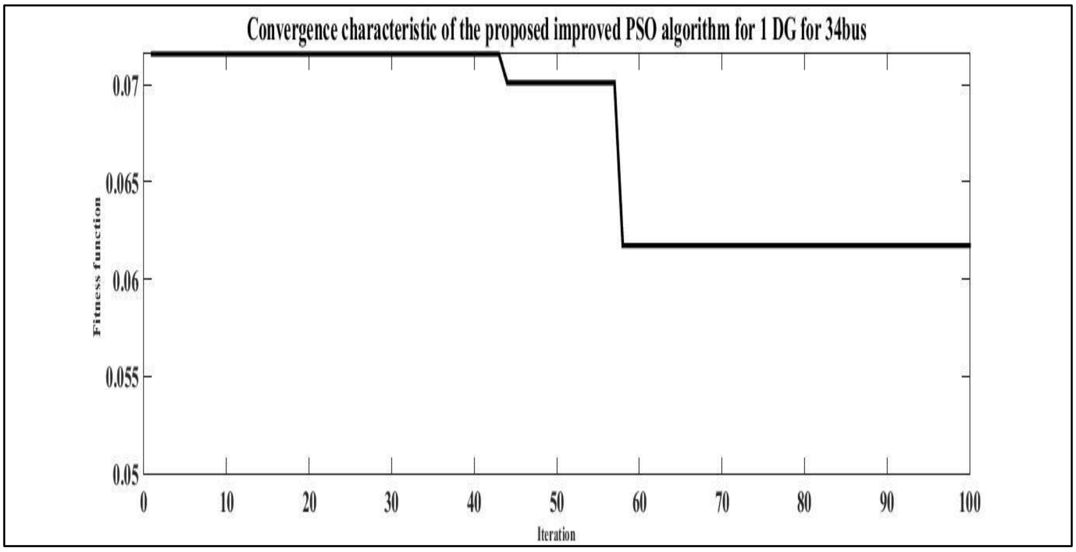

Figure 4.13: Convergence characteristic of using the proposed Improved PSO algorithm.

Here, a comparison between conventional PSO algorithm and the improved algorithm is presented in terms of elapse time. Table 4.2 shows a comparison between conventional PSO algorithm, the algorithm presented in [Obaidy and Ayesh, 2008] and the proposed Improved PSO algorithm. The elapse time is decreased by using Improved PSO. From the table it’s seen that the improvement in algorithm performance is achieved by the new proposed equation as the lowest elapse time is achieved by using the proposed algorithm.

If a comparison conducted between the bus that proposed PSO has chosen and the farthest bus which is bus no 34, a load flow analysis is conducted by inserting 1.6115 MW distributed generation unit at bus 24. As a result the total active power losses is 0.18 MW and 0.238 MW for buses 24 and 34 respectively. This insure that proposed PSO has better performance to choose the optimum location.

Table 4.2: Comparison between adapted PSO algorithms and the proposed algorithm.

	Proposed PSO	Convectional PSO	PSO in [Obaidy and Ayesh, 2008]
DG1_ size (MW)	1.6115	1.6722	1.3764
DG1_ Vc	1.0155	1.0055	1.0163
DG1_ location	24	10	26
Fitness losses	0.0401	0.0406	0.0425
Total active power losses MW	0.18	0.225	0.194
Average _elapsed time (s)	62.2325	78.6212	69.0836

To highlight the effect of the installation of a DG unit on the operating parameters of the testing system, the cost of this proposal is briefly discussed. According to [Abdul Kadir et.al., 2014], the total cost of 1 kWp of a large scale distributed generation is about 1,200 USD/kWp. Such a system has a life cycle time of 25 years. In the meanwhile, real power losses can be financially evaluated by the cost of total amount of kWh through the life cycle of the distributed generation. In this research the cost of the kWh is assumed to be 0.14 USD. Meanwhile, reactive power losses cost can be estimated depending on the status of the network which is indicated by the power factor of the network. In general, the kVArh in this research is assumed to be 0.2 USD considering relatively low power factor.

According to the results one DG is installed considering the best place and the best capacity for minimum losses at bus 24 with a capacity of 1.6115 MW. In this case, the cost of the suggested DG is 1,933,800 USD and the amount of power losses is reduced by 0.104 MW. Considering the nature of the installed DG system (generates real power only), the savings of the reactive power are neglected. Following that, the estimated saving of this practice over the life cycle time of the DG system is 3,188,640 USD. This clarifies that installing a DG unit could significantly decrease the total cost and power losses. However, this is not the only benefit of installing DG as it affects positively system's voltage and stability.

Chapter 5

Conclusion and future work

5.1 Conclusion

In this thesis an improved particle swarm optimization method (IPSO) was used to find the optimum size and location of a distributed generation unit in IEEE 34 bus power system in order to improve the voltage profile and reduce the losses. A new equation of weight inertia was proposed so as to improve the performance of PSO conventional algorithm. This development was done by controlling the inertia weight affected the updating velocity of the particles in the algorithm. By using non-linear equation of the inertia weight. This development has a significant impact on the performance of the conventional PSO algorithm which is based on liner inertia weight equations. Maltab codes were developed for the power system, improved PSO algorithm and power flow analysis so as to conduct the research. Results showed that 5.58% of the total active power generation is consumed as active power losses before the installation of the distribution unit in the power system. In the meanwhile, 2.84% of the total reactive power generation is consumed as losses before the installation of the distribution unit in the power system. Moreover, results indicate that buses which are located in the range of bus number 19 and bus number 27 have the lowest voltage magnitude (below 0.95). Following that, the applied conventional PSO algorithm successfully found the optimal size and location of the desired DG unit with a capacity of 1.6722 MW at bus number 10. This made the voltage magnitude equal to 1.0055 pu and improved the status of the power system in general. The minimum value of fitness losses using the applied algorithm was 0.0.0406 while average elapse time was 78.6212 s. In addition to that, the applied PSO optimization algorithm reduced the active power losses by 31.61%. As a comparison conventional PSO algorithm that are based on liner inertia weight equations, consumed 78.6212 s to provide the optimum solution. On the other hand, the proposed algorithm consumed 62.2325 s to provide the optimum solution. As a conclusion it was found that installing DG unit at the optimum bus with optimum size reduces active power losses and improved the voltage profile better than installing DG unit at the farthest buses or weakest buses based on current role of thumps in the literature.

5.2 Future work

In this research a significant contribution is proposed to the science of optimum sizing and placement of DG units in electrical power system. However there are still some challenges to this science which needs to be considered in future research as listed below,

1- To study more completed power networks considering other network topologies.

2- To apply a multi-objective optimization problem considering other important issues in the power network such as network stability and total harmonic distortion.

3- To consider installing multi DG units in the network and compare the results with single DG unit installation.

4- To apply other optimization methods and compare the results with the proposed Improved PSO

References

- Abdul Kadir A., Khatib T.,Elmenreich W. “***Integrating photovoltaic systems in power system: power quality impacts and optimal planning challenges”*** **International Journal of Photo energy**, pp. 1-8, 2014.

- Abu-Mouti F. S., El-Hawary M. E., “**Optimal distributed generation allocation and sizing in distribution systems via artificial bee colony algorithm,”** IEEE transactions on power delivery, vol. 26, no. 4, pp. 2090–2101, 2011.

- Acharya N., Mahat P., Mithulananthan N., “***An analytical approach for DG allocation in primary distribution network,”*** **International Journal of Electrical Power & Energy Systems,** vol. 28, no. 10, pp. 669–678, 2006.

- Ackermann Thomas, Andersson Göran, Söder Lennart, **" Distributed generation: a definition",** Electric Power Systems Research, Volume 57, Issue 3, pp. 195-204, 2001.

- Aman M.M., Jasmon G.B., Bakar A. H.A., Mokhlis H. , " **A new approach for optimum DG placement and sizing based on voltage stability maximization and minimization of power losses"** , Energy Conversion and Management , volume 70 pp. 202–210, 2013.

- Al Abri R. S., El-Saadany Ehab F., Atwa Yasser M. **," Optimal Placement and Sizing Method to Improve the Voltage Stability Margin in a Distribution System Using Distributed Generation"** , IEEE Transactions on Power Systems Volume 28, Issue: 1, pp.326-334, 2013.

- AlHajri M. F., AlRashidi M. R., El-Hawary M. E., "**Improved sequential quadratic programming approach for optimal distribution generation deployments via stability and sensitivity analyses,"** Electric Power Components and Systems Volume 38, Issue 14, pp. 1595–1614,2010.

- Arya L.D., A., Choube S. C., ***"Distributed generation planning using differential evolution accounting voltage stability consideration***," **International Journal of Electrical Power & Energy Systems**, vol. 42, no. 1, pp. 196–207, 2012.

- Atwa Y. M., El-Saadany E. F., "**Probabilistic approach for optimal allocation of wind-based distributed generation in distribution systems,"** IET Renewable Power Generator, vol. 5, no. 1, pp. 79–88, 2011.

- Bai Q., **"Analysis of Particle Swarm Optimization Algorithm**," Computer and Information Science, volume 3, No.1,pp.180-184, 2010.

- Barker P.P., De Mello R.W., **"Determining the impact of distributed generation on power systems Radial distribution systems**", Power Engineering Society Summer Meeting IEEE, vol. 3, pp. 1645–1656,2000.

- Borbely A. M. , Kreidel.(J. F. 2001).**Distributed Generation: The Power Paradigm for the New Millennium.**, CRC Press, NewYork, NY, USA.

- Blum Christian, Roli Andrea," **Meta-heuristics in combinatorial optimization: Overview and conceptual comparison** ",ACM Computing Surveys Volume 35 issue 3, pp.268-308, 2003.

- Coles L., Beck R.W., "**Distributed generation can provide an appropriate customer price response to help fix wholesale price volatility**", in Power Engineering Society Winter Meeting IEEE, vol. 1, pp. 141–143, 2001.

- Chen Haiyan, Chen Jinfu, Shi Dongyuan, Duan Xianzhong ," **Power Flow Study and Voltage Stability Analysis for Distribution Systems with Distributed Generation"** , Power Engineering Society General Meeting, Power Engineering Society General Meeting, IEEE,2006.

- Daud S. , Kadir A.F.A. , Gan C.K. , Mohamed A., Khatib Tamer , "**A comparison of heuristic optimization techniques for optimal placement and sizing of photovoltaic based distributed generation in a distribution system"** , Solar Energy, Volume 140, pp. 219-226, 2016.

- Del Monaco J.L. , "**The role of distributed generation in the critical power infrastructure"**, Power Engineering Society Winter Meeting IEEE, vol. 1, pp.144– 145, 2001.

- Devi S., Geethanjali M**.,*" Optimal location and sizing determination of Distributed Generation and DSTATCOM using Particle Swarm Optimization algorithm "***, **International Journal of Electrical Power & Energy Systems,** Volume 62, pp. 562-570, 2014 .

- Dondi P., Bayoumi D., Haederli C., D. Julian, Suter M., ***“Network integration of distributed power generation,”*** **Journal of Power Sources,** vol. 106, no. 1–2, pp. 1–9, 2002.

- Dorigo M., Maniezzo V., Colorni A., **“Ant System : Optimization by a Colony of Cooperating Agents**,” vol. 26, no. 1, 1996.

- Doyne Farmer J., Packard Norman H, Perelson Alan S, “**The Immune System, Adaptaation , and Machine Learning,”** Physica D: Nonlinear Phenomena, Volume 22, Issues 1–3, pp. 187-204, 1986.

- Ellis M.W., Von Spakovsky M.R., Nelson D.J., “**Fuel cell systems: efficient, flexible energy conversion for the 21st century**”, Proceedings of the IEEE, vol. 89, issue 12, pp. 1808–1818, 2001.

- El-Nozahy M. S. , Salama M. M. A. ***,"A review Technical impacts of grid-connected photovoltaic systems on electrical networks***" , **Journal of Renewable and Sustainable Energy**, volume 5, 2013.

- El-Khattam W., Salama M.M.A**," Distributed generation technologies, definitions and benefits"**, Electric Power Systems Research, Volume 71, Issue 2, pp. 119-128, 2004.

- El-Zonkoly A. M., “**Optimal placement of multi-distributed generation units including different load models using particle swarm optimization,”** IET Generation, Transmision, Distribution, vol. 7, pp. 760–771, 2011.

- Engin Karatepe, Faruk Ugranlı, Takashi Hiyama ," **Comparison of single- and multiple-distributed generation concepts in terms of power loss, voltage profile, and line flows under uncertain scenarios**", Renewable and Sustainable Energy Reviews, Volume 48, pp.317-327, 2015.

- Esmaili Masoud , Firozjaee Esmail Chaktan, Shayanfar Heidar Ali, " **Optimal placement of distributed generations considering voltage stability and power losses with observing voltage-related constraints**" , Applied energy volume 113, pp. 1252-1260, 2014 .

- Esmaili Masoud , " **Placement of minimum distributed generation units observing power losses and voltage stability with network constraints**" , IET Generation, Transmission & Distribution, 9 pages, 2013.

- Evangelopoulos Vasileios A., Georgilakis Pavlos S., Hatziargyriou Nikos D.," **Optimal Distributed Generation Placement in Power Distribution Networks: Models,Methods, and Future Research**", Electric Power Systems Research, Volume 140, pp.95-106, 2016.

- Falco D., Cioppa A. D., Tarantino E., “**Facing classification problems with Particle Swarm Optimization “,** Applied Soft Computing, pp. 652–658, 2007.

- Farooque, Maru H.C., “**Fuel cells—the clean and efficient power generators”** , Proceedings of the IEEE ,volume. 89, issue 12, pp. 1819–1829, 2001.

- Fazliana Aida, Kadir Abdul, Khatib Tamer, Elmenreich Wilfried," ***Review Article Integrating Photovoltaic Systems in Power System: Power Quality Impacts and Optimal Planning Challenges"*** , **International Journal of Photoenergy,** Article ID 321826, 7 pages,2014,.

- Geem Z. W., Kim J. H., Logonathan G. V., “**A New Heuristic Optimization Algorithm: Harmony Search,”** Simulation, volume. 78, no. 2, , pp. 60–68, 2001.

- Georgilakis Pavlos S., Hatziargyriou Nikos D.," **Optimal Distributed Generation Placement in Power Distribution Networks: Models, Methods, and Future Research"** , IEEE Transactions on Power Systems, volume. 28, no. 3, pp.3420-3428, 2013.

- Ghalia M. B., "**Particle Swarm Optimization with an Improved Exploration-Exploitation Balance**," IEEE, 2008.

- Hadjsaid N., Canard J.-F., Dumas F., “**Dispersed generation impact on distribution networks”**, IEEE Computer Applications in Power, volume 12 issue 2, pp.22-28,1999.

- Hamedi H. , Gandomkar M., “***A straightforward approach to minimizing unsupplied energy and power loss through DG placement and evaluating power quality in relation to load variations over time***,” **Int. J. Electr. Power Energy Syst**., vol. 35, no. 1, pp. 93–96,2012.

- Hedayati Hasan, Nabaviniaki S. A., , Akbarimajd Adel ," **A Method for Placement of DG Units in Distribution Networks"**, IEEE Transactions ON Power Delivery, volume. 23, NO. 3, pp. 1620-1628,2008.

- Hua Lidan, LuYuping, “**Study on the effect of distributed generation size on digital protective device in distribution system**”, ELECTRIC POWER. vol41, issue 3,pp.12-16,2008.

- Ilic M., “**The information technology (IT) role in future energy generation**”, in Power Engineering Society Winter Meeting IEEE, volume 1, pp. 196–198,2001.

- Jabr R. A. , Pal B. C., “**Ordinal optimisation approach for locating and sizing of distributed generation**,” IET Gener., Transm., Distrib., vol. 3, no. 8, pp. 713–723,2009.

- Jamil Majid, Sharique Anees Ahmed," **Optimal sizing and location of SPV (solar photovoltaic) based MLDG (multiple location distributed generator) in distribution system for loss reduction, voltage profile improvement with economical benefits**", Energy, Volume 103, pp.231-239, 2016.

- Joseph B. Abugri; Marc Karam, **"Particle Swarm Optimization for the Minimization of Power Losses in Distribution Networks",** in 12th International Conference on Information Technology - New Generations**,** 2015.

- Kanwar Neeraj, Gupta Nikhil, Niazi K.R., Swarnkar Anil, Bansal R.C., " **Simultaneous allocation of distributed energy resource using improved particle swarm optimization**", Applied Energy, Volume 185, Part 2, pp. 1684-1693, 2017.

- Karaboga D. , Akay B., **"A comparative study of Artificial Bee Colony algorithm,"** Applied Mathematics and Computation archive Volume 214 Issue 1, pp.108-132,2009.

- Keane A., O'Malley M., **"Optimal allocation of embedded generation on distribution networks,**" IEEE Transaction Power System, vol. 20, no. 3, pp. 1640–1646,2005.

- Kennedy J., "**The particle swarm: social adaptation of knowledge**", in IEEE International Evolutionary Computation ICEC´97, Indianapolis, USA, pp. 303-308,1997.

- Kennedy J., Eberhart R.C., et al., **"Particle swarm optimization**", In IEEE international conference on neural networks, volume 4,pp. 1942–1948,1995.

- Khalesi N., Rezaei N., Haghifam M.-R., “***DG allocation with application of dynamic programming for loss reduction and reliability improvement,”*** **Int. J. Electric Power Energy System**, vol. 33, no. 2, pp. 288–295,2011.

- Kim J. O., Nam S. W., Park S. K., Singh C., “**Dispersed generation planning using improved Hereford ranch algorithm,”** Electric Power System Reserch, vol. 47, no. 1,pp. 47–55,1998.

- Kirkpatrick S., Gelatt C.D., Vecchi M.P., “**Optimization by Simulated Annealing.”** Science, New Series, Vol. 220, No. 4598, pp. 671-680,1983.

- Kuang Honghai, Li Shengqing, Wu Zhengqiu," **Discussion on advantages and disadvantages of distributed generation connected to the grid**", Electrical and Control Engineering (ICECE), 2011.

- Lasseter R. H., Paigi P., “**Microgrid : A Conceptual Solution”,** Power Electronics Specialists Conference,pp. 4285–4290,2004.

- Lasseter B., “**Microgrids distributed power generation**”, Power Engineering Society Winter Meeting IEEE, vol.1, pp. 146–149,2004.

- Liang H.T., Kang F.H., " ***Adaptive mutation particle swarm algorithm with dynamic nonlinear changed inertia weight*** ", Optik - **International Journal for Light and Electron Optics**, Volume 127, Issue 19, pp. 8036-8042, 2016.

- Lucian Ioan Dulău, Mihail Abrudean, Dorin Bică ," **Effects of Distributed Generation on Electric Power Systems",** Procedia Technology, Volume 12, pp. 681-686, 2014 .

- Mahmoud Pesaran H.A, Phung Dang Huy, Vigna K. Ramachandaramurthy," **A review of the optimal allocation of distributed generation: Objectives, constraints, methods, and algorithms"**, Renewable and Sustainable Energy Reviews, Volume 75, pp.293-312, 2017.

- Master C. L., ***"Voltage rise: the big issue when connecting embedded generation to long 11kV overhead lines***" **Power Engineering Journal**, vol. 16, no. 1, pp. 5–12, 2002 .

- Math H. J. Bollen ‹Fainan Hassan.(2011).**Integration Of Distributed Generation In The Power System**. Hoboken, New Jersey: by John Wiley & Sons, Inc.

- Mehta V.K , Mehta Rohit.(2005) .**Principles of power system**. S Chand & Co Ltd.

- Meinshausen M., Meinshausen N., Hare W., Raper S. C. B., Frieler K., Knutti R., Frame D. J., Allen M. R., "**Greenhouse-gas emission targets for limiting global warming to 2 C,"** Nature volume 458, pp. 1158–1162, 2009.

- Moradi Mohammad H. , Reza Tousi S.M., Abedini Mohammad ," **Multi-objective PFDE algorithm for solving the optimal siting and sizing problem of multiple DG sources" ,** Electrical Power and Energy Systems volume 56 , pp. 117–126, 2014.

- Nahilia H. , Boudour M., "**Voltage Stability Analysis and Optimal Distributed Generetors Placement Study on Algerian Power Network"**, in Third IEEE International Control, Engineering & Information Technology (CEIT),2015.

- Nara K., Hayashi Y., Ikeda K., Ashizawa T., "**Application of tabu search to optimal placement of distributed generators,**" in IEEE Power Engineering Sociaty Winter Meeting, 2001, pp. 918–923.

- Obaidy M. Al. , Ayesh A. ,"**The Implementation of Optimization Algorithm for Energy Efficient Dynamic Ad hoc Wireless Sensor Networks"**, at Fourth International Workshop on Advance Computation for Engineering Applications, Japan, pp. 17-23, 2008.

- Ojha Rajesh, Das Madhabananda," ***An Adaptive Approach for Modifying Inertia Weight using Particle Swarm Optimisation***", **IJCSI International Journal of Computer Science Issues**, Vol. 9, Issue 5, No 2, pp. 105-111, 2012.

- Osman, I.H., Kelly J.P.," **Meta-Heuristics: Theory and Applications**". Kluwer Academic Publishers,USA,1996.

- Paliwal P., Patidar N. P., Nema R. K., "**A Comprehensive Survey of Optimization Techniques used for Distributed Generator Siting and Sizing,"** Proceeding in IEEE, pp. 1-7,2012.

- Prakash D.B., Lakshminarayana C.," **Multiple DG Placements in Distribution System for Power Loss Reduction Using PSO Algorithm**", Procedia Technology, Volume 25, pp.785-792, 2016 .

- Rahman S., "**Fuel gm as a distributed generation technology**",Power Engineering Society Summer Meeting IEEE, vol. 1, pp. 551–552, 2001.

- Rao R. S., Ravindra K., Satish K., Narasimham S. V. L., "**Power loss minimization in distribution system using network reconfiguration in the presence of distributed generation,**" IEEE Transaction Power System, pp. 317-325, 2013.

- Rau N. S. , Wan Y.-H., "**Optimum location of resources in distributed planning,**" IEEE Transaction Power System, vol. 9, no. 4, pp. 2014–2020, 1994.

- Rini Dian Palupi, Shamsuddin Siti Mariyam, Yuhaniz Siti Sophiyati**,** *"* ***Particle Swarm Optimization: Technique, System and Challenges***" ,**International Journal of Computer Applications**, Volume 14– No.1, pp. 19-27, 2011.

- Saadat Hadi.(1999) "**Power System Analysis**", The Mc-Grew Hill Companies.

- Shi Y., Eberhart R.C., “**Empirical study of particle swarm optimization”**, Congress on Evolutionary Computation, 3, pp.1945-1950, 1999.

- Shi Y., Eberhart R.C., “**Fuzzy adaptive particle swarm optimization”,** in IEEE Conference on Evolutionary Computation, 1, pp.101-106, 2001.

- Shi Y. , Eberhart R.., “**A modified particle swarm optimizer**”, IEEE, 2002, pp. 69–73

- Singh Bindeshwar, Sharma Janmejay ," **A review on distributed generation planning**", Renewable and Sustainable Energy Reviews, Volume 76, pp.529-544, 2017.

- Short T. A..(2006). **Electric Power Distribution Equipment and Systems,** Taylor & Francis Group, LLC.

- Silvestri A., Berizzi A., Buonanno S., “**Distributed generation planning using genetic algorithms”**, in Electric Power Engineering International Conference Power Technology, Budapest, p. 257, 1999.

- Stevenson William D.. (1982). Element Of Power System. MC Grew-Hill Series in Electrical Engineering. Suter M., “**Active filter for a microturbine”**, Telecommunications Energy Conference, , pp. 162–165, 2001.

- Toledo Olga Moraes, Filho Delly Oliveira, Cardoso Diniz Antônia Sônia Alves," **Distributed photovoltaic generation and energy storage systems: A review**", Renewable and Sustainable Energy Reviews, Volume 14, Issue 1, pp. 506-511, 2010.

- Vasconcelos Sampaio Priscila Gonçalves, Aguirre González Mario Orestes, " **Photovoltaic solar energy: Conceptual framework'**", Renewable and Sustainable Energy Reviews, Volume 74, pp. 590-601, 2017.

- Wai Lip Theo, Jeng Shiun Lim, Wai Shin Ho, Haslenda Hashim, Chew Tin Lee," **Review of distributed generation (DG) system planning and optimization techniques: Comparison of numerical and mathematical modeling methods",** Renewable and Sustainable Energy Reviews, Volume 67, pp. 531-573, 2017.

- Wang L., Singh C., "**Reliability-constrained optimum placement of reclosers and distributed generators in distribution networks using an ant colony system algorithm,"** IEEE Transaction System, Man, Cybern. C, Appl. Rev., vol. 38, no. 6, pp. 757–764, 2008.

- Willis H. L., "**Analytical methods and rules of thumb for modeling DG-distribution interaction,"** in IEEE Power Engineering Sociaty Summer Meeting, pp. 1643–1644, 2000.

- Xin J., Chen G., , Hai Y.., "**A Particle Swarm Optimizer with Multistage Linearly-Decreasing Inertia Weight**", International Joint Conference on, volume 1, pp. 505–508, 2009.

- Xu D., Girgis A.A., "**Optimal load shedding strategy in power systems with distributed generation",** in Power Engineering Society Winter Meeting IEEE, vol. 2, pp. 788–793, 2001.

- Yang X. S., "**Firefly algorithms for multimodal optimization**," Lect. Notes Comput.Sci., vol. 5792 LNC, pp. 169–178, 2009.

- Zahedi A., "**Maximizing solar PV energy penetration using energy storage technology,"** Renewable Sustainable Energy Rev.volume15, pp. 866–870, 2011.

Appendixes

Appendix A

IEEE 34 Network

Cas34balanced.m

function mpc = case34balanced   %% load IEEE 34 bus system code

%% MATPOWER Case Format :
Version 2 mpc.version = '2';
 %%----- Power Flow Data -----%%

%% system MVA base

mpc.baseMVA = 100;												
%% bus data												
% bus_i type Pd			Qd	Gs	Bs		area	Vm	Va	baseKV	zone	Vmax
Vmin												
mpc.bus = [												
1	3	0	0	0	0	1	1.00	0	11	1	1.05	0.9;
2	1	0.276	0.171	0	0	1	1.00	0	11	1	1.05	0.9;
3	1	0	0	0	0	1	1.00	0	11	1	1.05	0.9;
4	1	0.276	0.171	0	0	1	1.00	0	11	1	1.00	0.9;
5	1	0.276	0.171	0	0	1	1.00	0	11	1	1.00	0.9;
6	1	0	0	0	0	1	1.00	0	11	1	1.05	0.9;
7	1	0	0	0	0	1	1.00	0	11	1	1.05	0.9;
8	1	0.276	0.171	0	0	1	1.00	0	11	1	1.05	0.9;
9	1	0.276	0.1425	0	0	1	1.00	0	11	1	1.05	0.9;
10	1	0	0	0	0	1	1.00	0	11	1	1.05	0.9;
11	1	0.276	0.171	0	0	1	1.00	0	11	1	1.05	0.9;
12	1	0.1644	0.1008	0	0	1	1.00	0	11	1	1.05	0.9;
13	1	0.0864	0.054	0	0	1	1.00	0	11	1	1.05	0.9;
14	1	0.0864	0.054	0	0	1	1.00	0	11	1	1.05	0.9;
15	1	0.0864	0.054	0	0	1	1.00	0	11	1	1.05	0.9;
16	1	0.0162	0.009	0	0	1	1.00	0	11	1	1.05	0.9;
17	1	0.276	0.171	0	0	1	1.00	0	11	1	1.05	0.9;
18	1	0.276	0.171	0	0	1	1.00	0	11	1	1.05	0.9;

19	1	0.276	0.171	0	0	1	1.00	0	11	1	1.05	0.9;
20	1	0.276	0.171	0	0	1	1.00	0	11	1	1.05	0.9;
21	1	0.276	0.171	0	0	1	1.00	0	11	1	1.05	0.9;
22	1	0.276	0.171	0	0	1	1.00	0	11	1	1.05	0.9;
23	1	0.276	0.171	0	0	1	1.00	0	11	1	1.05	0.9;
24	1	0.276	0.171	0	0	1	1.00	0	11	1	1.05	0.9;
25	1	0.276	0.171	0	0	1	1.00	0	11	1	1.05	0.9;
26	1	0.276	0.171	0	0	1	1.00	0	11	1	1.05	0.9;
27	1	0.1644	0.102	0	0	1	1.00	0	11	1	1.05	0.9;
28	1	0.09	0.0576	0	0	1	1.00	0	11	1	1.05	0.9;
29	1	0.09	0.0576	0	0	1	1.00	0	11	1	1.05	0.9;
30	1	0.09	0.0576	0	0	1	1.00	0	11	1	1.05	0.9;
31	1	0.0684	0.0414	0	0	1	1.00	0	11	1	1.05	0.9;
32	1	0.0684	0.0414	0	0	1	1.00	0	11	1	1.05	0.9;
33	1	0.0684	0.0414	0	0	1	1.00	0	11	1	1.05	0.9;
34	1	0.0684	0.0414	0	0	1	1.00	0	11	1	1.05	0.9;

];

```
%% generator data

%   bus Pg Qg Qmax Qmin Vg mBase status Pmax Pmin Pc1 Pc2 Qc1min
Qc1max Qc2min Qc2max ramp_agc ramp_10 ramp_30 ramp_q apf mpc.gen = [

   1    3   1    1      -1   1.00    100      1      3     0      0       0       0      0     0      0
0       0   0    0       0;
   ];
```

```
%% branch data
%   fbus   tbus      r          x          b    rateA    rateB    rateC    ratio    angle    status  angmin
angmax
mpc.branch = [
    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       0.13590   0.03772    0    9900    0    0     0     0     1     -360    360;
    4      5       0.13590   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       0.04330   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       0.13590   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 B

Voltage magnitude and phase angle before a DG installation

Bus number	Voltage magnitude (pu)	Angle (deg.)
1	1.000	0.000
2	0.993	-0.061
3	0.987	-0.115
4	0.978	-0.251
5	0.97	-0.381
6	0.963	-0.494
7	0.959	-0.6
8	0.956	-0.658
9	0.953	-0.725
10	0.952	-0.759
11	0.951	-0.773
12	0.951	-0.777
13	0.986	-0.125
14	0.986	-0.133
15	0.986	-0.136
16	0.986	-0.136
17	0.958	-0.586
18	0.954	-0.663
19	0.949	-0.764
20	0.945	-0.846
21	0.941	-0.917
22	0.937	-1.015
23	0.934	-1.095
24	0.931	-1.171
25	0.929	-1.208
26	0.929	-1.222
27	0.929	-1.227
28	0.958	-0.611
29	0.958	-0.617
30	0.958	-0.621
31	0.951	-0.769
32	0.951	-0.779
33	0.951	-0.784
34	0.951	-0.785

Appendix C

Active and reactive power losses before a DG installation

Branch number	From bus	To bus	From bus injection		To bus injection		Losses (I^2 * Z)	
			P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)
1	1	2	5.89	3.52	-5.85	-3.5	0.046	0.02
2	2	3	5.57	3.33	-5.53	-3.31	0.038	0.02
3	3	4	5.26	3.14	-5.21	-3.13	0.052	0.01
4	4	5	4.93	2.95	-4.88	-2.94	0.047	0.01
5	5	6	4.61	2.77	-4.57	-2.76	0.038	0.01
6	6	7	1.56	0.93	-1.55	-0.93	0.009	0
7	7	8	1.28	0.75	-1.27	-0.75	0.004	0
8	8	9	1	0.58	-0.99	-0.58	0.004	0
9	9	10	0.72	0.44	-0.71	-0.44	0.001	0
10	10	11	0.44	0.27	-0.44	-0.27	0	0
11	11	12	0.16	0.1	-0.16	-0.1	0	0
12	3	13	0.28	0.17	-0.28	-0.17	0	0
13	13	14	0.19	0.12	-0.19	-0.12	0	0
14	14	15	0.1	0.06	-0.1	-0.06	0	0
15	15	16	0.02	0.01	-0.02	-0.01	0	0
16	6	17	3.01	1.83	-2.99	-1.83	0.02	0.01
17	17	18	2.72	1.66	-2.7	-1.65	0.015	0
18	18	19	2.43	1.48	-2.41	-1.48	0.015	0
19	19	20	2.14	1.31	-2.12	-1.3	0.011	0
20	20	21	1.85	1.13	-1.84	-1.13	0.008	0
21	21	22	1.56	0.96	-1.56	-0.96	0.008	0
22	22	23	1.28	0.79	-1.27	-0.79	0.006	0
23	23	24	1	0.62	-0.99	-0.62	0.004	0
24	24	25	0.72	0.44	-0.72	-0.44	0.001	0
25	25	26	0.44	0.27	-0.44	-0.27	0	0
26	26	27	0.16	0.1	-0.16	-0.1	0	0
27	7	28	0.27	0.17	-0.27	-0.17	0	0
28	28	29	0.18	0.12	-0.18	-0.12	0	0
29	29	30	0.09	0.06	-0.09	-0.06	0	0
30	30	31	0.27	0.17	-0.27	-0.17	0	0
31	31	32	0.21	0.12	-0.21	-0.12	0	0
32	32	33	0.14	0.08	-0.14	-0.08	0	0
33	33	34	0.07	0.04	-0.07	-0.04	0	0

Appendix D

Conventional PSO code

```
MainPSO_34.m              %% Main code for conventional PSO
clear all
close all
clc
grandmp_array = [];
DG1_array = [];
VC1_array = [];
Location1_array = [];
fit_loss_array   = [];
elapse_array = [];
for i=1:100
   [grandmp,DG1_size,DG1_V,DG1_location,elapsed_time,objfunc,fit_loss]= pso_34;
      grandmp_array = [grandmp;grandmp_array];
      DG1_array = [DG1_size;DG1_array];
      VC1_array = [DG1_V;VC1_array];
      Location1_array = [DG1_location;Location1_array];
      fit_loss_array = [fit_loss;fit_loss_array];
      elapse_array = [elapsed_time;elapse_array];
      figure
      %       x = 1:length(minmp);
      %       plot(x,minmp,'b-')
      % % plot graph
      y = objfunc;
      x = 1:length(y);
      plot(x,y,'k','LineWidth',2.5)
      axis([0 max(x) 0 max(y)])
      % xlabel('chemotatic step')
      xlabel('Iteration','FontSize',10)
      ylabel('Fitness function ','FontSize',10')
      title('Convergence characteristic of the PSO algorithm for 1 DG for 34bus')
```

```
end
grandmp_array;
DG1_array;
VC1_array;
Location1_array;
fit_loss_array;
subplot(4,1,1);
 y=DG1_array;
 x = 1:length(y);
 plot(x,y,'k','LineWidth',2.5)
 xlabel('Iteration','FontSize',10)
 ylabel('DG size MW ','FontSize',10')
 title('Size of DG units')
 subplot(4,1,2);
 y=VC1_array;
 x = 1:length(y);
 plot(x,y,'k','LineWidth',2.5)
 xlabel('Iteration','FontSize',10)
 ylabel('voltage magnitude pu ','FontSize',10)
 subplot(4,1,3);
 y=Location1_array;
 x = 1:length(y);
 plot(x,y,'k','LineWidth',2.5)
 xlabel('Iteration','FontSize',10)
 ylabel('DG unit  location ','FontSize',10)
 title('location of DG unit')
 subplot(4,1,4);
 y=fit_loss_array;
 x = 1:length(y);
 plot(x,y,'k','LineWidth',2.5)
 xlabel('Iteration','FontSize',10)
 ylabel('fitness losses ','FontSize',10')
 title('Fitness losses')
```

```
elapse_array;
[MIN MIN_INDEX]=min(grandmp_array);
[MAX MAX_INDEX]=max(grandmp_array);
Otimization_Results_Array = [grandmp_array,DG1_array,
VC1_array,Location1_array,fit_loss_array]
The_Optimum_Choice = Otimization_Results_Array(MIN_INDEX)
The_Optimum_fitness = min(grandmp_array)
Average_fitness = sum(grandmp_array)/30
AVERAGE_ELAPSE = sum(elapse_array)/30
MAX
MAX_INDEX
MIN
MIN_INDEX
result=Otimization_Results_Array(MIN_INDEX,:)
DG1size = result (2)
DG1_VC = result (3)
DG1_Loc = result (4)
Losses = result (5)
PSO_34.m      %% Conventional PSO code
function [grandmp,DG1_size,DG1_V,DG1_location,elapsed_time,objfunc,fit_loss]=
pso_34
% bus system input and harmonic source
% sample_number=1;
% nombor = 0;
% elitsm = 10^10;
bus_no=34;
mpc=loadcase('case34balanced');
nodg = 1;
mpc.gen = repmat(mpc.gen,nodg+1,1);       %input PV bus in the mpc.gen data
vref(1:bus_no,1)=1;
tic;                          %start stopwatch
maxagent=50; %number of particles
nb=3*nodg; %number of dimension
```

```
maxiteration=100; % maximum number of generation cycles
kagent = 0;
weight_max=0.9; weight_min =0.4;
c1 = 2; c2 = 2; vmax = 6;
% V_base=12.66e3;
% S_base=100e6;
% Z_base=V_base^2/S_base;
% powerload=newload2/S_base;
up=[2.0 1.02 34]; % maxPdg1 Vdg1 location1
down=[1.2 0.98 2]; %min Pdg1  Vdg1 location1
%randomly create 1st particle positions
for searchcycle=1:10000
  for j=1:nb
      if j >= (nodg*2+1)
          PVdg(j) = round((rand(1))*(up(j)-down(j))+down(j));
      else
          PVdg(j)=(rand(1))*(up(j)-down(j))+down(j);
      end
  end
  vref_new=vref; % reset
   for m = 1:nodg
       mpc.gen(m+1,2)= PVdg(m);% for sizing dg
       mpc.gen(m+1,6)= PVdg(m+nodg);% for V dg
       mpc.gen(m+1,1)= PVdg(m+2*nodg);% for Location
       mpc.bus(PVdg(m+2*nodg),2) = 2; % for L dlm bus type
       vref_new((PVdg(m+2*nodg)),1) = PVdg(m+nodg);
   end

   [Ybus,V_bus, Vr,loss] = runpf(mpc);
   Vmin=Vr(2);
   Vmax=Vr(1)
   %%% calculation for voltage deviation %%%%
   for b = 1:bus_no
```

```
    vreg(b,1)= (vref_new(b) - V_bus(b))/(vref_new(b));
end
vreg1=sum(vreg,1)/bus_no;
Pd = mpc.bus(:,3);
Qd = mpc.bus(:,4)*1i;
Sd = Pd + Qd;
Sbase=100;
Sdpu= Sd/Sbase;
V_pu= V_bus;
vsqrt=(V_pu).^2;
zd = vsqrt./Sdpu;
yd=1./zd;
yload = zeros(bus_no,bus_no);
for i=1:bus_no
    for j=1:bus_no
        if i==j
            yload(i,j)=yd(i);
        else
            yload (i,j) = 0;
        end
    end
end
if ((Vmin>0.90)&&(Vmax<=1.05))
    kagent = kagent+1;
    for j=1:nb
        agent_pos(kagent,j)=[PVdg(j)];
        fit(kagent,:)=[loss];
        Vrec(kagent,:)=[Vr];
        Vbus(kagent,:)=[V_bus];
        weight=[fit(:,1)*1];
        obj=sum(weight,2);
    end
end
```

```
    if kagent==maxagent
        break
    end
end
gbest = 10^10; pbest = ones(maxagent,1)*10^10; % reset G best
for iteration = 1:maxiteration
    % objective function
    for k=1:maxagent
        fitness(k) = (obj(k,:));
        % update P best
        if fitness(k) < pbest(k)
            pbest(k) = fitness(k);
            P_pos(k,:) = agent_pos(k,:);
        end
        % update G best
        if pbest(k) < gbest
            gbest = pbest(k); %record gbest or fitness
            G_pos = P_pos(k,:); %record g_pos or dg sizing
            minfit =  fit(k,:); %record loss n thdv
        end
    end
    objfunc(iteration) = gbest;  %record fitness
    % update particle velocities
    weight = weight_max - (weight_max-weight_min)*(iteration/maxiteration);
    for j = 1:maxagent
        % determination of omega
        phi1 = rand(1);
        phi2 = rand(1);
        for k = 1:nb
            % update velocity
            dist1 = c1*phi1*(P_pos(j,k)-agent_pos(j,k)); %P_pos atau pbest?
            dist2 = c2*phi2*(G_pos(k)-agent_pos(j,k));
            if iteration == 1
```

```
                velo(j,k) = dist1 + dist2;
            else
                velo(j,k) = weight*(velo(j,k))+ dist1 + dist2;
            end
%               % velocity in interval [-vmax, vmax]
%               if velo(j,k) > vmax
%                   velo(j,k) = vmax;
%               end
%               if velo(j,k) < (-vmax)
%                   velo(j,k) = -vmax;
%               end
        end
    end
    % update particle positions
    kthagent = 1; % reset
    while kthagent < maxagent
        for k = 1:nb
            if k >= (nodg*2+1)
                PVdg(k) = round(agent_pos(kthagent,k)+velo(kthagent,k));
            else
                PVdg(k)=agent_pos(kthagent,k)+velo(kthagent,k);
            end
            if (PVdg(k)>down(k)) && (PVdg(k)<up(k))   % check upper bound and lower bound
                PVDG(k)=PVdg(k);
            else
                if k >= (nodg*2+1)
                    PVDG(k)=round((rand(1))*(up(k)-down(k))+down(k));
                else
                    PVDG(k)=(rand(1))*(up(k)-down(k))+down(k);
                end
            end
        end
```

```
    vref_new=vref; % reset
    for m = 1:nodg
        mpc.gen(m+1,2)= PVDG(m);% untuk P
        mpc.gen(m+1,6)= PVDG(m+nodg);% untuk V
        mpc.gen(m+1,1)= PVDG(m+2*nodg);% untuk L
        mpc.bus(PVDG(m+2*nodg),2) = 2; % untuk L dlm bus type
        vref_new((PVDG(m+2*nodg)),1) = PVDG(m+nodg);
    end
    vref_new=vref;
    [Ybus,V_bus, Vr,loss] = runpf(mpc);
    Vmin=Vr(2);
    Vmax=Vr(1);
    %% check condition %%
    if ((Vmin>0.90)&&(Vmax<=1.05))
        for k=1:nb
            agent_pos(kthagent,k)=PVDG(k);
            fit(kagent,:)=[loss];
            Vrec(kagent,:)=[Vr];
            Vbus(kagent,:)=[V_bus];
            weight=[fit(:,1)*1];
            obj=sum(weight,2);
        end
    end
    if kthagent==maxagent
        break
    end
    kthagent = kthagent+1;
  end
end
elapsed_time=toc
% % % select the fitness value
grandmp = min(objfunc);
% fit_loss=minfit(1);
```

```
% fit_THDV=minfit(2);
G_pos;
DG1_size=G_pos(1);
DG1_V=G_pos(2);
DG1_location=G_pos(3);
minfit
fit_loss= minfit(1);
```

Appendix E

Matpower packages

```
Runpf.m         %% m file used to run the power flow analysis
function [Ybus,V_bus, Vr, loss, MVAbase, bus, gen, branch, success, et] = ...
            runpf(mpc, mpopt, fname, solvedcase)
%RUNPF  Runs a power flow.
%   Output arguments options:
%   results = runpf(...)
%   [results, success] = runpf(...)
%   [baseMVA, bus, gen, branch, success, et] = runpf(...)
%   Input arguments options:
%   runpf(casename)
%   runpf(casename, mpopt)
%   runpf(casename, mpopt, fname)
%   runpf(casename, mpopt, fname, solvedcase)
%   Runs a power flow (full AC Newton's method by default) and optionally
%   returns the solved values in the data matrices, a flag which is true if
%   the algorithm was successful in finding a solution, and the elapsed time
%   in seconds. Alternatively, the solution can be returned as fields in a
%   results struct and an optional success flag.
%   All input arguments are optional. If casename is provided it specifies
%   the name of the input data file or struct (see also 'help caseformat' and
%   'help loadcase') containing the power flow data. The default value is
%   'case9'. If the mpopt is provided it overrides the default MATPOWER options
%   vector and can be used to specify the solution algorithm and output options
%   among other things (see 'help mpoption' for details). If the 3rd argument
%   is given the pretty printed output will be appended to the file whose name
%   is given in fname. If solvedcase is specified the solved case will be
%   written to a case file in MATPOWER format with the specified name. If
%   solvedcase ends with '.mat' it saves the case as a MAT-file otherwise it
%   saves it as an M-file.
%   If the ENFORCE_Q_LIMS options is set to true (default is false) then if
```

```
%   any generator reactive power limit is violated after running the AC power
%   flow, the corresponding bus is converted to a PQ bus, with Qg at the
%   limit, and the case is re-run. The voltage magnitude at the bus will
%   deviate from the specified value in order to satisfy the reactive power
%   limit. If the reference bus is converted to PQ, the first remaining PV
%   bus will be used as the slack bus for the next iteration. This may
%   result in the real power output at this generator being slightly off
%   from the specified values.
%   MATPOWER
%   $Id: runpf.m,v 1.19 2009/12/04 18:58:38 ray Exp $
%   by Ray Zimmerman, PSERC Cornell
%   Enforcing of generator Q limits inspired by contributions
%   from Mu Lin, Lincoln University, New Zealand (1/14/05).
%   Copyright (c) 1996-2005 by Power System Engineering Research Center (PSERC)
%   See http://www.pserc.cornell.edu/matpower/ for more info.
%%-----  initialize  -----
%% define named indices into bus, gen, branch matrices
[PQ, PV, REF, NONE, BUS_I, BUS_TYPE, PD, QD, GS, BS, BUS_AREA, VM, ...
    VA, BASE_KV, ZONE, VMAX, VMIN, LAM_P, LAM_Q, MU_VMAX,
MU_VMIN] = idx_bus;
[F_BUS, T_BUS, BR_R, BR_X, BR_B, RATE_A, RATE_B, RATE_C, ...
    TAP, SHIFT, BR_STATUS, PF, QF, PT, QT, MU_SF, MU_ST, ...
    ANGMIN, ANGMAX, MU_ANGMIN, MU_ANGMAX] = idx_brch;
[GEN_BUS, PG, QG, QMAX, QMIN, VG, MBASE, GEN_STATUS, PMAX, PMIN,
...
    MU_PMAX, MU_PMIN, MU_QMAX, MU_QMIN, PC1, PC2, QC1MIN,
QC1MAX, ...
    QC2MIN, QC2MAX, RAMP_AGC, RAMP_10, RAMP_30, RAMP_Q, APF] =
idx_gen;
%% default arguments
if nargin < 4
    solvedcase = '';                %% don't save solved case
    if nargin < 3
```

```
        fname = '';                   %% don't print results to a file
        if nargin < 2
            mpopt = mpoption;       %% use default options
            if nargin < 1
                mpc = mpc;% 'case69'; %% default data file is 'case9.m'
            end
        end
    end
end
%% options
verbose = mpopt(31);
qlim = mpopt(6);                    %% enforce Q limits on gens?
dc = mpopt(10);                     %% use DC formulation?
%% read data
%   mpc = loadcase('case34balanced');
%% add zero columns to branch for flows if needed
if size(mpc.branch,2) < QT
  mpc.branch = [ mpc.branch zeros(size(mpc.branch, 1), QT-size(mpc.branch,2)) ];
end
%% convert to internal indexing
mpc = ext2int(mpc);
[baseMVA, bus, gen, branch] = deal(mpc.baseMVA, mpc.bus, mpc.gen, mpc.branch);
%% get bus index lists of each type of bus
[ref, pv, pq] = bustypes(bus, gen);
%% generator info
on = find(gen(:, GEN_STATUS) > 0);      %% which generators are on?
gbus = gen(on, GEN_BUS);                %% what buses are they at?
%%-----  run the power flow  -----
t0 = clock;
if dc                               %% DC formulation
    %% initial state
    Va0 = bus(:, VA) * (pi/180);
    %% build B matrices and phase shift injections
```

```
    [B, Bf, Pbusinj, Pfinj] = makeBdc(baseMVA, bus, branch);
    %% compute complex bus power injections (generation - load)
    %% adjusted for phase shifters and real shunts
    Pbus = real(makeSbus(baseMVA, bus, gen)) - Pbusinj - bus(:, GS) / baseMVA;
    %% "run" the power flow
    Va = dcpf(B, Pbus, Va0, ref, pv, pq);
    %% update data matrices with solution
    branch(:, [QF, QT]) = zeros(size(branch, 1), 2);
    branch(:, PF) = (Bf * Va + Pfinj) * baseMVA;
    branch(:, PT) = -branch(:, PF);
    bus(:, VM) = ones(size(bus, 1), 1);
    bus(:, VA) = Va * (180/pi);
    %% update Pg for swing generator (note: other gens at ref bus are accounted for in
Pbus)
    %%      Pg = Pinj + Pload + Gs
    %%      newPg = oldPg + newPinj - oldPinj
    refgen = find(gbus == ref);             %% which is(are) the reference gen(s)?
    gen(on(refgen(1)), PG) = gen(on(refgen(1)), PG) + (B(ref, :) * Va - Pbus(ref)) *
baseMVA;
    success = 1;
else                                %% AC formulation
    %% initial state
    % V0    = ones(size(bus, 1), 1);            %% flat start
    V0  = bus(:, VM) .* exp(sqrt(-1) * pi/180 * bus(:, VA));
    V0(gbus) = gen(on, VG) ./ abs(V0(gbus)).* V0(gbus);
    if qlim
        ref0 = ref;                         %% save index and angle of
        Varef0 = bus(ref0, VA);             %%   original reference bus
        limited = [];                       %% list of indices of gens @ Q lims
        fixedQg = zeros(size(gen, 1), 1);   %% Qg of gens at Q limits
    end
    repeat = 1;
    while (repeat)
```

```
        %% build admittance matrices
        [Ybus, Yf, Yt] = makeYbus(baseMVA, bus, branch);
        %% compute complex bus power injections (generation - load)
        Sbus = makeSbus(baseMVA, bus, gen);
        %% run the power flow
        alg = mpopt(1);
        if alg == 1
            [V, success, iterations] = newtonpf(Ybus, Sbus, V0, ref, pv, pq, mpopt);
        elseif alg == 2 || alg == 3
            [Bp, Bpp] = makeB(baseMVA, bus, branch, alg);
            [V, success, iterations] = fdpf(Ybus, Sbus, V0, Bp, Bpp, ref, pv, pq, mpopt);
        elseif alg == 4
            [V, success, iterations] = gausspf(Ybus, Sbus, V0, ref, pv, pq, mpopt);
        else
            error('Only Newton''s method, fast-decoupled, and Gauss-Seidel power flow algorithms currently implemented.');
        end
        %% update data matrices with solution
        [bus, gen, branch] = pfsoln(baseMVA, bus, gen, branch, Ybus, Yf, Yt, V, ref, pv, pq);

        if qlim             %% enforce generator Q limits
            %% find gens with violated Q constraints
            mx = find( gen(:, GEN_STATUS) > 0 & gen(:, QG) > gen(:, QMAX) );
            mn = find( gen(:, GEN_STATUS) > 0 & gen(:, QG) < gen(:, QMIN) );
            if ~isempty(mx) || ~isempty(mn)  %% we have some Q limit violations
                if isempty(pv)
                    if verbose
                        if ~isempty(mx)
%                               fprintf('Gen %d (only one left) exceeds upper Q limit : INFEASIBLE PROBLEM\n', mx);
                        else
```

```
%                       fprintf('Gen %d (only one left) exceeds lower Q limit :
INFEASIBLE PROBLEM\n', mn);
                    end
                end
                success = 0;
                break;
            end
            %% one at a time?
            if qlim == 2    %% fix largest violation, ignore the rest
                [junk, k] = max([gen(mx, QG) - gen(mx, QMAX);
                                 gen(mn, QMIN) - gen(mn, QG)]);
                if k > length(mx)
                    mn = mn(k-length(mx));
                    mx = [];
                else
                    mx = mx(k);
                    mn = [];
                end
            end
            if verbose && ~isempty(mx)
%                   fprintf('Gen %d at upper Q limit, converting to PQ bus\n', mx);
            end
            if verbose && ~isempty(mn)
%                   fprintf('Gen %d at lower Q limit, converting to PQ bus\n', mn);
            end
            %% save corresponding limit values
            fixedQg(mx) = gen(mx, QMAX);
            fixedQg(mn) = gen(mn, QMIN);
            mx = [mx;mn];
            %% convert to PQ bus
            gen(mx, QG) = fixedQg(mx);      %% set Qg to binding limit
            gen(mx, GEN_STATUS) = 0;        %% temporarily turn off gen,
            for i = 1:length(mx)            %% (one at a time, since
```

```
                    bi = gen(mx(i), GEN_BUS);   %%  they may be at same bus)
                    bus(bi, [PD,QD]) = ...      %% adjust load accordingly,
                        bus(bi, [PD,QD]) - gen(mx(i), [PG,QG]);
                end
                bus(gen(mx, GEN_BUS), BUS_TYPE) = PQ;   %% & set bus type to PQ

                %% update bus index lists of each type of bus
                ref_temp = ref;
                [ref, pv, pq] = bustypes(bus, gen);
                if verbose && ref ~= ref_temp
%                       fprintf('Bus %d is new slack bus\n', ref);
                end
                limited = [limited; mx];
            else
                repeat = 0; %% no more generator Q limits violated
            end
        else
            repeat = 0;     %% don't enforce generator Q limits, once is enough
        end
    end
    if qlim && ~isempty(limited)
        %% restore injections from limited gens (those at Q limits)
        gen(limited, QG) = fixedQg(limited);    %% restore Qg value,
        for i = 1:length(limited)               %% (one at a time, since
            bi = gen(limited(i), GEN_BUS);      %%  they may be at same bus)
            bus(bi, [PD,QD]) = ...              %% re-adjust load,
                bus(bi, [PD,QD]) + gen(limited(i), [PG,QG]);
        end
        gen(limited, GEN_STATUS) = 1;               %% and turn gen back on
        if ref ~= ref0
            %% adjust voltage angles to make original ref bus correct
            bus(:, VA) = bus(:, VA) - bus(ref0, VA) + Varef0;
        end
```

```
    end
end
mpc.et = etime(clock, t0);
mpc.success = success;

%%-----  output results  -----
%% convert back to original bus numbering & print results
[mpc.bus, mpc.gen, mpc.branch] = deal(bus, gen, branch);
results = int2ext(mpc);

%% zero out result fields of out-of-service gens & branches
if ~isempty(results.order.gen.status.off)
  results.gen(results.order.gen.status.off, [PG QG]) = 0;
end
if ~isempty(results.order.branch.status.off)
  results.branch(results.order.branch.status.off, [PF QF PT QT]) = 0;
end
if fname
    [fd, msg] = fopen(fname, 'at');
    if fd == -1
        error(msg);
    else
        printpf(results, fd, mpopt);
        fclose(fd);
    end
end
loss=printpf(results, 1, mpopt);
loss=real(sum(loss));
V_bus=abs(V);
Vr=[max(abs(V)) min(abs(V))];

%% save solved case
if solvedcase
```

```
    savecase(solvedcase, results);
end
if nargout == 1 || nargout == 2
    MVAbase = results;
    bus = success;
elseif nargout > 2
    [MVAbase, bus, gen, branch, et] = ...
        deal(results.baseMVA, results.bus, results.gen, results.branch, results.et);
% else  %% don't define MVAbase, so it doesn't print anything
end
```

newtonpf.m   %% Newton raphson code

```
function [V, converged, i] = newtonpf(Ybus, Sbus, V0, ref, pv, pq, mpopt)
%NEWTONPF  Solves the power flow using a full Newton's method.
%   [V, converged, i] = newtonpf(Ybus, Sbus, V0, ref, pv, pq, mpopt)
%   solves for bus voltages given the full system admittance matrix (for
%   all buses), the complex bus power injection vector (for all buses),
%   the initial vector of complex bus voltages, and column vectors with
%   the lists of bus indices for the swing bus, PV buses, and PQ buses,
%   respectively. The bus voltage vector contains the set point for
%   generator (including ref bus) buses, and the reference angle of the
%   swing bus, as well as an initial guess for remaining magnitudes and
%   angles. mpopt is a MATPOWER options vector which can be used to
%   set the termination tolerance, maximum number of iterations, and
%   output options (see 'help mpoption' for details). Uses default
%   options if this parameter is not given. Returns the final complex
%   voltages, a flag which indicates whether it converged or not, and
%   the number of iterations performed.

%   MATPOWER
%   $Id: newtonpf.m,v 1.9 2009/12/04 20:31:20 ray Exp $
%   by Ray Zimmerman, PSERC Cornell
```

```
%   Copyright (c) 1996-2005 by Power System Engineering Research Center (PSERC)
%   See http://www.pserc.cornell.edu/matpower/ for more info.
%% default arguments
if nargin < 7
    mpopt = mpoption;
end
%% options
tol     = mpopt(2);
max_it  = mpopt(3);
verbose = mpopt(31);
%% initialize
converged = 0;
i = 0;
V = V0;
Va = angle(V);
Vm = abs(V);
%% set up indexing for updating V
npv = length(pv);
npq = length(pq);
j1 = 1;         j2 = npv;           %% j1:j2 - V angle of pv buses
j3 = j2 + 1;    j4 = j2 + npq;      %% j3:j4 - V angle of pq buses
j5 = j4 + 1;    j6 = j4 + npq;      %% j5:j6 - V mag of pq buses
%% evaluate F(x0)
mis = V .* conj(Ybus * V) - Sbus;
F = [   real(mis([pv; pq]));
        imag(mis(pq))   ];
%% check tolerance
normF = norm(F, inf);
if verbose > 1
    fprintf('\n it    max P & Q mismatch (p.u.)');
    fprintf('\n----  ---------------------------');
    fprintf('\n%3d        %10.3e', i, normF);
end
```

```
if normF < tol
    converged = 1;
    if verbose > 1
        fprintf('\nConverged!\n');
    end
end
%% do Newton iterations
while (~converged && i < max_it)
    %% update iteration counter
    i = i + 1;
    %% evaluate Jacobian
    [dSbus_dVm, dSbus_dVa] = dSbus_dV(Ybus, V);
    j11 = real(dSbus_dVa([pv; pq], [pv; pq]));
    j12 = real(dSbus_dVm([pv; pq], pq));
    j21 = imag(dSbus_dVa(pq, [pv; pq]));
    j22 = imag(dSbus_dVm(pq, pq));
    J = [   j11 j12;
            j21 j22;    ];
    %% compute update step
    dx = -(J \ F);
    %% update voltage
    if npv
        Va(pv) = Va(pv) + dx(j1:j2);
    end
    if npq
        Va(pq) = Va(pq) + dx(j3:j4);
        Vm(pq) = Vm(pq) + dx(j5:j6);
    end
    V = Vm .* exp(1j * Va);
    Vm = abs(V);            %% update Vm and Va again in case
    Va = angle(V);          %% we wrapped around with a negative Vm

    %% evalute F(x)
```

```
    mis = V .* conj(Ybus * V) - Sbus;
    F = [   real(mis(pv));
            real(mis(pq));
            imag(mis(pq))   ];
    %% check for convergence
    normF = norm(F, inf);
    if verbose > 1
        fprintf('\n%3d        %10.3e', i, normF);
    end
    if normF < tol
        converged = 1;
        if verbose
            fprintf('\nNewton"s method power flow converged in %d iterations.\n', i);
        end
    end
en
if verbose
    if ~converged
        fprintf('\nNewton"s method power did not converge in %d iterations.\n', i);
    end
end
```

loadcase.m   %% m file that describe the function load

```
function [baseMVA, bus, gen, branch, areas, gencost, info] = loadcase(casefile)
%LOADCASE   Load .m or .mat case files or data struct in MATPOWER format
%   [baseMVA, bus, gen, branch, areas, gencost] = loadcase(casefile)
%   [baseMVA, bus, gen, branch, gencost] = loadcase(casefile)
%   [baseMVA, bus, gen, branch] = loadcase(casefile)
%   mpc = loadcase(casefile)
%   Returns the individual data matrices or a struct containing them as fields.
%   Here casefile is either (1) a struct containing the fields baseMVA,
%   bus, gen, branch and, optionally, areas and/or gencost, or (2) a string
%   containing the name of the file. If casefile contains the extension
```

```
%   '.mat' or '.m', then the explicit file is searched. If casefile contains
%   no extension, then LOADCASE looks for a '.mat' file first, then for an
%   '.m' file.  If the file does not exist or doesn't define all required
%   matrices, the routine aborts with an appropriate error message.
%   Alternatively, it can be called with the syntax:
%   [baseMVA, bus, gen, branch, areas, gencost, info] = loadcase(casefile)
%   [mpc, info] = loadcase(casefile)
%   In this case, the function will not abort, but info will contain an exit
%   code as follows:
%       0:  all variables successfully defined
%       1:  input argument is not a string or struct
%       2:  specified extension-less file name does not exist in search path
%       3:  specified .MAT file does not exist in search path
%       4:  specified .M file does not exist in search path
%       5:  specified file fails to define all matrices or contains syntax err
%   If the input data is from an M-file or MAT file defining individual
%   data matrices, or from a struct with out a 'version' field whose
%   gen matrix has fewer than 21 columns, then it is assumed to be a
%   MATPOWER case file in version 1 format, and will be converted to
%   version 2 format.
%   MATPOWER
%   $Id: loadcase.m,v 1.21 2009/12/10 16:43:13 ray Exp $
%   by Carlos E. Murillo-Sanchez, PSERC Cornell & Universidad Autonoma de
Manizales
%   and Ray Zimmerman, PSERC Cornell
%   Copyright (c) 1996-2005 by Power System Engineering Research Center (PSERC)
%   See http://www.pserc.cornell.edu/matpower/ for more info.
info = 0;
if nargout < 3
    return_as_struct = true;
else
    return_as_struct = false;
end
```

```
if nargout >= 5
    expect_gencost = true;
    if nargout > 5
        expect_areas = true;
    else
        expect_areas = false;
    end
else
    expect_gencost = false;
    expect_areas = false;
end
%%-----  read data into struct  -----
if ischar(casefile)
    %% check for explicit extension
    l = length(casefile);
    if l > 2
        if strcmp(casefile(l-1:l), '.m')
            rootname = casefile(1:l-2);
            extension = '.m';
        elseif l > 4
            if strcmp(casefile(l-3:l), '.mat')
                rootname = casefile(1:l-4);
                extension = '.mat';
            end
        end
    end

    %% set extension if not specified explicitly
    if ~exist('rootname', 'var')
        rootname = casefile;
        if exist([casefile '.mat'], 'file') == 2
            extension = '.mat';
        elseif exist([casefile '.m'], 'file') == 2
```

```
        extension = '.m';
    else
        info = 2;
    end
end
%% attempt to read file
if info == 0
    if strcmp(extension,'.mat')         %% from MAT file
        try
            s = load(rootname);
            if isfield(s, 'mpc')        %% it's a struct
                s = s.mpc;
            else                        %% individual data matrices
                s.version = '1';
            end
        catch
            info = 3;
        end
    elseif strcmp(extension,'.m')       %% from M file
        try                             %% assume it returns a struct
            s = feval(rootname);
        catch
            info = 4;
        end
        if info == 0 && ~isstruct(s)    %% if not try individual data matrices
            clear s;
            s.version = '1';
            if expect_gencost
                try
                    [s.baseMVA, s.bus, s.gen, s.branch, ...
                        s.areas, s.gencost] = feval(rootname);
                catch
                    info = 4;
```

```
               end
            else
               if return_as_struct
                  try
                     [s.baseMVA, s.bus, s.gen, s.branch, ...
                        s.areas, s.gencost] = feval(rootname);
                  catch
                     try
                        [s.baseMVA, s.bus, s.gen, s.branch] = feval(rootname);
                     catch
                        info = 4;
                     end
                  end
               else
                  try
                     [s.baseMVA, s.bus, s.gen, s.branch] = feval(rootname);
                  catch
                     info = 4;
                  end
               end
            end
         end
         if info == 4 && exist([rootname '.m'], 'file') == 2
            info = 5;
            err5 = lasterr;
         end
      end
   end
elseif isstruct(casefile)
   s = casefile;
else
   info = 1;
end
```

```
%%-----  check contents of struct  -----
if info == 0
    %% check for required fields
    if ~( isfield(s,'baseMVA') && isfield(s,'bus') && ...
            isfield(s,'gen') && isfield(s,'branch') ) || ...
            ( expect_gencost && ~isfield(s, 'gencost') ) || ...
            ( expect_areas &&   ~isfield(s,'areas') )
        info = 5;           %% missing some expected fields
        err5 = 'missing data';
    else
        %% remove empty areas if not needed
        if isfield(s, 'areas') && isempty(s.areas) && ~expect_areas
            s = rmfield(s, 'areas');
        end

        %% all fields present, copy to mpc
        mpc = s;
        if ~isfield(mpc, 'version') %% hmm, struct with no 'version' field
            if size(mpc.gen, 2) < 21    %% version 2 has 21 or 25 cols
                mpc.version = '1';
            else
                mpc.version = '2';
            end
        end
        if strcmp(mpc.version, '1')
            % convert from version 1 to version 2
            [mpc.gen, mpc.branch] = mpc_1to2(mpc.gen, mpc.branch);
            mpc.version = '2';
        end
    end
end

%%-----  define output variables  -----
```

```
if return_as_struct
    bus = info;
end
if info == 0    %% no errors
    if return_as_struct
        baseMVA = mpc;
    else
        baseMVA = mpc.baseMVA;
        bus     = mpc.bus;
        gen     = mpc.gen;
        branch  = mpc.branch;
        if expect_gencost
            if expect_areas
                areas   = mpc.areas;
                gencost = mpc.gencost;
            else
                areas = mpc.gencost;
            end
        end
    end
else            %% we have a problem captain
    if nargout == 2 || nargout == 7   %% return error code
        if return_as_struct
            baseMVA = struct([]);
        else
            baseMVA = []; bus = []; gen = []; branch = [];
            areas = []; gencost = [];
        end
    else                                        %% die on error
        switch info
            case 1,
                error('loadcase: input arg should be a struct or a string containing a filename');
```

```
            case 2,
                error('loadcase: specified case not in MATLAB''s search path');
            case 3,
                error('loadcase: specified MAT file does not exist');
            case 4,
                error('loadcase: specified M file does not exist');
            case 5,
                error('loadcase: syntax error or undefined data matrix(ices) in the file\n%s',
err5);
            otherwise,

                error('loadcase: unknown error');
        end
    end
end
function [gen, branch] = mpc_1to2(gen, branch)

%% define named indices into bus, gen, branch matrices
[GEN_BUS, PG, QG, QMAX, QMIN, VG, MBASE, GEN_STATUS, PMAX, PMIN,
...
    MU_PMAX, MU_PMIN, MU_QMAX, MU_QMIN, PC1, PC2, QC1MIN,
QC1MAX, ...
    QC2MIN, QC2MAX, RAMP_AGC, RAMP_10, RAMP_30, RAMP_Q, APF] =
idx_gen;
[F_BUS, T_BUS, BR_R, BR_X, BR_B, RATE_A, RATE_B, RATE_C, ...
    TAP, SHIFT, BR_STATUS, PF, QF, PT, QT, MU_SF, MU_ST, ...
    ANGMIN, ANGMAX, MU_ANGMIN, MU_ANGMAX] = idx_brch;
%%-----  gen  -----
%% use the version 1 values for column names
if size(gen, 2) > APF
    error('mpc_1to2: gen matrix appears to already be in version 2 format');
end
shift = MU_PMAX - PMIN - 1;
```

```
tmp = num2cell([MU_PMAX, MU_PMIN, MU_QMAX, MU_QMIN] - shift);
[MU_PMAX, MU_PMIN, MU_QMAX, MU_QMIN] = deal(tmp{:});

%% add extra columns to gen
tmp = zeros(size(gen, 1), shift);
if size(gen, 2) >= MU_QMIN
   gen = [ gen(:, 1:PMIN) tmp gen(:, MU_PMAX:MU_QMIN) ];
else
   gen = [ gen(:, 1:PMIN) tmp ];
end
%%----- branch -----
%% use the version 1 values for column names
shift = PF - BR_STATUS - 1;
tmp = num2cell([PF, QF, PT, QT, MU_SF, MU_ST] - shift);
[PF, QF, PT, QT, MU_SF, MU_ST] = deal(tmp{:});
%% add extra columns to branch
tmp = ones(size(branch, 1), 1) * [-360 360];
tmp2 = zeros(size(branch, 1), 2);
if size(branch, 2) >= MU_ST
   branch = [ branch(:, 1:BR_STATUS) tmp branch(:, PF:MU_ST) tmp2 ];
elseif size(branch, 2) >= QT
   branch = [ branch(:, 1:BR_STATUS) tmp branch(:, PF:QT) ];
else
   branch = [ branch(:, 1:BR_STATUS) tmp ];
end
```

Appendix F

Conventional PSO results

Iteration number	DG capacity (MW)	DG voltage (pu)	DG location (no of bus)	Fitness losses
1	1.4165	0.9849	21	0.0498
2	1.8918	1.0152	7	0.1663
3	1.3156	1.0076	28	0.0645
4	1.344	1.0179	21	0.0664
5	1.9281	1.0127	28	0.041
6	1.8079	1.0113	3	0.1163
7	1.4609	1.0033	19	0.0801
8	1.9967	1.0076	3	0.1343
9	1.6618	1.0113	18	0.1431
10	1.4685	1.0027	4	0.1263
11	1.7772	0.9819	16	0.1169
12	1.8279	0.9816	27	0.1247
13	1.6402	1.0127	27	0.0984
14	1.472	0.9815	3	0.0721
15	1.751	0.9959	11	0.1136
16	1.338	0.995	5	0.1302
17	1.3875	1.0048	22	0.0684
18	1.2432	0.9907	24	0.1166
19	1.6481	1.0199	13	0.1025
20	1.7583	0.9801	16	0.1144
21	1.8081	0.9827	24	0.1149
22	1.9567	0.9915	15	0.136
23	1.5271	0.9997	6	0.1247
24	1.9477	0.9883	21	0.1092
25	1.9894	1.0107	11	0.1066
26	1.5073	0.9808	32	0.1121
27	1.5251	1.0076	14	0.0626
28	1.4467	1.0077	27	0.0697
29	1.3607	0.9954	8	0.1117
30	1.9343	0.9808	31	0.1102
31	1.8768	0.9815	24	0.1058
32	1.3653	1.0054	11	0.1135
33	1.2973	1.0033	13	0.1127
34	1.8637	0.9848	21	0.1087
35	1.8891	0.9929	7	0.0905
36	1.3801	1.0046	26	0.0551
37	1.5144	0.9859	4	0.1041
38	1.5378	1.0098	18	0.073
39	1.8128	0.9827	21	0.0648
40	1.9418	0.9854	25	0.1086
41	1.9973	0.9811	6	0.1216

42	1.2275	1.0062	28	0.1066
43	1.5495	0.9887	13	0.0894
44	1.5188	0.9923	27	0.1065
45	1.5526	1.0138	3	0.0998
46	1.8759	1.0018	25	0.1171
47	1.468	0.993	11	0.0573
48	1.6484	1.0015	22	0.0607
49	1.3791	1.0194	23	0.0798
50	1.8936	0.9838	26	0.1128
51	1.2808	1.0047	7	0.1302
52	1.9999	0.9865	24	0.111
53	1.7768	0.9944	15	0.0628
54	1.717	1.0175	8	0.1322
55	1.2466	0.9943	22	0.1103
56	1.2032	0.9873	19	0.0565
57	1.3759	0.9869	10	0.0447
58	1.7236	0.991	11	0.0805
59	1.4358	1.0072	10	0.1319
60	1.5348	1.0091	26	0.0679
61	1.9191	0.9822	23	0.1095
62	1.3079	0.9801	21	0.0495
63	1.2814	1.0116	27	0.0506
64	1.3493	0.986	27	0.063
65	1.543	0.9987	3	0.0738
66	1.9672	0.9839	7	0.07
67	1.9619	1.0147	24	0.0996
68	1.8082	1.0051	21	0.0701
69	1.8209	0.9822	20	0.1213
70	1.9628	0.98	19	0.1246
71	1.2988	0.999	22	0.1099
72	1.3773	1.0019	28	0.079
73	1.3185	0.9905	14	0.1116
74	1.599	1.0014	29	0.0956
75	1.5696	0.9922	24	0.0503
76	1.6722	1.0055	10	0.0406
77	1.769	0.9807	25	0.0564
78	1.9375	0.9837	24	0.1057
79	1.3305	1.0154	34	0.0776
80	1.5414	1.0052	23	0.0745
81	1.8384	0.9954	33	0.1209
82	1.9327	1.0028	17	0.1839
83	1.2197	1.0024	32	0.0693
84	1.2149	0.9941	17	0.1178
85	1.2092	0.9857	8	0.1078
86	1.6991	1.0071	26	0.0423
87	1.6308	0.9892	24	0.113
88	1.4318	1.0093	23	0.067
89	1.8131	1.0182	27	0.1184

90	1.7299	1.0064	24	0.0747
91	1.4127	1.0103	27	0.0761
92	1.4282	0.9896	17	0.115
93	1.6488	0.9812	26	0.1278
94	1.5179	1.0063	25	0.0706
95	1.2917	1.0125	22	0.0481
96	1.5318	1.0129	7	0.0642
97	1.9949	1.011	12	0.0686
98	1.9076	1.0096	26	0.0689
99	1.6535	0.9904	2	0.0633
100	1.406	1.0136	10	0.128

Appendix G

Voltage magnitude and phase angle after a DG installation

Bus number	Voltage magnitude (pu)	Angle (deg.)
1	1.000	0.000
2	0.995	-0.061
3	0.99	-0.115
4	0.984	-0.251
5	0.978	-0.381
6	0.974	-0.494
7	0.974	-0.6
8	0.974	-0.658
9	0.976	-0.725
10	0.977	-0.759
11	0.977	-0.773
12	0.977	-0.777
13	0.99	-0.125
14	0.989	-0.133
15	0.989	-0.136
16	0.989	-0.136
17	0.968	-0.586
18	0.964	-0.663
19	0.959	-0.764
20	0.955	-0.846
21	0.952	-0.917
22	0.948	-1.015
23	0.945	-1.095
24	0.942	-1.171
25	0.94	-1.208
26	0.939	-1.222
27	0.939	-1.227
28	0.973	-0.611
29	0.973	-0.617
30	0.973	-0.621
31	0.977	-0.769
32	0.977	-0.779
33	0.976	-0.784
34	0.976	-0.785

Appendix H

Active and reactive power losses after a DG installation

Branch number	From bus	To bus	From bus injection		To bus injection		Losses (I^2 * Z)	
			P(MW)	Q(Mvar)	P(MW)	Q(Mvar)	P(MW)	Q(Mvar)
1	1	2	4.12	3.48	-4.09	-3.47	0.028	0.01
2	2	3	3.81	3.3	-3.79	-3.29	0.023	0.01
3	3	4	3.51	3.12	-3.48	-3.11	0.031	0.01
4	4	5	3.21	2.94	-3.18	-2.93	0.027	0.01
5	5	6	2.9	2.76	-2.88	-2.76	0.021	0.01
6	6	7	-0.13	0.93	0.13	-0.92	0.002	0
7	7	8	-0.4	0.75	0.4	-0.75	0.001	0
8	8	9	-0.68	0.58	0.68	-0.58	0.002	0
9	9	10	-0.96	0.44	0.96	-0.44	0.002	0
10	10	11	0.44	0.27	-0.44	-0.27	0	0
11	11	12	0.16	0.1	-0.16	-0.1	0	0
12	3	13	0.28	0.17	-0.28	-0.17	0	0
13	13	14	0.19	0.12	-0.19	-0.12	0	0
14	14	15	0.1	0.06	-0.1	-0.06	0	0
15	15	16	0.02	0.01	-0.02	-0.01	0	0
16	6	17	3.01	1.83	-2.99	-1.83	0.019	0.01
17	17	18	2.72	1.66	-2.7	-1.65	0.015	0
18	18	19	2.43	1.48	-2.41	-1.48	0.015	0
19	19	20	2.13	1.31	-2.12	-1.3	0.011	0
20	20	21	1.85	1.13	-1.84	-1.13	0.008	0
21	21	22	1.56	0.96	-1.56	-0.96	0.008	0
22	22	23	1.28	0.79	-1.27	-0.79	0.005	0
23	23	24	1	0.62	-0.99	-0.62	0.004	0
24	24	25	0.72	0.44	-0.72	-0.44	0.001	0
25	25	26	0.44	0.27	-0.44	-0.27	0	0
26	26	27	0.16	0.1	-0.16	-0.1	0	0
27	7	28	0.27	0.17	-0.27	-0.17	0	0

28	28	29	0.18	0.12	-0.18	-0.12	0	0
29	29	30	0.09	0.06	-0.09	-0.06	0	0
30	30	31	0.27	0.17	-0.27	-0.17	0	0
31	31	32	0.21	0.12	-0.21	-0.12	0	0
32	32	33	0.14	0.08	-0.14	-0.08	0	0
33	33	34	0.07	0.04	-0.07	-0.04	0	0

Appendix I

Improved PSO results using linear used in [Obaidy and Ayesh, 2008]

Iteration number	DG capacity (MW)	DG voltage (p.u)	DG location (no of bus)	Fitness losses
1	1.9326	1.0029	34	0.0693
2	1.6661	0.9854	24	0.0706
3	1.6401	0.9935	6	0.072
4	1.6478	0.9918	25	0.0608
5	1.9822	1.014	25	0.0608
6	1.7122	0.9863	23	0.0682
7	1.549	0.9826	23	0.0724
8	1.8252	1.0032	24	0.061
9	1.417	1.0145	23	0.0503
10	1.6298	1.002	13	0.0621
11	1.6775	0.9984	14	0.0649
12	1.8085	1.0168	33	0.064
13	1.752	1.0141	9	0.0438
14	1.3028	1.018	7	0.0757
15	1.582	1.0032	7	0.0658
16	1.9278	1.0199	9	0.0683
17	1.7481	1.0154	29	0.052
18	1.2555	1.0166	12	0.0648
19	1.8214	0.999	10	0.0607
20	1.7482	0.9812	31	0.0706
21	1.6192	1.011	25	0.0707
22	1.2344	0.9972	24	0.0674
23	1.388	1.0006	11	0.07
24	1.7942	0.9864	23	0.0644
25	1.8039	1.011	10	0.0712
26	1.8471	0.9973	6	0.0731
27	1.8453	1.0162	16	0.0683
28	1.6678	0.9902	24	0.0675
29	1.2181	1.0076	29	0.068
30	1.7393	1.0145	23	0.0678
31	1.8074	0.9987	23	0.0679
32	1.3681	1.0102	27	0.0659
33	1.4793	0.9834	22	0.069
34	1.3058	0.989	31	0.0609
35	1.3134	1.0064	9	0.0671
36	1.9016	0.9833	21	0.0698
37	1.3336	1.0143	32	0.0723
38	1.6476	0.9911	8	0.0731
39	1.811	1.0044	29	0.0626

40	1.5266	0.9836	10	0.0667
41	1.6016	0.9821	23	0.071
42	1.8322	0.9877	33	0.0721
43	1.4156	1.0075	16	0.0706
44	1.4201	0.9954	29	0.0752
45	1.4459	0.9855	29	0.0778
46	1.9533	0.9908	23	0.0626
47	1.2489	1.0021	16	0.065
48	1.5706	1.0022	27	0.0691
49	1.7299	1.0051	24	0.0664
50	1.915	0.9851	4	0.066
51	1.9879	0.9865	20	0.0659
52	1.2296	0.9885	5	0.065
53	1.8767	0.9861	21	0.0657
54	1.9008	0.9972	11	0.0697
55	1.4868	0.9855	33	0.0647
56	1.4425	1.0056	27	0.0737
57	1.579	1.0108	11	0.0714
58	1.8343	1.0087	33	0.0746
59	1.8677	0.9963	27	0.0774
60	1.6188	0.9824	10	0.0726
61	1.5457	0.9991	19	0.0798
62	1.4731	1.0078	13	0.0657
63	1.8003	1.0178	8	0.0575
64	1.6784	1.0122	13	0.07
65	1.2903	1.0098	15	0.0664
66	1.53	1.0049	25	0.0737
67	1.3506	1.0164	23	0.0546
68	1.958	0.9908	24	0.0658
69	1.6046	0.9821	22	0.0711
70	1.7752	0.9883	23	0.0696
71	1.9669	1.001	32	0.0682
72	1.4995	0.9816	12	0.0739
73	1.268	0.9809	23	0.0695
74	1.9677	0.9861	20	0.0663
75	1.8938	0.9885	13	0.0609
76	1.6041	1.0004	28	0.0627
77	1.561	0.9805	22	0.0733
78	1.9779	1.0101	31	0.0683
79	1.4609	1.0012	32	0.0763
80	1.943	0.9933	26	0.0665
81	1.5103	0.9825	24	0.0748
82	1.3764	1.0163	26	0.0425
83	1.4772	1.0188	27	0.0493
84	1.8339	0.9875	24	0.0703
85	1.7331	1.0195	26	0.0593
86	1.6218	0.983	21	0.0754
87	1.5527	0.9957	4	0.0691

88	1.4111	1.0067	29	0.0607
89	1.2167	0.9888	13	0.0735
90	1.6427	0.9859	23	0.0737
91	1.5576	1.0096	21	0.0749
92	1.342	0.9846	29	0.0665
93	1.271	0.9818	2	0.0682
94	1.6712	0.9886	18	0.0734
95	1.5319	0.9948	8	0.0662
96	1.4057	1.0143	23	0.0492
97	1.7874	0.9827	29	0.0697
98	1.2119	0.9942	14	0.0623
99	1.9192	1.0138	19	0.0661
100	1.8577	0.9915	30	0.0764

Appendix J

Improved PSO results using non-linear proposed equation

Iteration number	DG capacity (MW)	DG voltage (p.u)	DG location (no of bus)	Fitness losses
1	1.818	1.0076	33	0.0658
2	1.4714	0.9846	23	0.0699
3	1.2954	1.0175	13	0.0677
4	1.2721	0.9931	5	0.0688
5	1.7053	0.9858	17	0.0714
6	1.3829	0.9921	20	0.0704
7	1.9303	1.0026	13	0.0666
8	1.6993	1.001	15	0.0676
9	1.3084	1.0199	26	0.0606
10	1.9185	0.9862	22	0.062
11	1.7568	1.0184	22	0.067
12	1.4658	0.9933	20	0.0665
13	1.8252	0.9864	21	0.0702
14	1.2809	1.0152	29	0.0736
15	1.3617	0.9972	17	0.076
16	1.237	0.9986	8	0.0666
17	1.5535	1.017	33	0.0796
18	1.9845	0.9875	22	0.0601
19	1.4327	1.0131	7	0.0645
20	1.2791	1.0115	26	0.0401
21	1.6392	0.982	23	0.0718
22	1.397	0.9908	5	0.0628
23	1.9445	1.0108	24	0.066
24	1.5016	0.9804	23	0.0745
25	1.6407	0.9959	16	0.072
26	1.7666	0.9859	22	0.0672
27	1.9782	0.9942	25	0.0683
28	1.7228	0.9807	31	0.0656
29	1.3355	1.0114	32	0.0643
30	1.8197	1.0182	26	0.0692
31	1.807	1.003	18	0.0642
32	1.5891	1.0164	5	0.061
33	1.7547	0.9839	19	0.0727
34	1.5571	0.9852	24	0.0746
35	1.9357	0.9916	30	0.076
36	1.9951	1.0063	11	0.0473
37	1.2134	1.0143	22	0.0562
38	1.4039	0.9821	21	0.061
39	1.9484	0.9956	24	0.0765
40	1.6649	0.9997	22	0.072
41	1.9861	0.9845	28	0.0647

42	1.2158	0.9963	6	0.0754
43	1.7469	0.9813	25	0.0724
44	1.2126	1.0153	26	0.0462
45	1.6198	1.0083	2	0.074
46	1.9366	1.0136	15	0.0647
47	1.6115	1.0155	24	0.0401
48	1.6606	1.0138	8	0.0713
49	1.9982	0.987	29	0.0738
50	1.5821	0.9828	13	0.0644
51	1.5876	0.9924	17	0.0736
52	1.8137	1.0173	15	0.0636
53	1.2587	1.0072	11	0.0502
54	1.4826	1.0025	25	0.0617
55	1.8877	0.9863	23	0.0657
56	1.4073	1.0001	21	0.0882
57	1.2452	0.999	6	0.0702
58	1.4542	1.0106	24	0.0617
59	1.3486	1.0186	4	0.0651
60	1.8978	0.9922	24	0.0663
61	1.7821	0.9845	22	0.0653
62	1.3257	1.0091	27	0.0549
63	1.8069	1.0193	19	0.0655
64	1.2522	1	26	0.0688
65	1.4658	0.9831	7	0.0697
66	1.6461	0.9821	22	0.07
67	1.3224	0.997	33	0.06
68	1.3218	0.9817	17	0.0763
69	1.7782	0.982	23	0.0809
70	1.5901	1.0089	4	0.0608
71	1.4629	1.0031	3	0.0619
72	1.9976	0.9936	24	0.0636
73	1.8016	0.9921	20	0.0664
74	1.7037	0.9988	2	0.066
75	1.6625	1.0086	29	0.0661
76	1.5365	0.981	22	0.0737
77	1.8702	1.007	6	0.0706
78	1.4626	0.9815	12	0.0611
79	1.9016	1.0073	15	0.0591
80	1.8523	0.9852	21	0.0659
81	1.6046	1.0111	33	0.0681
82	1.6623	0.9945	33	0.0476
83	1.2512	0.9802	7	0.0626
84	1.6098	0.9837	33	0.0428
85	1.2681	1.0164	16	0.0811
86	1.913	0.9842	21	0.0664
87	1.9957	1.0176	12	0.0719
88	1.4274	0.9846	14	0.0663
89	1.5875	0.9853	32	0.0619

90	1.7084	0.9821	5	0.0622
91	1.5927	1.01	12	0.0553
92	1.3728	0.9994	14	0.07
93	1.5542	1.0164	23	0.0612
94	1.9924	1.0123	16	0.0676
95	1.8731	1.0162	3	0.0486
96	1.9056	0.9972	9	0.0878
97	1.9459	0.9897	22	0.0654
98	1.9052	0.9815	29	0.0667
99	1.9359	1.0075	6	0.0622
100	1.2986	0.9874	10	0.0749

جامعة النجاح الوطنية

كلية الدراسات العليا

التحجيم والتركيب الأمثل لوحدات التوليد الموزع داخل أنظمة القوى الكهربائية باستخدام خوارزمية مطورة تحاكي حركة أسراب الطيور بهدف تقليل الفاقد ودعم استقرارية جهد الشبكة الكهربائية

اعداد

نداء محمود نمر هنطش

إشراف

د. ماهر خماش

د. تامر الخطيب

قدمت هذه الاطروحة استكمالاً لمتطلبات الحصول على درجة الماجستير في هندسة القوى الكهربائية، بكلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس- فلسطين.

2018

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الملخص

إن ادخال وحدات التوليد الموزع إلي الشبكات الكهربائية أصبح له أهميه كبرى في الآونة الأخيرة، وذلك من أجل دعم هذه الشبكات. إن التخطيط واختيار الحجم والمكان الأمثل لهذه الوحدات يحتاج إلى عمل وتركيز مهم، لذلك من أجل ذلك تم استخدام طرق كثيره بناء على بعض الحدود والشروط التي تفرضها الشبكة الكهربائية. في هذا البحث تم استخدام خوارزميه مطوره تحاكي أسراب الطيور من أجل اختيار أفضل مكان وحجم لوحدات التوزيع المولد وذلك لتقليل الفاقد ودعم استقراريه جهد الشبكة الكهربائية.

تم اعتماد شبكة ieee 34 bus التي تضم 34 نقطة ربط كمثال من أجل تطبيق هذه الخوارزمية، مع الأخذ بعين الاعتبار تقليل الفاقد ودعم استقراريه جهد الشبكة الكهربائية. بالإضافة إلى ذلك سيتم تطوير هذه الخوارزمية من أجل العمل على تقليل الزمن اللازم لإيجاد الحل الأمثل. إن تطوير الخوارزمية اعتمد على التحكم في وزن القصور الذاتي باستخدام معادله جديده، حيث أن وزن القصور الذاتي له أهميه كبرى في تحديث سرعة أعضاء السرب. تم استخدام بيئة برمجيه تعتمد على Matlab program الذي يمكن من دراسة الشبكة الكهربائية وتحليلها وأيضا تطبيق الخوارزمية التقليدية بالإضافة إلى التطوير عليها.

كنتيجة نهائية لهذا البحث أظهرت الخوارزمية التقليدية نجحت في ايجاد الحجم والمكان الامثل، حيث حصلت على حجم مناسب بمقدار 1.6722 كسعه لهذه الوحدة على نقطة ربط 10، التي بدورها جعلت الفولتية على هذه النفطة 1.0055. إن هذه الوحدة قللت الفاقد بمقدار 50.75%. استطاعت الخوارزمية ايجاد الحل المناسب بزمن حسابي مقداره h78.6212 خيرا، كمقارنه بين الخوارزمية التقليدية التي اعتمدت على معادله خطيه للوزن وبين تطويرها الذي استخدم معادله غير خطيه للوزن، فان الزمن كان 78.6212 69.0836 62.2325 بالترتيب، حيث كما يبدو فإن استخدام الخوارزمية المطورة التي تعتمد على المعادلة الغير خطيه كان الأقل من حيث الزمن مع إعطاء نفس النتيجة من ناحية تقليل الفاقد وتطوير الشبكة.