Distributed Generation Placement Based on Voltage Stability Using Genetic Algorithm

Alireza Gholami

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Approval of the Institute of Graduate Studies and Research

Prof. Dr. Mustafa Tümer
Director

I certify that this thesis satisfies the requirements as a thesis for the degree of Master of Science in Electrical and Electronic Engineering

Prof. Dr. Hasan Demirel
Chair, Department of Electrical and Electronic Engineering

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Electrical and Electronic Engineering.

Prof. Dr. Osman Kükrer
Supervisor

Examining Committee

1. Prof. Dr. Osman Kükrer
2. Prof. Dr. Mustafa Kemal Uyguroğlu
3. Prof. Dr. Şener Uysal

ABSTRACT

In this thesis, a genetic algorithm (GA) based optimization is used to improve the voltage stability of a power network using Distributed Generation (DG) Units. GA determines the best places of DG Units in the power network. Also, the number and sizes of DGs used are calculated by the proposed algorithm.

First, we have solved the problem without using GA. In this step, just one DG with constant size is considered. The main reason of using GA to solve the problem is that finding the best places of DGs could be very complicated and time consuming, considering the number and size of DGs.

To evaluate and compare the possible solutions, an index called Voltage Index (VI), is proposed which shows the voltage stability of the power network. A Forward/Backward load flow is used to determine the bus voltages, and consequently the VI of the network.

The results show that by using DGs the voltage stability of the network is improved. In addition, GA, as an optimization algorithm, can find the best solution for the problem considering number, size and place of DGs after a specific number of iterations. The best solution for the problem and the results of the load flow for best state are shown as the results of the thesis.

Keywords: Power Systems, Distributed Systems, Distributed Generation, Renewable Energy Systems

ÖZ

Bu tezde, elektrik enerji sistemlerinde Dağıtılmış Üretim (DÜ) birimleri kullanarak gerilim kararlılığı genetik eniyileştirme algoritması (GA) kullanmak suretiyle iyileştirilmiştir. Bu algoritma kullanılarak, DÜ birimlerinin sayısı, büyüklükleri ve sistemde hangi noktalara yerleştirilecekleri belirlenmiştir.

Bu problem ilk olarak GA kullanılmadan çözülmüştür. Bu aşamada, büyüklüğü sabit olan yalnız bir DÜ ele alınmıştır. GA kullanmanın esas nedeni, GA kullanılmadan yapılmaya çalışılan çözümün, DÜ'lerin sayıları ve büyüklükleri dikkate alındığında, oldukça karmaşık ve zaman alıcı bir işlem olmasıdır.

Mümkün olan çözümleri değerlendirmek ve karşılaştırabilmek amacıyla, şebekenin gerilim kararlılığının bir göstergesi olarak, Voltaj Endeksi denilen bir endeks önerilmiştir. Bara gerilimlerini, ve sonuç olarak Voltaj Endeksini, hesaplamak amacıyla İleri/Geri yük akışı yöntemi kullanılmıştır.

Sonuçlar, DÜ'ler kullanıldığında şebekenin gerilim kararlılığı iyileşmektedir. Ayrıca GA problemin en iyi çözümünü belirli bir tekrar sayısından sonra vermektedir. Bu çözüm DÜ'lerin sayısını, büyüklüklerini ve şebekede yerleştirilecekleri baraları içermektedir. Bu çözüm ve karşılık gelen şebekedeki yük akışı tezde sonuç olarak verilmiş ve tartışılmıştır.

Renewable Energy Systems Anahtar Kelimeler: Güç Şebekeleri, Dağıtım Şebekeleri, Dağıtılmış Üretim, Yenilenebilir Enerji Şebekeleri.

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I would also love to acknowledge, Prof. Dr. Hasan demirel for being so supportive. My thanks go to my friends who helped and encouraged me during the period of my studies and this thesis.

DEDICATION

I would like to dedicate this thesis and everything I do to my family. In addition to I have always been surrounded with strong supportive from my brother Mohammad.

I would not be who I am today without the love and support of my mother Moloud; Although our time together was brief since she has passed away but her contributions to my life will be felt forever. Last but not least, thanks to my great father who stand behind me and help me to build my own world.

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INTRODUCTION AND OBJECTIVES

1.1 General Introduction

In traditional power systems, electricity was generated by generators and transmitted by transmission lines to distribution systems. In such systems the problems were: high transmission prices, environmental problems and instability of voltage and frequency. But, nowadays, consumption of power has increased due to the increase in population and load demand. So many countries prefer to use DG to supply some part of their power demand.

One of the most important issues in using DGs in power systems is determining the optimal number, size and place of DGs. Finding the best place for DGs in a network considering various parameters, such as the number and sizes of DGs is a complicated and time consuming problem. Due to the complexity of the problem many researches have been performed and many algorithms have been used to solve this problem. Recently many researches have used various optimization algorithms such as the Genetic Algorithm, Particle Swarm Optimization and Simulated Annealing to determine the parameters and location of DGs. The Genetic Algorithm (GA) is one of the best optimization algorithms, which is used to find the optimal solutions to a given computational problem that maximizes or minimizes the given function (fitness function).

Distributed Generation (DG) is a small generation unit which are used in distribution networks. Due to their advantages in power systems, the number of DGs is increasing rapidly and they play an important role in contemporary power systems. Many researches have been done showing the benefits of using DGs in power systems [1-7]. These benefits are not limited but can be listed as follows:

- Using common types of DG sources (wind, solar and wave), many problems regarding air pollution and environmental issues can be solved.
- Cost benefits: The price of power generated by a DG unit is more than a plant, however as we don't need transmission lines to transmit the power to consumers, the total price of power generated by a DG unit is less. This is shown at figure 1.1.

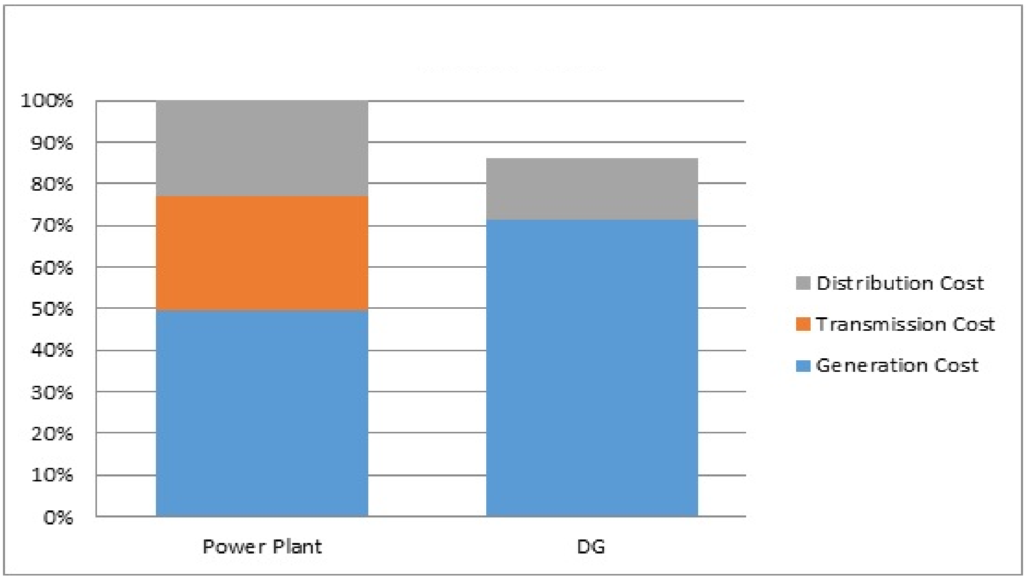

Figure 1.1: Economic Comparison between DGs and Power Plants

As mentioned before, with elimination of transmission lines, the losses in the power system is reduced; consequently, voltage stability is improved. Therefore, by using a DG unit in a network the voltage stability of the network can be improved. This fact is investigated to determine the best place for DG in this thesis. Also in Figure 1.2

the different fields of study of power system stability are given. As shown in the figure the principle areas of power stability are rotor angle, frequency and voltage stability issues of distribution systems and networks. Among the areas above, voltage stability of the system can be categorized as small and large disturbance stability. In this thesis we will discuss the effect of DG on voltage stability. Beside all of the above benefits, DG indirectly affects these system characteristics [8-10]:

1) voltage profile, by reducing the losses
2) power quality, defined as adaptability of electric power to consumer devices
3) power flow in the distribution network
4) stability, which is the ability of the system to return to its steady state after disturbance

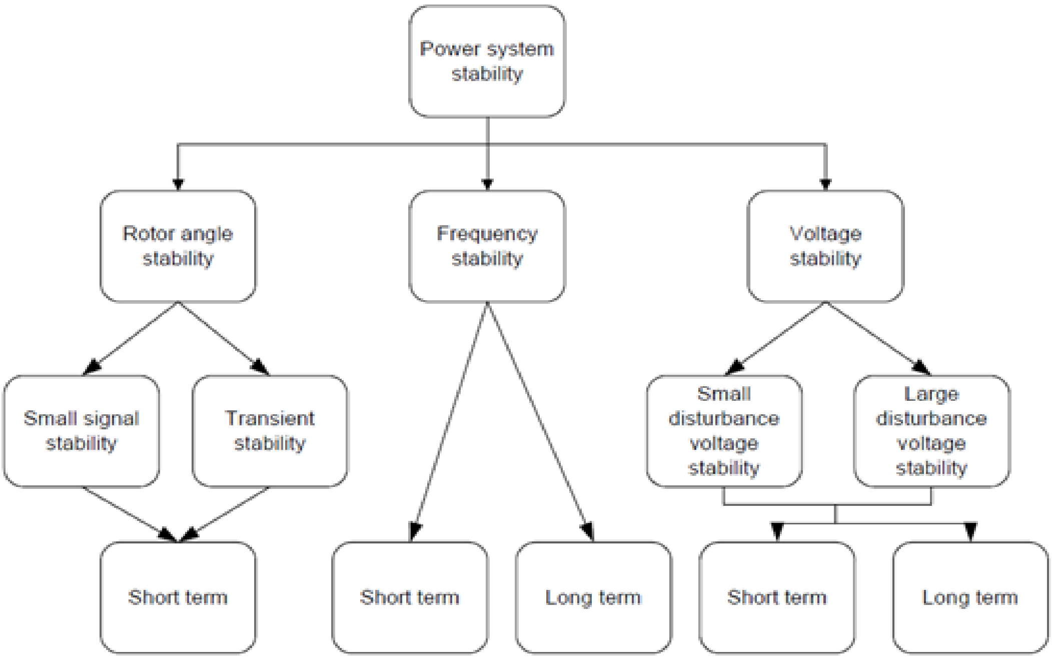

Figure 1.2: Different Aspects of Power System Stability

Engineers predict that DG units would have a contribution of about 20% of new generating unit. With penetration level of distributed generation increasing, it is important to find out how DG units should be appropriately integrated into the grid, and in particular where they should be placed to enhance voltage stability and improve voltage profiles. The stability of voltage is a new and demanding problem in power system engineering. As the operation of a power system, which possess more limitation, continues, it gains importance. When a disturbance occurs in the power system, voltage instability is more probable to occur at the weakest bus. The weakest bus has the capability for providing the data for optimizing the plan of reactive power generation which should determine which bus is the most intensive and can be considered as a new source of reactive power for installing. When the penetration level of the DGs increases, the problem mentioned becomes highly serious. For using DGs in large amounts and with high reliability in power systems, voltage stability analysis is required. By using the power flow methods, we find the values of active and reactive power and other data at each bus before placement of DGs. To see the effect of DGs on the power distribution network, we shall use the power flow method after placement of DGs for obtaining the data again.

On the other hand, finding the best place for DG in a network considering various parameters, such as the number and size of DGs is a complicated time consuming task. Nowadays, optimization algorithms help engineers to solve such problems with ease. The Genetic Algorithm (GA) is one of the main optimization algorithms, used to find the optimal solution to a given computational problem that maximizes or minimizes the given function (fitness function). In DG placement problems, determining the best number of DGs that should be used, sizes of DGs used and the buses at which DGs should be installed, is a very time consuming problem and is hard to solve. In this project we use the GA algorithm to solve the DG placement problem. Also an index (Voltage Index) is presented to evaluate voltage stability and as the fitness function of the problem.

1.2 Thesis Objectives

Due to problems in distribution networks after instabilities, the motivation of this research is to find the best place for DG considering the effect of DG on voltage stability of the system. Therefore in this research the main objectives are:

- Analyzing for more understanding the impacts of DGs on voltage stability.
- Present a method to find the best place and size of DG units for improving voltage stability.
- Analysis of the effect of the number of DGs on voltage instability when the number of DGs is high.

This thesis is organized as follows. A literature review of power distribution systems, distribution generators and GA are given in chapter II. In this chapter, different types of distribution systems and distribution generators are discussed. Also, voltage stability as the main factor of concern of DG on network systems is described. In addition, an introduction to the Genetic Algorithm is presented and some of the applications of GA to power system problems are introduced. In chapter III, the load flow technique used to solve the problem is described. The formulation as well as the algorithm used is presented in this chapter. Chapter IV includes the results of the thesis in which a standard 33_bus network is used as a test system. The results show the positive effect of DG on the voltage stability of systems. To reach this target an index is used which will be discussed later in chapter IV. Finally, Chapter V includes conclusions and future study of the project.

1.3 Contribution

The main contribution of this thesis is the use of the Genetic Algorithm (GA) to solve the problem of placement of Distributed Generations in a power distribution network. The GA has been successfully applied to this problem with good results. This is a new approach compared to the methods presented in the IEEE paper [1].

Chapter 2

DISTRIBUTED GENERATION IN POWER DISTRIBUTION NETWORKS

2.1 Distribution System

The three main parts of a power system are: Generation system (generation units), transmission lines and the distribution system (Figure 1). Generation is related to power plants and distributed generation in which electrical power is generated. In the transmission system, which include transformers, transmission devices and transmission lines, the generated power is transmitted to distribution networks. Finally, the distribution system delivers the power to customers. On the other hand, a distribution system can be defined as an electrical system, which among sub-station feeders, can be divided into two parts such as: transmission systems and consumers.

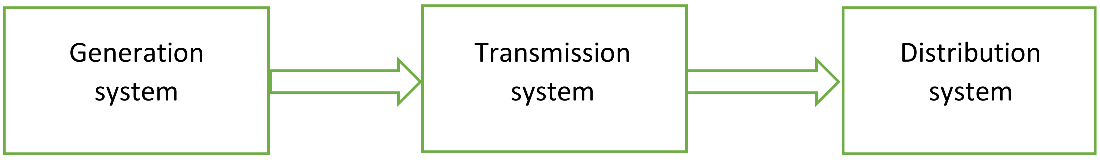

Figure 2.1: Power System Main Sections

A distribution system includes three parts as follows:

- Distributers: A distributer is a conductor for the supply of power to consumers.
- Feeders: A feeder can be considered as a conductor for connection between sub-stations in an area where power is distributed.

- Service: generally a service can be considered as connection from the distributer to consumer’s terminal with a small cable.

2.2 Classification of Distribution Systems

It is possible to classify distribution systems as:

1) type of current: based on the nature of the distribution system’s currents; it is possible to classify distribution systems such as:
    - AC distribution system
    - DC distribution system

Because of the economic efficiency and simplicity, an AC distribution system is more universal than DC distribution.

1) Type of structure: it is possible to classify the construction in two models such as overhead system and underground system; generally the overhead system is cheaper than underground system. When using the overhead system is impracticable we use the underground system.

Connection schemes: we can classify the scheme of the connection in three parts such as:

- Radial system
- Ring main system
- Inter-connected system

In this thesis we have focused on the impacts of DG units on radial networks. In a radial system, there is a single substation where separates feeders are radiated from and distributors are fed at one end only. Figure 2-2 shows a radial system network with 30 buses [11].

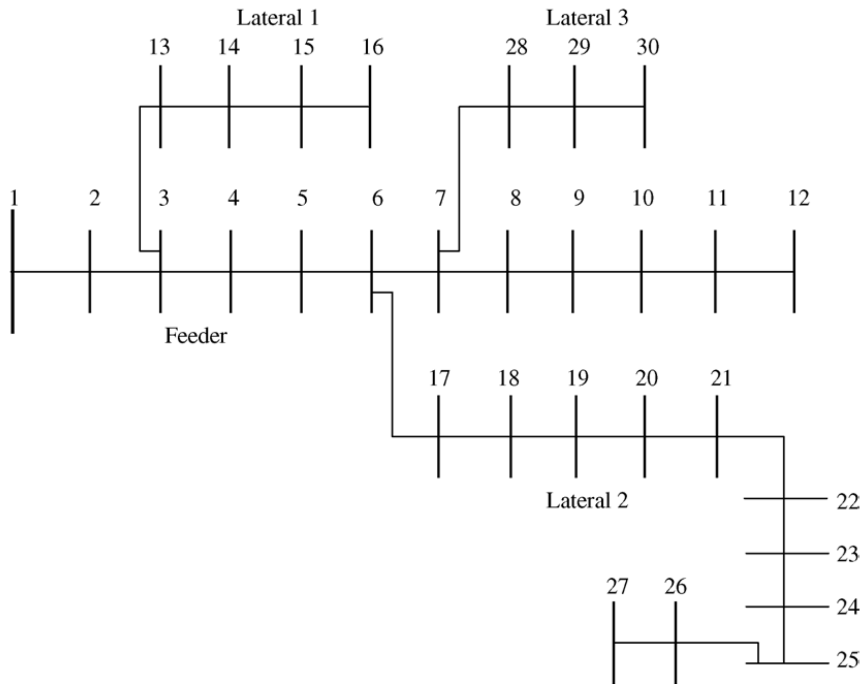

Figure 2.2: Radial Network with 30 Buses

This model of distribution can be considered as the simplest model with the lowest primary cost. However this model suffers from some disadvantages:

- We have heavy load at the nearest feeding point which is placed at the end of the distributer.
- In this model consumers are always dependent on a single distributer and single feeder; therefore if any fault occurs in the feeder or the single distributer the supply of the consumers on the other side of the fault from substation will be cut off.
- Changing the voltage will affect the consumers which are placed at the end of the distributer.

2.3 Distributed Generation

DG can be considered as technology which is new in the electric power industry, but there are various different definitions which describe DG. According to the definition of DG in IEEE [12], units which produce electrical power, which are smaller than generating plants and are connected to any point in the system, can be called DG. For example in different countries DGs are defined by different terms, such as “embedded” in Anglo-American, “dispersed” in the north countries and “distribution” or “decentralized” in Asian countries.

Furthermore, the following definition currently can be used, which depends on the ratings of power units of distributed generation:

- Distributed generation between 0 to 50 kW, defined by the electric power institute [13].
- Distributed generation as generation between 500 kW and 1 MW, defined by Cardell [14].
- The size of DG more than 100 kW is defined by Preston and Rastler. However, DG units can be described with respect to maximum power rating, type of the prime mover, and voltage level. They are placed near loads as small-scale generation units.

2.3.1 Types of Distributed Generation Sources

This study is based on two main types of DG sources which are classified in two types such as Dispatchable and Non-Dispatchable, shown in Figure 2-3 and described as follows[15].

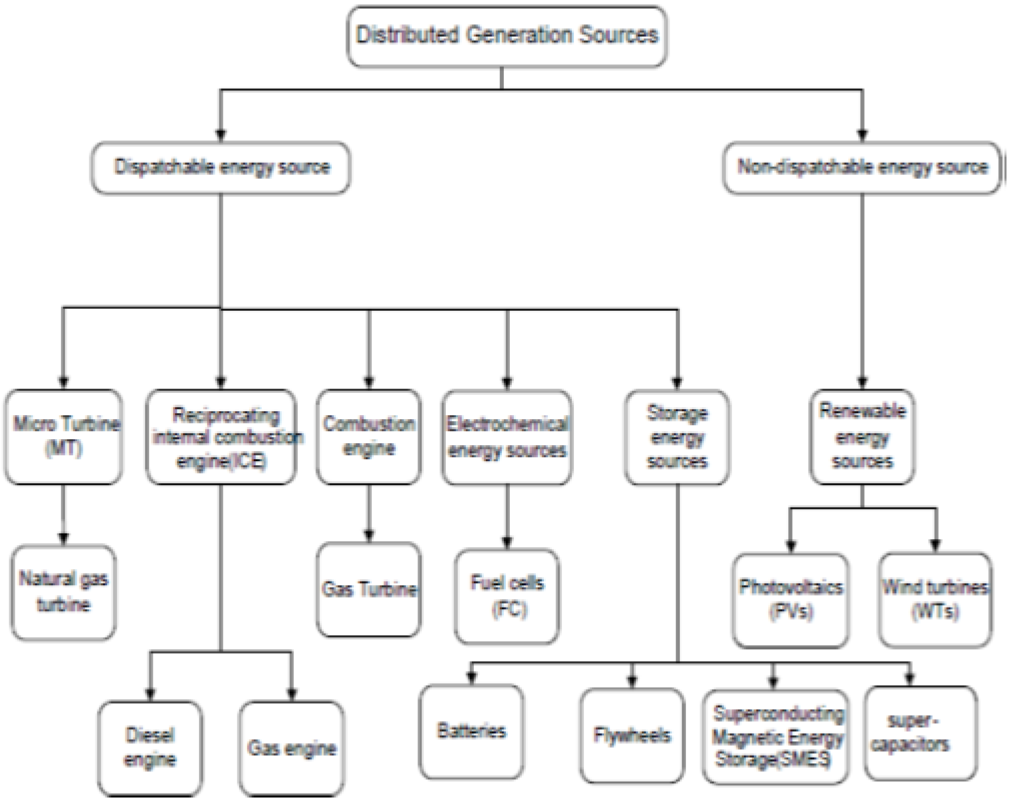

Figure 2.3: (DG) Units' Sources

2.3.1.1 Wind Turbines

Nowadays, countries that follow the renewable energy technology mostly use wind energy due to its benefits. Wind turbines are used to generate electrical power from the kinetic power of the wind. In this way, mechanical energy is generated from the kinetic power of the wind and then electrical power is generated from mechanical energy. Induction and synchronous machines are used to generate power. The wind turbine includes blades, nacelle, rotor, gear box, coupling devices and a shaft. Normally electric capacity of a wind turbine depends on the amount of wind. Therefore they should be place in a windy location. A group of them are installed at a location named as a wind farm. The total efficiency of a wind turbine varies between 20-40 percent. The power rating of a wind turbine is between 0.3-7 MW. Wind turbines have some advantages such as:

- It is a clean power source.
- This technology is cheaper than other technologies of distributed generation.

Wind turbines can be classified in four types illustrated in Figure 2.4:

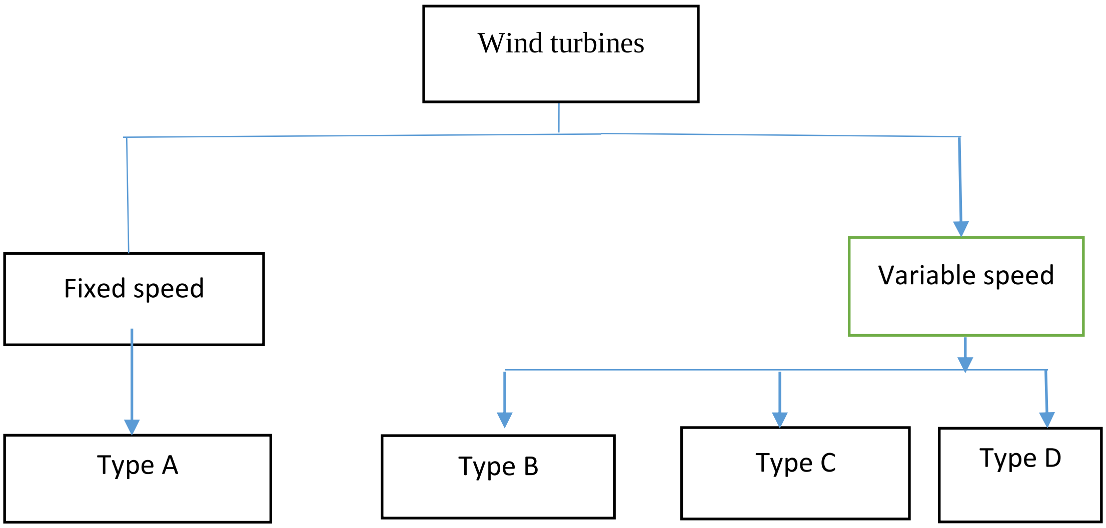

Figure 2.4: Types of Wind Turbines

- Type A: in this type, the wind turbine has fixed rotation speed and induction generators are used connected to the grid. If the grid is not strong, it is possible that wind speed’s fluctuations convert to fluctuations in electrical power then subsequently to fluctuations in voltage.
- Type B: In this type Wound rotor Induction Generator is used. The slip from 0 to -0.1 is controlled. In this way the speed of the generator will increase about 10% over the synchronous speed.
- Type C: This type uses a doubly-fed induction generator via a wound rotor induction generator and a partial scale frequency converter on the rotor circuit.

- Type D: In this type a full variable speed wind turbine, and a synchronous or an induction generator is used to connect to the grid via a full load frequency converter.

The comprehensive study with regards wind turbines have been done in [16].

2.3.1.2 Photovoltaics

In this technology electrical power supplied depends on the temperature and solar radiation. Solar cells are the most important components of a photovoltaic system. It includes some semiconductor materials such as: polycrystalline or monocrystalline silicon. Solar cells can be used in the form of a panel or module. Normally a PV module can be formed by about 36 to 72 cells. A PV array is one of the most important elements in renewable energy systems, for generating electrical energy from sunlight. Modules can be connected in series or parallel to form a solar array. Solar cells have photovoltaic ratings from 0.3 kW to multi-megawatt in huge systems. Generally the efficiency of a photovoltaic cell is 20% and it is less than that of wind turbines. The lifetime of photovoltaics is more than 25 years. With aging the efficiency will decrease between 75-80 percent. Maximum Power Point Tracking (MPPT) is an effective method for raising the efficiency of PV cells, which can be used in photovoltaic DG units through power electronic converters. Some techniques are used in MPPT such as: fuzzy logic control, linear line approximation, neural network method, voltage feedback, partial and observe method. Also in [17-21] this type of DG is the main subject of the research.

2.3.1.3 Fuel Cells

Another type of DG technology which can be used as a clean source is the fuel cell. It is a device for converting chemical energy to thermal and electrical energy. Their operation is similar to a battery; two electrodes and one electrolyte comprise a fuel cell. But there is the disadvantage that the reactants cannot be recovered, hence are constantly fed to the cell. This technology has high efficiency about 40-60 % for producing electricity. However the efficiency can be more than 80% when combined with exothermic reactions. The capacity of a fuel cell depends on the application such as stationary or portable or transportation, which can change from 1 kW to more than 5 MW.

Energy density of fuel cells is 200 Wh/lt which is ten times more than a battery. Fuel cell types are given below:

- solid fuel
- alkaline fuel
- phosphoric fuel
- molten carbonate
- solid oxide

We can use fuel cells as a Dispatchable such as propane, gasoline, and natural gas. In addition many applications and types of fuel cells are discussed in [22-24].

2.3.1.4 Micro Turbines

This technology is used as dynamic devices in power distribution systems. It means that they have an effective dynamic behavior while connected to the distribution system. They are small and have simple-cycle gas. Their outputs are from 25 to 300 kW. They have high-speed and single-shaft units. The compressor and turbine are installed on the same shaft and drives an electric alternator. There is a combustion chamber and a gas/water heat exchanger. The range of turbine’s speed can be around 5000 to 120000 rpm. For regulating the electric power, speed and temperature, a control system is used. Power electronics is useful for controlling the voltage and current, and the frequency of the output power. Because of the variety of potential applications, this technology is useable in many places with different operating conditions. The advantages are good efficiency, low emissions, low investment costs, low maintenance costs, and can utilize a variety of fuels, even waste fuels. Disadvantages are high operating rpms, reduced power outputs, low efficiency with higher temperature and low fuel-to-electricity efficiency. Figure 2-5 shows a micro turbine system [25]

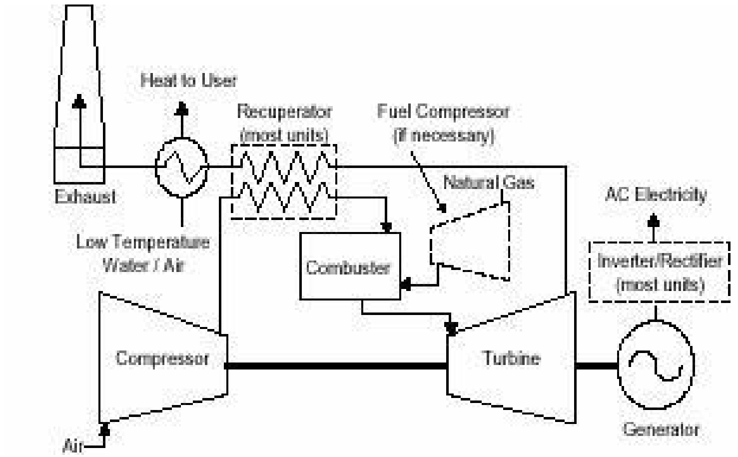

Figure 2.5: Micro Turbine System

2.3.1.5 Storage Devices

In power systems, application of storage devices are power quality, reliability of supply and improving system stability. This type of technology should be interfaced to the power system by power electronics converters. They can be used in some types such as: flywheels, super-capacitors, batteries. The application of storage devices in DGs improve the reliability and enables picking up of rapid load variations, and in non-Dispatchable DG sources.

2.3.2 Connecting DG Units to the Grid

There are two types of linking DG units to the grid:

- Direct grid

In this type DG units involve synchronous and induction generators operating at constant speed.

- Indirect grid

This type is used when the output of the sources can be DC such as fuel cells and photovoltaics, micro-turbines with high frequency and wind turbines (type C and D) with variable frequency, in which case for all of the sources power electronic converters are used.

2.3.3 Effects of DG Units on a Power System

In power systems, integration of DG units has some advantages but they can improve the complexity too. The impacts of DG units on a power system involve, power flow, voltage profile, system losses, protection, reliability, stability and power quality. This study is focused on voltage stability in case of high penetration of the DG units. The impacts of DG units on voltage stability are presented in this chapter.

2.4 Stability of a Power System

In this section, definition and classification of stability, and discussion about stability of the power system are provided, which are important to understanding the stability of the system.

2.4.1 Definition of Stability in a Power System

Stability of the system is defined as ability of the system to return its operation to the steady state situation in the least possible time after occurrence of some type of transience or disturbance in the system. In the definition, the disturbance could be load changes, generator outages, voltage collapse, line outages or faults.

2.4.2 Classification of Power System Stability

As mentioned before (see Figure 2.3) stability of power systems is classified into frequency stability, rotor stability and voltage stability. [26]. In the following, we explain the three aspects separately:

2.4.2.1 Rotor Angle Stability

The system remains in synchronous operation while subjected to a disturbance. When mechanical torque caused by input mechanical power and electromagnetic torque caused by generator electrical power output is balanced, rotor angles of all the generators remain constant. When this balance is disturbed, it means that we have disturbance in the system. Rotor angle stability can be classified as large and small disturbance stability.

2.4.2.2 Frequency Stability

This refers to the power system's ability to protect the steady state frequency after each disturbance between generation and load.

2.4.2.3 Voltage Stability

Voltage stability is used to describe the ability of the network to have steady voltages after any changes in system. Instability can result in various forms as voltage changes at the buses. Voltage stability in the system can be considered as long changes such as faults, large outages, large changes in the loads, and small disturbances (such as small load differences). Voltage stability is the result of a balance between reactive power demand and reactive generation in the power system.

Voltage stability is classified in two types such as long term and short term.

- Long term: It involves slow acting equipment such as controlled loads and generator current limiters.
- Short term: It involves fast acting load components

There are two methods for voltage stability analysis, such as static and dynamic which are discussed in the following subsection.

- **Static analysis**

In this method, an operating condition of the power system is examined to determine whether or not it represents an equilibrium point. Therefore by using this method, it is possible to examine stability for a wide range of power system conditions. PV and QV curves are used in the electric utility industry for determining stability at candidate buses.

For evaluating the static method a variety of techniques is used, such as:

a) For generating the PV-QV curves, a large number of power flow studies using a power flow method is executed. In this case a non-linear differential algebraic equation is used for modeling a power system.

$$dx/dt = f(x, \lambda) \tag{2.1}$$

where $x \in \mathrm{R}^n$ represents a state vector (n is the dimension of the vector), including the bus voltage magnitudes (V) and angles (δ), $\lambda \in \mathrm{R}^n$ is a parameter vector that represents the real and reactive power demand at each bus.

The λ parameter can be considered as a variable according to variations in the load. Therefore, variations of the power flow solution depends on λ. The power flow in power system is represented by

$$0 = f(x, \lambda) \tag{2.2}$$

There is an example for more illustration about P-V curves: a single-machine PV bus is considered as shown in Figure 2-6.

There is a transmission line with a PQ load of constant power factor which is supplied by a PV bus. As shown in equation (2.2) the state x represents the voltage

(V), and the power angle (δ) . The real and reactive power is represented by parameter vector λ.

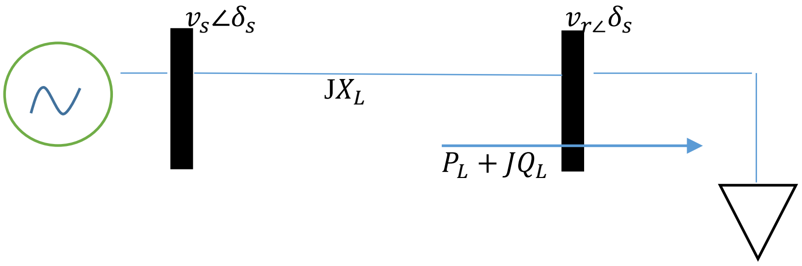

Figure 2.6: A single-machine PV is Supplied by a PQ Load Bus

Assume that loading is low; therefore the power flow equation (2.2) has two equilibrium solutions:

1) With a high voltage value
2) With a lower voltage value

Here the stable solution is the high voltage value. With increasing load, the high voltage value will decrease and the lower voltage will increase. Solution points appear on PV curves as in Figure 2.7 [27] and continue moving until they unite at a critical loading power and after a specific point disappear. After this critical value, the load flow will diverge.

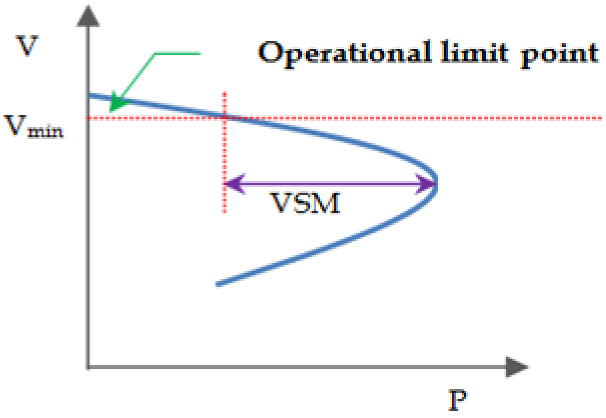

Figure 2.7: PV Curve

b) V-Q sensitivity analysis

In this method, the power flow equations can be linearized as given in equation (2.3)

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}=\begin{bmatrix}J_{P\theta} & J_{PV}\\ J_{Q\theta} & J_{\theta V}\end{bmatrix}\begin{bmatrix}\Delta\theta\\ \Delta V\end{bmatrix} \tag{2.3}$$

where

ΔQ: As an increasing variation for bus reactive power

ΔP: As an increasing variation for bus real power

$\Delta\theta$: As an increasing variations for voltage angle of bus

ΔV: As an increasing variation for voltage magnitude

J: Is defined as the Jacobian matrix

Suppose that the real power is constant, therefore increasing variation for real power of bus ΔP is zero. Solving for the variations of the bus reactive power and voltage from the above equation gives (2.4) and (2.5):

$$\Delta Q=(J_{Qv}-J_{P\theta}\,J_{P\theta}{}^{-1}\,J_{PV})\Delta V \tag{2.4}$$

Or

$$\Delta V=(J_{QV}-J_{P\theta}J_{P\theta}{}^{-1}J_{pv})^{-1}\,\Delta Q \tag{2.5}$$

The V-Q sensitivity is obtained by solving equation (2.4). The QV curve is found by the sensitivity at a bus (Figure 2-6) at a specified operating point [28]. The positive part of V-Q sensitivity can be considered as stable operation and negative part of V-Q sensitivity can be considered as unstable operation.

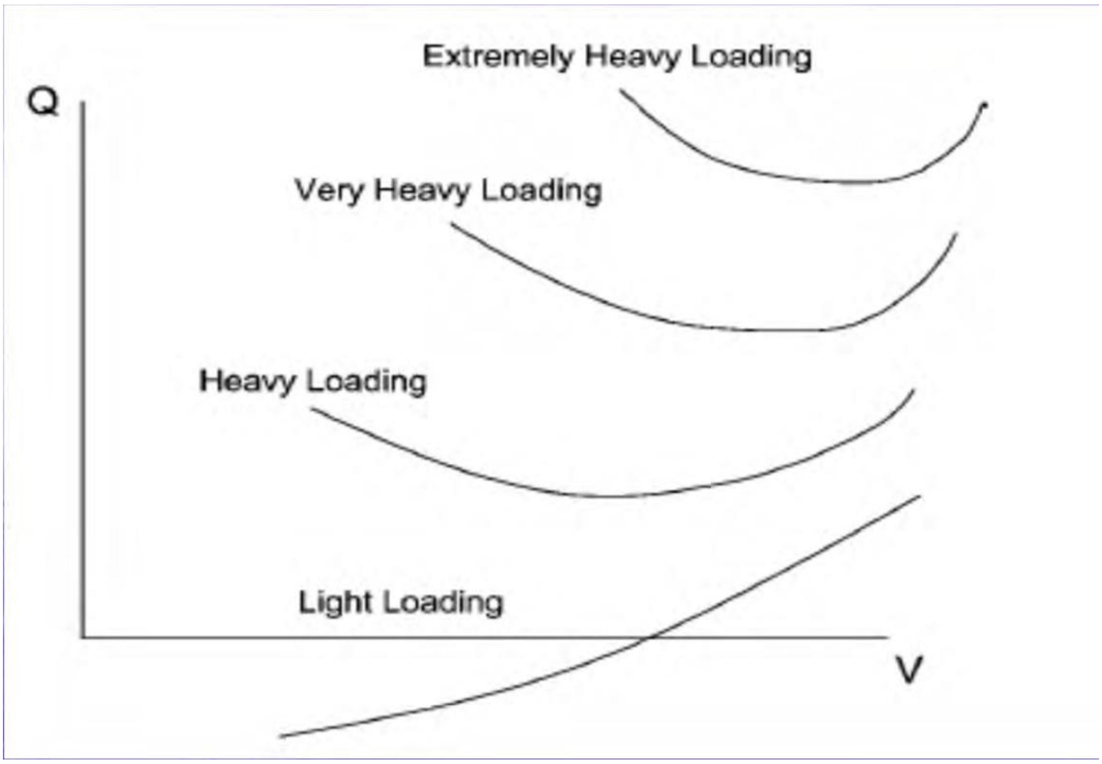

Figure 2.8: Curve of QV

- **Dynamic analysis**

In this method, real behavior of the system is shown involving DG units, loads, protection system, frequency control equipment and automatic voltage regulation. A set of first order differential equations as given in equation (2.6):

$$\dot{X}=(X,V) \tag{2.6}$$

and a collection of algebraic equations

$$I(X,V)=Y_n\, V \tag{2.7}$$

represent the overall power system with a collection of initial conditions (X_0, V_0).

where:

X: state vector of the system

V: vector of bus voltages

Y_n: admittance matrix of network nodes

I: vector of current injections

By using the numerical integration method in the time domain, equations (2.6) and (2.7) are calculated. In this study the time domain solution is provided. The system, by the help of different simulation software such as MATLAB, can be modeled or simulated.

2.5 Voltage Stability Margin

By using the relation between the voltages (V) and power (P), it is possible to analyze the static techniques at a certain bus in the distribution system, which is known as a nose curve or P-V curve.

By using the continuous power flow method, a nose curve can be obtained. In the nose curve λ_{max} can be considered as a critical point which shows the maximum loading of the distribution system. This point is obtained from the singularity of the Jacobian in the power flow equations. In this curve, the MW distance from the operating point to the critical point is defined as the stability margin.

It is possible to change the value of voltage stability margin depending on lead or lag power factors as well as their locations or their action in unity with penetrating the DG units in a distribution network. P-V curve or nose curve of an electric system can be shown in Figure (2-5).

λ at the operating point can be considered as a scaling factor of load demand in the x-axis in equations (2.8) and (2.9). λ changes from zero to the maximum of the load (λmax)

$$P_i = \lambda p_{0,i} \tag{2.8}$$

$$Q_i = \lambda Q_{0.i} \tag{2.9}$$

However, it is not the static analysis ability which determines the interaction and action of penetrations of DG units in the system. For determining these issues, proximity to instability of the voltage method can be used. In the literature, small-signal stability analysis of the impacts of DG units' dynamics has been used. In power systems, small-signal analysis in the frequency domain by using analysis of eigenvalues has been achieved. By linearizing the model mathematical of the system at an operating point, it is possible to solve the eigenvectors and eigenvalues of the linearized system.

Chapter 3

ANALYSIS OF THE EFFECTS OF DG'S IN RADIAL DISTRIBUTION NETWORKS

3.1 Introduction

Power flow studies have been performed to determine the operation of a power system in the steady state condition, or at the design level. The application of load flow analysis is for finding the distribution system objectives such as: voltage profile, losses, voltage magnitudes, etc.. In recent years, researchers have been studying load flow of distribution systems (radial, ring, interconnected). Because of some special features, these methods can be: the Newton Raphson, the Gauss-Seidel or backward forward (b/f) sweep methods .The main features are listed below:

- scheme of connection
- high ratio between R and X (R/X ratio)
- unbalanced operation or multiphase
- unbalancing in load distribution
- DG units

It is not possible to use the Newton-Raphson (NR) or the Gauss-Seidel (GS) methods in distribution systems [29]. Therefore, for load flow analysis of distribution networks, the backward/forward sweep method has been introduced in radial networks. In this method, the Jacobian matrix is not required. In recent years many researchers tried to develope the backward/forward sweep method [30-34]. In these papers the standard model of this method in the radial 33-bus network is used. In distribution network flow, the first stage is to obtain all the voltages of the nodes. So, by determining the voltages it's possible to directly find the other quantities in the system such as power flows, system losses and current.

3.2 Formulation and Algorithm

The main goal of running the load flow algorithm is to determine the voltages and power losses of a network. So, the objective is to find the power flowing out of buses. Then power losses of lines can be calculated. After this the total active and reactive powers of the feeder can be calculated. Figure 3-1 shows the flowchart of the forward-backward load flow method used in this thesis. The forward-backward method is divided into two sections: forward sweep and backward sweep. In forward sweep nodal voltages are evaluated from the start branches to the last ones. Also, in backward sweep updated voltages sweep from the last layer branches to the first ones.

This algorithm is formulated as follows:

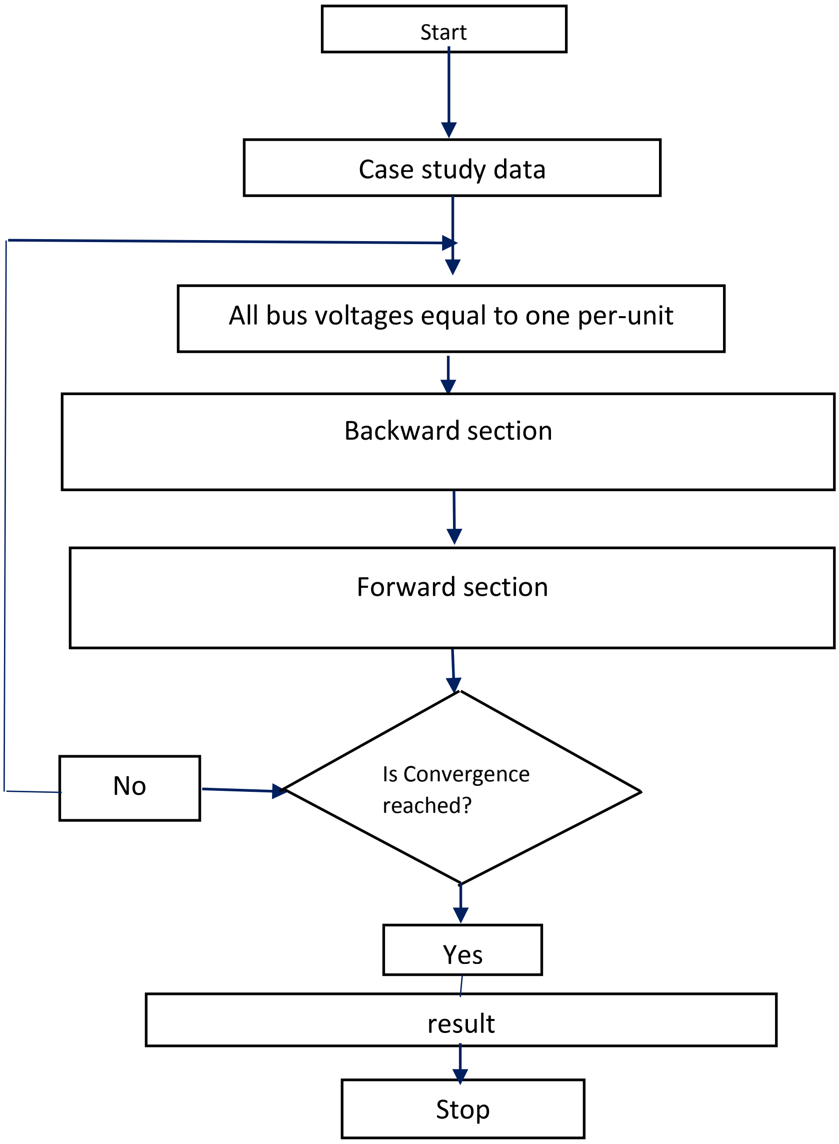

Figure 3.1: Diagram Flow Chart of b/f Algorithm

$$P_{k+1} = P_k - P_{loss,k} + P_{l,k+1} \tag{3.1}$$

$$Q_{k+1} = Q_k - Q_{loss,k} + Q_{l,k+1} \tag{3.2}$$

$$P_{loss}(k, k+1) = R_k \frac{p_k^2 + q_k^2}{v_k^2} \tag{3.3}$$

$$Q_{loss}(k,k+1) = \; X_k \, \frac{p_k^2 + q_k^2}{v_k^2} \tag{3.4}$$

$$P_{T,loss}(k,k+1) = \sum_{K=1}^{N} P_{loss}(k,k+1) \tag{3.5}$$

$$Q_{T,loss}(k,k+1) = \sum_{K=1}^{N} Q_{loss}(k,k+1) \tag{3.6}$$

where:

P_k= Real power of bus number k;

Q_k= Reactive power of bus number k;

$P_{l,k+1}$ = Real power of load bus number k+1;

$Q_{l,k+1}$=Reactive power of load bus number k+1;

$P_{loss}(k,k+1)$ = Real power Loss in the line section connecting buses k and k+1;

$Q_{loss}(k,k+1)$ = Reactive power Loss in the line section connecting buses k and k+1;

$P_{T,loss}(k,k+1)$= Total Real Power Loss in the line section;

$Q_{T,loss}(k,k+1)$= Total Reactive Power Loss in the line section;

In this chapter the method and algorithm used for the placement of DGs is described. First, the forward-backward used as a load flow method for distribution networks is discussed. Then, we present an algorithm for placement of the DGs. Also, an index, as an objective function, is presented to determine the effect of DGs on a sample network.

Many researches have solved the DG placement problem by considering different objective functions. Loss minimization, economical issues, environmental impact reduction, reliability enhancement and voltage improvement are the most common objectives used in previous researches [21-24]. In this project, we solve the DG placement problem considering voltage stability enhancement. For this reason, we use an index to determine how the DG affects bus voltages of the sample network. The index is called the Voltage Index (VI) and calculated as in equation (3-7):

$$\mathrm{VI} = \sqrt{\sum_{i=1}^{n} (V_i - V_b)^2} \tag{3.7}$$

where:

i = The bus number

V_i = Voltage of bus number i

V_b = Voltage of base bus= 1.0 PU

N = the total number of buses.

The VI indicates the effect of DGs on network bus voltages properly. It is obvious that the lower amount of this index shows the better performance of DG units. So, the bus for which the calculated index is the lowest is the best place for DG to use. The flowchart of the algorithm used is shown in Figure 3.1.

As shown in Figure 3-2, first we run load flow for the base state of the network. All bus voltages are calculated and saved. Then, a bus is selected and DG is placed at this bus. The load flow is run for this state considering the DG. The size of the DG is set to 50 MW for this project. All bus voltages and the VI index are calculated for this state. This is repeated until reaching the termination criteria.

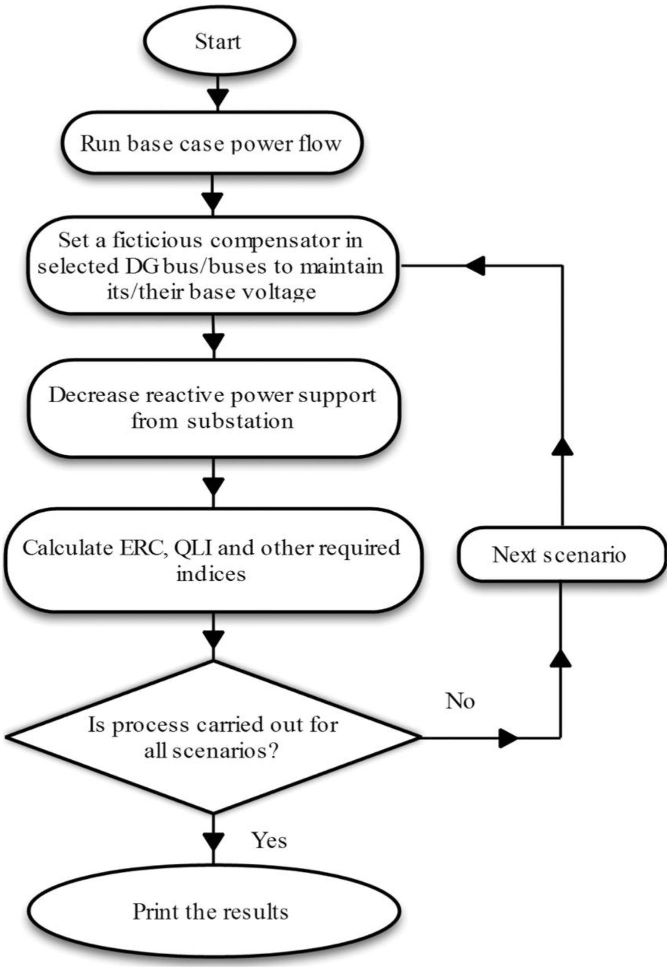

Figure 3.2: Flow Chart of the Algorithm

3.3 The impact of DG Units on a Distribution Network

Figure 3-3 shows the effects of DG units on voltage stability in the distribution system. In this way we can see that after placing the DG unit on the weakest bus we have improved the value of the voltage stability margin. As shown in the figure, injection of real power by DG units in the network can improve the (λ). λ is a factor which shows the load demand at specific operating points of the system. In this figure λ in the x- axis is considered as the load demand. Also, λmax represents the maximum load of the system. From the figure, by using DG the amount of load ability and voltage stability margin is increased from λ_{max1} to λ_{max2}. In addition, for the same load, operating point voltage is increased from V1 toV2 as well.

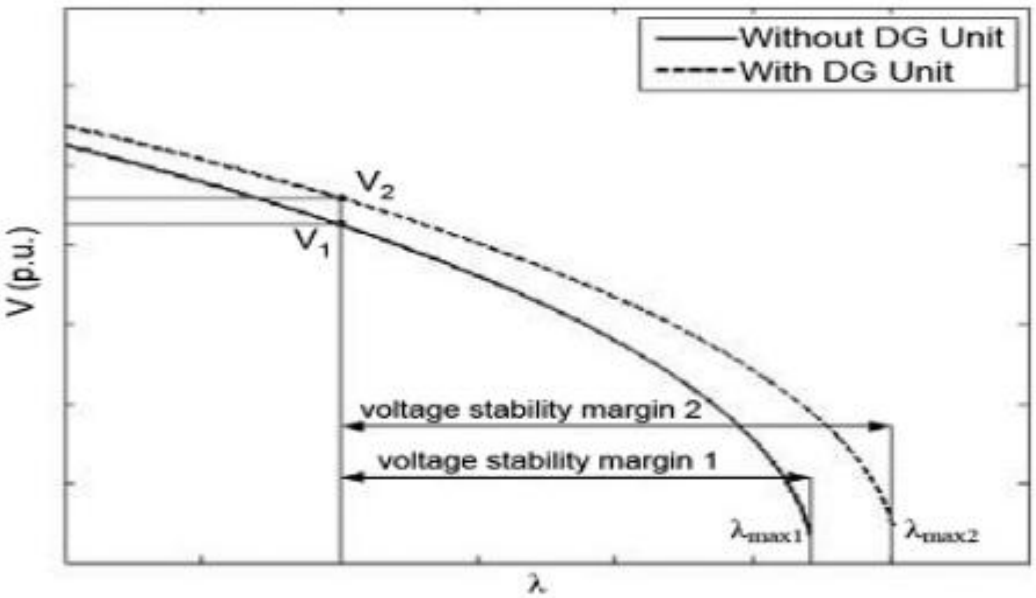

Figure 3.3: The Impacts of DG Units

3.4 DG Placement without Using GA

In this section of the thesis, results are presented and the efficiency of the algorithm used is discussed. First, load flow is used to calculate the voltage of each bus for the base case (without using DG). Then, VI for the base case is calculated. In the next step, according to the flowchart, the effect of using DG at different buses is analyzed. For this, every time the load flow is run and the VI is calculated. The well-known 33 bus network is used as a case study. The single line diagram of the system is shown in Figure 4-1. Also the bus data and line data of the 33-bus system are given in Tables 4-1 and 4-2 respectively. As shown in Figure 4-1, the network contains 33 buses and 34 lines. The total power is 4.3694 MVA and the system has one base feeder and three laterals.

3.5 Introduction to Genetic Algorithms

First time, Holland from University of Michigan proposed the genetic algorithm in the 1960's and 1970's. GA is based on natural selection in evolution. GA, to find the best answer, creates possible answers, as solutions. Each solution is evaluated to see if it’s a good or bad answer. Then, best solutions are compared to each other. These iterations continue until we reach the stopping criteria. Stopping criteria can be different items such as number of iterations or a very small tolerance in the difference between answers. Each chromosome consists of genes, which are individual characters that represent the variables of the problem. The population is the number of chromosomes in every iteration. For example in this work, the number of DGs and their sizes can be considered as genes. A chromosome represents the buses of the network, such that a number other than zero means that DG will be installed at that bus. The initial population of various amounts of chromosomes, based on the size of the problem, is normally created randomly. In some problems a population with 50 chromosomes will be enough, while, in some problems we should take more than 100 chromosomes in the population to reach a better answer.

In the next section, how GA works is described, i.e. how GA reaches the optimum answer.

3.5.1 Genetic Algorithm Parameters and Operations

The Genetic Algorithm is an optimization tool which is widely used in engineering problems. Most of the time, we use GA in problems that are non-linear or in problems that are very time consuming and difficult to solve. GA can help us to find the best solution without evaluating or searching for all possible answers. In other words, GA reduces the search space of the problem. The following briefly shows how GA works: First, some of the possible solutions are produced randomly. Each solution is called a chromosome. Also, these chromosomes constitute the population. Then, these chromosomes are evaluated based on the main goal of the problem. For example, in this thesis, we calculate voltages of the system and evaluate each solution according to the average value of all buses voltages. Now, we can sort the chromosomes of the population based on their fitness. To generate the next population (or change the current population intelligently) first we copy some chromosomes to other chromosomes with less fitness. This operation is called selection. Each chromosome has the chance to be copied but chromosomes with higher amount of fitness have more chance to be copied than others. In the next step, the mutation operation is applied. In this operation, some of the chromosomes are slightly changed. We should consider that the rate of this operation should be small, because if the rate of this operation is selected to be high, the GA may find the best solution and then go far from the best answer. Finally, the last operation called selection is applied. To apply this operation, two chromosomes should be selected and then genes of the selected chromosomes are shared which each other. These steps are performed repeatedly until the last iteration. The stopping criteria can be chosen based on the type of the problem. In some problems, the number of iterations is the stopping criterion. But in some problems the amount of the difference between calculated fitness's are considered. A sample of crossover and mutation operations are shown in Figure 3.4. Figure 3.5 shows the GA operation.

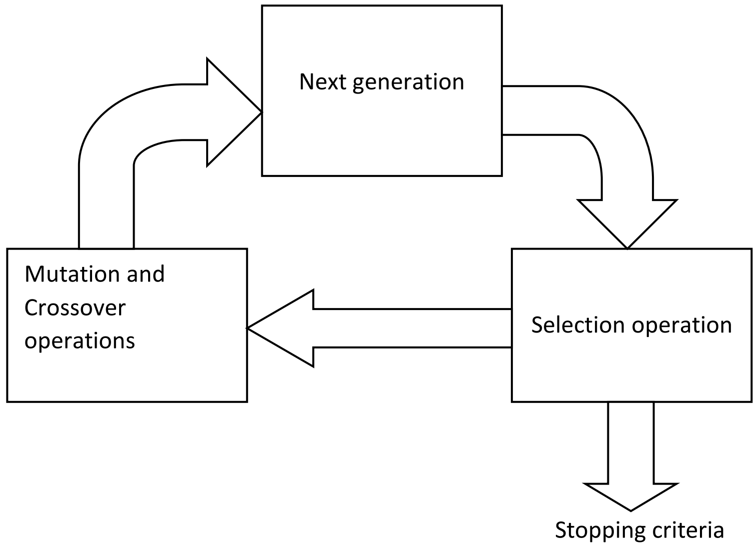

Figure 3.4: The Genetic Algorithm

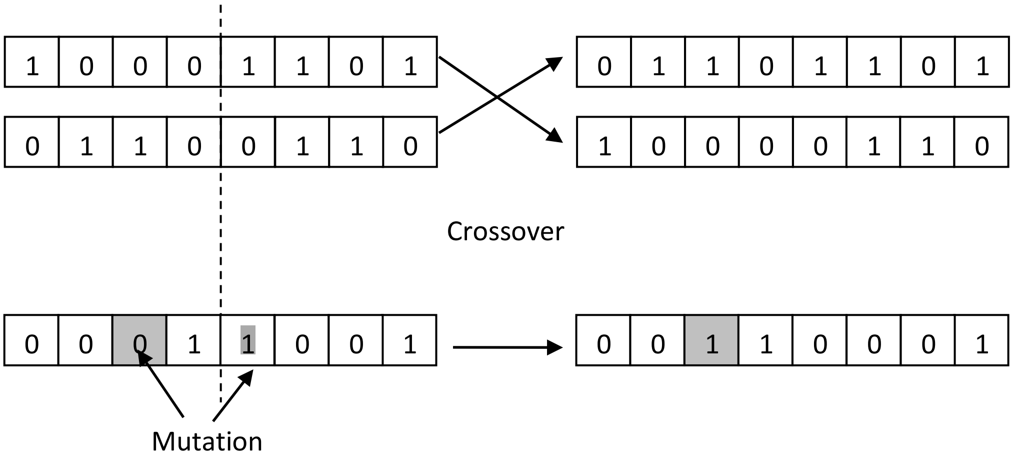

Figure 3.5: Samples of Mutation and Crossover operations

3.6 Application of the Genetic Algorithm to DG Placement

Generations in the Genetic Algorithm consist of various amounts of chromosomes. Each chromosome in our problem represents the number of DGs, number of the buses at which DGs should be installed and sizes of DGs. For example, one of the possible chromosomes is shown below:

Chromosome_i = [7 0 4 1 4 4 0 0 6 0 0 0 0 0 0 0 0 0 0 0 0 5 5 0 0 0 0 0 0 0 0 0 0];

The chromosome above is a 1x33 array (Jen). First element of the chromosome array determines how many DGs should be considered in the network. In this sample we use 7 DGs in the network. Also, most of the elements are zeros except the elements with indices (3, 4, 5, 6, 9, 22, 23). This shows that the 7 DGs should be installed at the buses with numbers 3, 4, 5, 6, 9, 22, 23.

In addition, a value is allocated to each non-zero element. For example, the value of element 3 is considered as 4. This shows that the size of the DG installed at this bus is 0.4 per unit (P.U.) and the size of the DG installed at bus no.4 is considered as 0.1 P.U.

In the rest of the algorithm, a load flow is performed to determine the bus voltages for this state. After that, an index (VI) is calculated. This chromosome will be evaluated based on its calculated index.

In the GA algorithm these chromosomes will be changed by different operations. As described before, in the selection operation, the best chromosome will be copied to some other chromosomes randomly. So, we have no new solutions after the selection operation.

Then, in the mutation operation, the sizes of the DGs used will be changed. Or even the numbers of the buses can be changed as well. Finally, in the crossover operation, some information of chromosome 1 is transferred to chromosome 2. After crossover is performed, we recall the load flow program for the new generation again and this will continue until the last iteration. In each iteration the best value of the VI is saved in a matrix, named Best_Values, and the best chromosome is saved in a matrix named Best_Co. After all iterations have been performed, the minimum element of the Best_Value matrix is considered as the best solution of the algorithm.

Chapter 4

RESULTS

4.1 Radial Distribution Network

In this type of a distribution system, there is only one main source to supply the branches. In each branch busses are placed. It is possible to use this system in rural or suburban areas. The real and reactive powers are specified at each bus. Generally the last bus in each branch is the weakest of the other buses. Therefore, the last bus can be considered as the best location to place the Distributed Generation, but we need to consider that one of the buses in the middle of each branch can also be the weakest bus because of the distribution of loads at the busses.

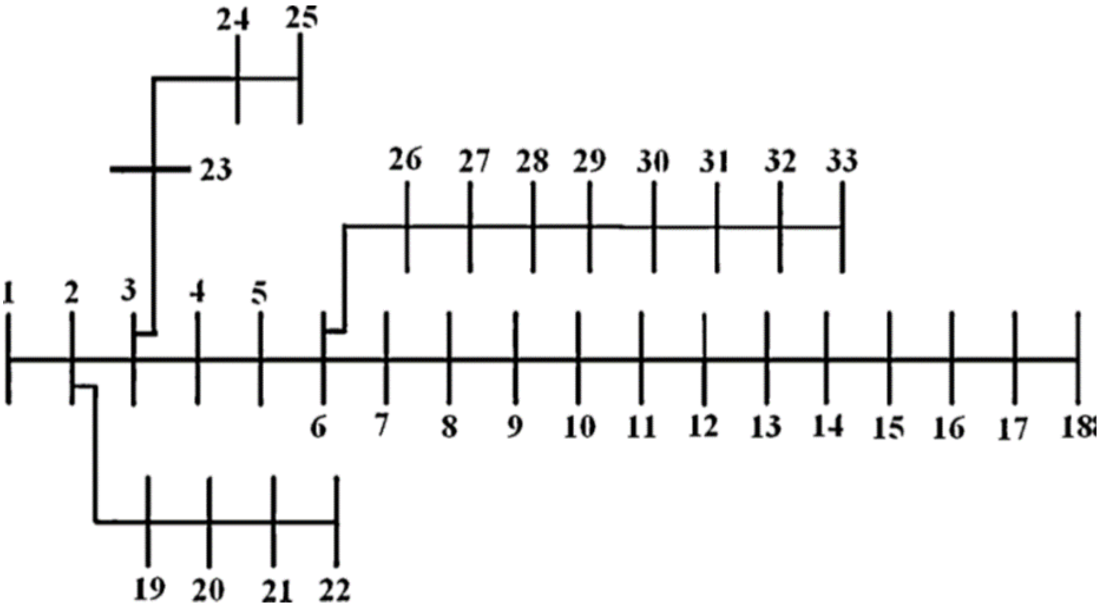

Figure 4.1: Single Line Diagram of the 33-Bus Radial Distribution Network

Table 4.1: Line Data of the Case Study

Line No	SE	RE	Resistance (Ω)	Reactance (Ω)	Line No	SE	RE	Resistance (Ω)	Reactance (Ω)
1	1	2	0.0922	0.0470	17	17	18	0.7320	0.5740
2	2	3	0.4930	0.2511	18	2	19	0.1640	0.1565
3	3	4	0.3660	0.1864	19	19	20	1.5042	1.3554
4	4	5	0.3811	0.1941	20	20	21	0.4095	0.4784
5	5	6	0.8190	0.7070	21	21	22	0.7089	0.9373
6	6	7	0.1872	0.6188	22	3	23	0.4512	0.3083
7	7	8	0.7114	0.2351	23	23	24	0.8980	0.7091
8	8	9	1.0300	0.7400	24	24	25	0.8960	0.7011
9	9	10	1.0440	0.7400	25	6	26	0.2030	0.1034
10	10	11	0.1966	0.0650	26	26	27	0.2842	0.1447
11	11	12	0.3744	0.1238	27	27	28	1.0590	0.9337
12	12	13	1.4680	1.1550	28	28	29	0.8042	0.7006
13	13	14	0.5416	0.7129	29	29	30	0.5075	0.2585
14	14	15	0.5910	0.5260	30	30	31	0.9744	0.9630
15	15	16	0.7463	0.5450	31	31	32	0.3105	0.3619
16	16	17	1.2890	1.7210	32	32	33	0.3410	0.5302

Table 4.2: Bus Data for

Bus No.	P_D (kW)	Q_D (kW)	Bus No	P_D (kW)	Q_D (kW)
2	100	60	18	90	40
3	90	40	19	90	40
4	120	80	20	90	40
5	60	30	21	90	40
6	60	20	22	90	40
7	200	100	23	90	50
8	200	100	24	420	200
9	60	20	25	420	200
10	60	20	26	60	25
11	45	30	27	60	25
12	60	35	28	60	20
13	60	35	29	120	70
14	120	80	30	200	600
15	60	10	31	150	70
16	60	20	32	210	100
17	60	20	32	60	40

4.2 DG Placement without Using the Genetic Algorithm

The results of the load flow (bus voltages) for this system without using DG are given

in Table 4-3.

Table 4.3: Bus Voltages without Using DG (In this Case Bus 18 is the Weakest Bus)

Bus Number	Voltage (PU)	Number of Bus	Voltage (PU)
1	1	18	1.26
2	0.96	19	0.95
3	0.81	20	0.89
4	0.77	21	0.87
5	0.75	22	0.86
6	0.82	23	0.76
7	0.89	24	0.69
8	0.92	25	0.67
9	0.98	26	0.82
10	1.05	27	0.82
11	1.06	28	0.88
12	1.07	29	0.92
13	1.15	30	0.94
14	1.18	31	0.98
15	1.2	32	0.99
16	1.22	33	1
17	1.25		

The VI for the basic state (system without DG), which is calculated by equation (3.7) is 0.9413. In Table 4-2 the VI index values calculated when the DG is placed at each bus successively are given. As mentioned in Chapter 3, the lower value of VI index is better. That means the bus voltages are totally near to 1 P.U. The results show that by using DG at bus number 18 we will have the best state. After that we can use DG at bus number 17.

Table 4.4: The Amount of VI Using DG for each Bus (Bus 18)

Number of Bus containing DG	VI Index	Number of Bus containing DG	VI Index
2	0.9405	18	0.8773
3	0.9382	19	0.9401
4	0.9372	20	0.9367
5	0.9366	21	0.936
6	0.935	22	0.9355
7	0.929	23	0.9388
8	0.9257	24	0.9435
9	0.9164	25	0.9482
10	0.9076	26	0.936
11	0.9067	27	0.9371
12	0.9051	28	0.9411
13	0.8941	29	0.943
14	0.889	30	0.9435
15	0.8858	31	0.9442
16	0.8831	32	0.9443
17	0.8782	33	0.9444

Figure 4.2 shows the differences between the bus voltages when we don’t use DG and when the DG is placed at bus number 18.

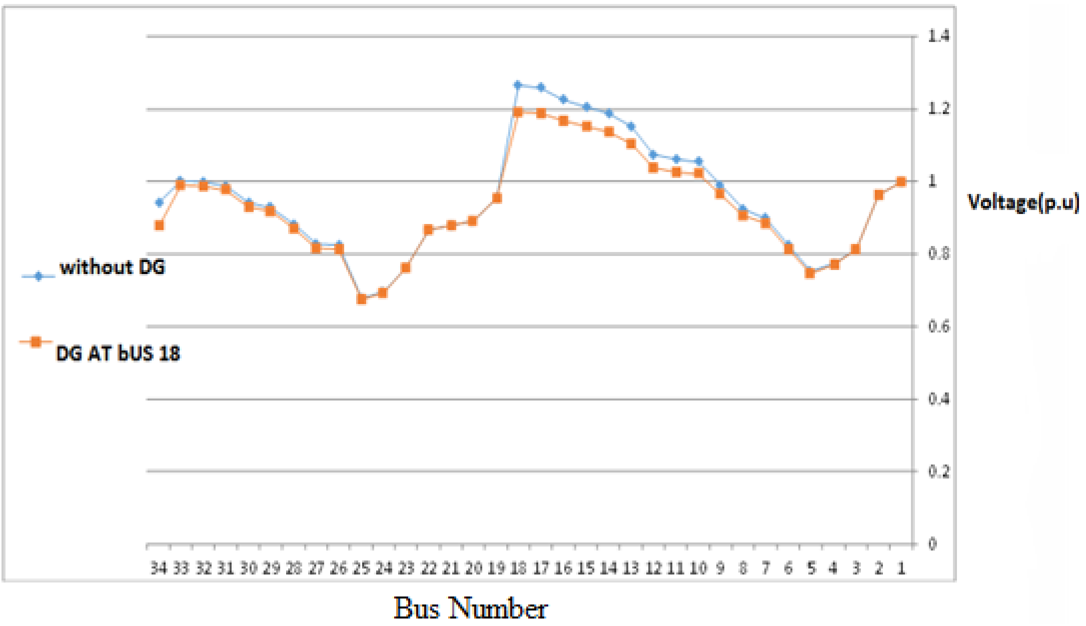

Figure 4.2: Differences Values between Buses with DG or without DG

In addition the VI values calculated for all buses with DG are shown in Figure 4-3. The results in Figure 4-3 shows that the best place for using DG is bus number 18; then buses 17 and 16.

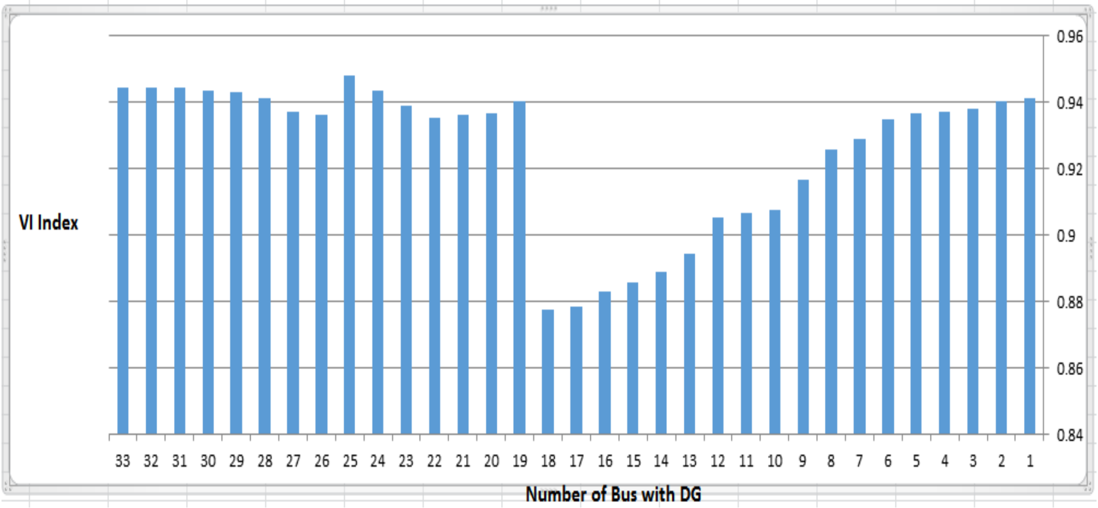

Figure 4.3: Best Place for DG Units at Bus 18

Table 4.5: Bus Data for different Loads (In this Case Bus 25 is the Weakest Bus)

Bus number	Real power	Reactive power	Bus number	Real power	Reactive power
2	100	60	19	90	40
3	90	40	20	90	40
4	120	80	21	90	40
5	60	30	22	90	40
6	60	20	23	90	50
7	50	25	24	420	200
8	50	25	25	420	200
9	25	15	26	200	150
10	50	15	27	200	125
11	45	15	28	200	120
12	50	15	29	200	170
13	50	15	30	200	80
14	25	10	31	250	170
15	15	10	32	200	150
16	25	20	33	250	140
17	25	15			
18	20	15			

Table 4.6: Voltage Index Values (Weakest Bus is 25)

Number of bus	Voltage Index	Number of bus	Voltage index
1	1	21	0.8794
2	0.9639	22	0.8683
3	0.8176	23	0.7686
4	0.7747	24	0.7049
5	0.7467	25	0.6870
6	0.8998	26	0.7919
7	0.8164	27	0.7975
8	0.8227	28	0.8814
9	0.8467	29	0.9469
10	0.8708	30	0.9671
11	0.8727	31	1.0293
12	0.8756	32	1.0437
13	0.8957	33	1.0544
14	0.9041		
15	0.9088		
16	0.9127		
17	0.9213		

18	09225
19	0.9547
20	0.8917

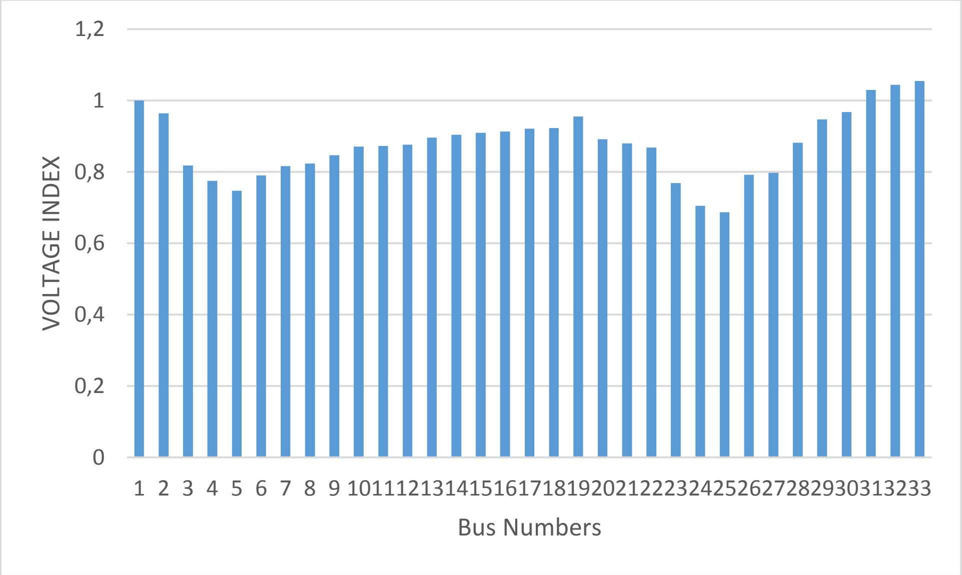

Figure 4.4: Best Place for DG Units at Bus 25

4.2.1 Discussion

The results of the first method show that in two different cases, buses 18 and 25 are the weakest buses in the radial distribution network with different bus data and they are the best locations for placing the distributed generations. After placing distributed generations we can improve the voltage index values by changing the size of the distributed generation. In this method we can choose just one DG with the constant size. It is obvious that distribution of load powers of the buses in each branch impact determine the weakest bus in that branch.

4.3 DG Placement Using the Genetic Algorithm

In this section, GA is used to solve the problem. Also, we consider the following parameters for the problem:

- The number of DGs is variable. We can use maximum 10 DGs in the network.

  (In previous section we assumed that we have just one DG).

- The sizes of DGs are variable as well. We consider sizes of DGs in steps of 0.1 to 1 P.U.
- The following parameters were chosen for GA:

POPULATION SIZE= 100;

Iteration=3000-10000

Pm= Probability of Mutation= 0.04

Pc= Probability of Cross Over= 0.8

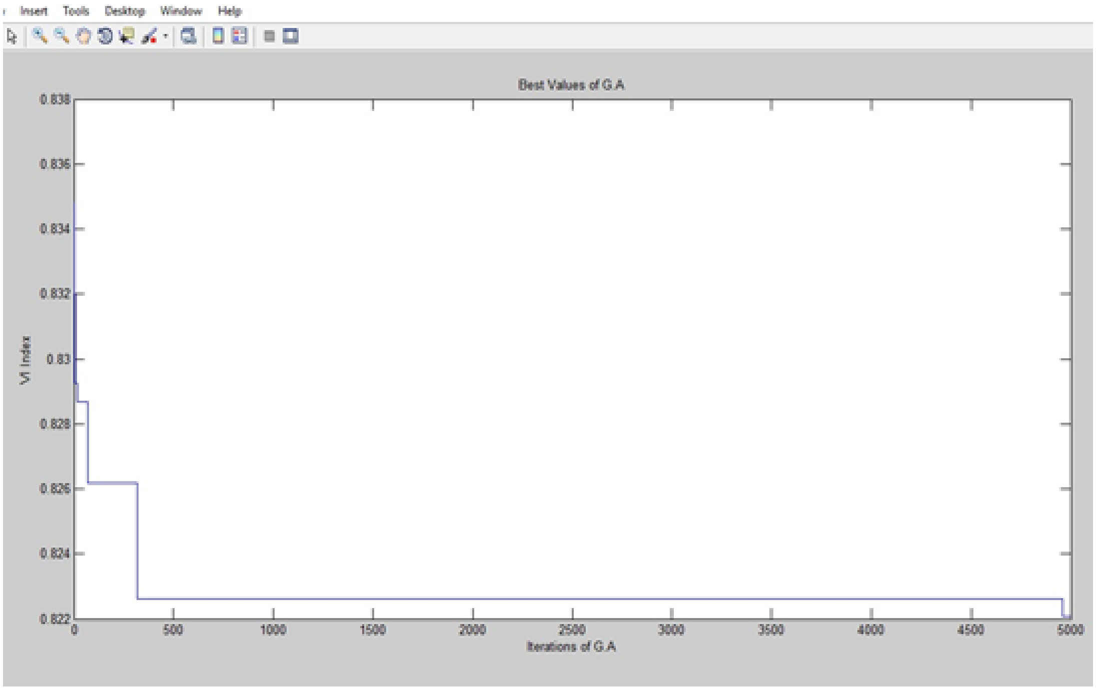

Figure 4.5: Answers of G.A

Figure 4-5 shows the best solution of GA in each iteration. GA is able to find better solutions with increasing number of iterations. For this problem, the best solution (the best value of VI) can be achieved after 5000 iterations. Also the parameters for the best solution are given in Table 4.7

Table 4.7: Size of DGs Used in the Network

Number of Bus	Size (MW.PU)	Number of Bus	Size (MW.PU)
1	0	18	0
2	0	19	0
3	0.4	20	0
4	0.1	21	0
5	0.4	22	0.5
6	0.4	23	0.5
7	0	24	0
8	0	25	0
9	0.6	26	0
10	0	27	0
11	0	28	0
12	0	29	0
13	0	30	0
14	0	31	0
15	0	32	0
16	0	33	0
17	0		

```
best_best = [7    0    4    1    4    4    0    0    6    0    0    0    0    0    0    0    0
0    0    0    0    5    5    0    0    0    0    0    0    0 0    0    0];
```

As the result shows, it’s better to use 7 DGs at buses with numbers 3, 4, 5, 6, 9, 22, 23. Also the size of the DG that should be used is different for each bus. For example for bus number 3, we should use DG with size 4*0.1=0.4 P.U. and so on. In Table 4-8 bus voltages for the best solution are given.

Table 4.8: Bus Voltages for Best Answer

Number of Bus	Voltage (PU)	Number of Bus	Voltage (PU)
1	1	18	1.03
2	0.97	19	0.96
3	0.87	20	0.89
4	0.87	21	0.88
5	0.88	22	0.87
6	0.90	23	0.80
7	0.86	24	0.68
8	0.89	25	0.63
9	0.91	26	0.92
10	0.94	27	0.95
11	0.95	28	1.06
12	0.96	29	1.15
13	0.99	30	1.21
14	1.00	31	1.24
15	1.0	32	1.24
16	1.02	33	1.24
17	1.029		

4.3.1 Discussion

In the GA method we can find the best locations for placing the distributed generations. Furthermore, we are able to choose the optimum number of distributed generations with different sizes at different bus locations. The GA algorithm is more complicated and time consuming compared with the first method. However, it is more general and flexible. It allows us to use variable numbers and sizes of DGs, whereas it is very difficult to apply the first method in such cases.

Chapter 5

CONCLUSION AND FUTURE STUDY

5.1 Conclusions

In this thesis the effect of Distribution Generation (DG) units on voltage stability of a network was investigated. First, the problem of DG placement was solved without using GA. In this case the size of DG was set to a constant amount and just one DG was used. The results have shown that bus no. 18 is the best place for DG to be installed to have the minimum VI.

In the next step, a Genetic Algorithm (GA) based optimization method was proposed to solve the problem due to its complexity and time consuming nature. By using GA, we were able to consider the number of DGs, size of each DG and best place of the DG units in the network. Also, an index, named VI, was proposed to evaluate the voltage stability of the network using a forward/backward load flow. The results have shown that using DG units on networks makes changes in the value of VI and improve the voltage stability of the system. Also, GA was able to find better solutions. To find the best solution 5000 iteration, considering 100 different states every time, was set as stopping criterion for the problem.

The standard 33 bus IEEE network was chosen as case study. The results have shown that the best solution is to use 7 DGs at bus numbers (3, 4, 5, 6, 9, 22, and 23). Also the sizes of DGs that should be used at different buses are 0.4, 0.1, 0.4, 0.4, 0.6, 0.5 and 0.5 P.U respectively.

5.2 Future study

In the following the possible future works of this thesis are given:

- In this study we have focused on DG unit's placement and impacts on voltage stability in the distribution network. According to other advantages of DG placement such as improving voltage profile, economic benefits, improving reliability of the system, reducing the losses of the system and environmental issues, it is possible to further investigate these problems.
- Moreover, in this thesis we used GA as an optimization algorithm to solve the problem. We suggest using other optimization algorithms such as Particle Swarm Optimization, Ant Colony etc. to solve the problem.

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APPENDIX

Appendix A: Matlab Codes

```
clc
clear all
%%%% Genetic Algorithm Parameters%%%%%
population_size=100;
jen=33;
pm=0.1;
pc=0.1;
ga_iteration=10;
ga_iter=1;
mutation_iter=0;
%%%% constant Parameters%%%%%
dg_size_base=10;
dg_number_max=10;
%%%% Genetic Algorithm %%%%%
for ga_iter=1:ga_iteration

   if ga_iter==1
   choromosom=zeros(population_size,jen);
for bb=1:population_size
ga_x=randint(1,1,[1,dg_number_max]);
```

```
ga_y=round(randperm(ga_x).*(jen/ga_x));
ga_z=randint(1,ga_x,[1,10]);


    choromosom(bb,1)=ga_x;
    for cc=1:ga_x
           choromosom(bb,ga_y(cc))=ga_z(cc);
    end
    choromosomi=choromosom(bb,:);
    [VI]=fittness(choromosomi);
    fitt(bb)=VI;
end
      [value num]=min(fitt);
      bestvalue(ga_iter)=value;
      bestco(ga_iter,:)=choromosom(num,:);
      ga_iter=ga_iter+1;
    else
%%%%%%%%%%%%selection%%%%%%%%%%%
x=randint(1,1,[0,5]);
y=randint(1,x,[1,population_size]);
 for bb=1:x
choromosom(y(x),:)=bestco(ga_iter-1,:);
 end
 %%%%%%%%mutation%%%%%%%%%%%%%
 for i=1:population_size/2
     if pm>rand
         mutation_iter=mutation_iter+1;
        ga_x=randint(1,1,[1,dg_number_max]);
```

```
        ga_y=round(randperm(ga_x).*(jen/ga_x));
        ga_z=randint(1,ga_x,[1,10]);
        choromosom(i,1)=ga_x;
        for cc=1:ga_x
          choromosom(i,ga_y(cc))=ga_z(cc);
        end
     end
 end
 for i=(population_size/2):population_size
     if pm>rand
         mutation_iter=mutation_iter+1;
         for hh=2:33
             if choromosom(i,hh)>0
                 choromosom(i,hh)= randint(1,1,[1,10]);
             end
         end
     end
 end
%%%%cross over%%%%%%%%%%%%
for nn=1:population_size
    for mm=nn+1:population_size
        if pc>rand
x=randint(1,1,[0,jen]);
for i=2:x
    choromosom_help(nn,i)=choromosom(nn,i);
    choromosom(nn,i)=choromosom(mm,i);
    choromosom(mm,i)=choromosom_help(nn,i);
```

```
end
        end
    end
end
for ll=1:population_size
    ee=0;
    for kk=2:jen
        if choromosom(ll,kk)>0
            ee=ee+1;
        end
    end
    choromosom(ll,1)=ee;
end
 %%%%%%%%%%%%fittness%%%%%%%%%%
 for bb=1:population_size
     choromosomi=choromosom(bb,:);
     [VI]=fittness(choromosomi);
     fitt(bb)=VI;
 end
    end
      [value num]=min(fitt);
      bestvalue(ga_iter)=value;
      bestco(ga_iter,:)=choromosom(num,:);
      ga_iter=ga_iter+1
end

function [VI] = fittness(choromosomi)
```

```
jen=33;

dg_size_base=10;

BD=[    1         0            0

        2         1           0.6

        3       0.9           0.4

        4       1.2           0.8

        5       0.6           0.3

        6       0.6           0.2

        7       2.00          1.00

        8       2.00          1.00

        9       0.60          0.2

        10       0.6          0.2

        11       0.45          0.3

        12       0.6          0.35

        13       0.6          0.35

        14       1.20          0.8

        15       0.6          0.1

        16       0.6          0.2

        17       0.6          0.2

        18       0.9          0.4

        19       0.9          0.4

        20       0.9          0.4

        21       0.9          0.4

        22       0.9          0.4

        23       0.9          0.5

        24       4.20          2.00

        25       4.20          2.00
```

```
     26      0.6         0.25
     27      0.6         0.25
     28      0.6         0.2
     29      1.20         0.7
     30      2.00         6.00
     31      1.50         0.7
     32      2.10         1.00
     33      0.6         0.4 ];
%    Inbus  Outbus Resistance(pu) Reactance(pu) ldata stands for
line data


LD=[1    1     2      0.0922        0.0470
   2    2     3      0.4930        0.2511
   3    3     4      0.3660        0.1864
   4    4     5      0.3811        0.1941
   5    5     6      0.8190        0.7070
   6    6     7      0.1872        0.6188
   7    7     8      0.7114        0.2351
   8    8     9      1.0300        0.7400
   9    9     10      1.0440        0.7400
   10    10    11      0.1966        0.0650
   11    11    12      0.3744        0.1238
   12    12    13      1.4680        1.155
   13    13    14      0.5416        0.7129
   14    14    15      0.5910        0.5260
   15    15    16      0.7463        0.5450
   16    16    17      1.2890        1.7210
   17    17    18      0.7320        0.5740
```

```
    18     2      19      0.1640         0.1565
    19     19      20      1.5042         1.3554
    20     20      21      0.4095         0.4784
    21    21      22      0.7089         0.9373
    22     3      23      0.4512         0.3083
    23     23      24      0.8980         0.7091
    24    24      25      0.8960         0.7011
    25     6      26      0.2030         0.1034
    26     26      27      0.2842         0.1447
    27     27      28      1.0590         0.9337
    28     28      29      0.8042         0.7006
    29     29      30      0.5075         0.2585
    30     30      31      0.9744         0.9630
    31     31      32      0.3105         0.3619
    32     32      33      0.3410         0.5302];

for i=2:jen
    if choromosomi(1,i)>0
    BD(choromosomi(1,i),2)=BD(choromosomi(1,i),2)-
((choromosomi(1,i)*(dg_size_base)/100));
    end
end
LD(:,4)=LD(:,4)/100;
LD(:,5)=LD(:,5)/100;
  F=LD(:,2:3);
M=max(LD(:,2:3));
N=max(M);
f=[1:N]';
```

```
for i=1:N
    g=find(F(:,:)==i);
    h(i)=length(g);
end
k(:,1)=f;
k(:,2)=h';
  cent=1;
% this section of the code is to adjust line data to the standard
  NLD=zeros(N,size(LD,2));
c=find(LD(:,2:3)==cent);
NLD=LD(c,:);
LD(c,:)=[];
t=find(k(:,1)==cent);
k(t,2)=k(t,2)-size(c,1);
j=size(c,1);
i=1;
while sum(k(:,2))>0
    c=[];
    b=[];
    t=[];
    [c e]=find(LD(:,2:3)==NLD(i,3));
    if size(c,2)~=0
        b=LD(c,:);
        LD(c,:)=[];
        t=find(k(:,1)==NLD(i,3));
        k(t,2)=k(t,2)-(size(c,1)+1);
        d=find(b(:,3)==NLD(i,3));
```

```
        b(d,2:3)=[b(d,3),b(d,2)];
        NLD(j+1:j+size(c,1),:)=b;
        j=j+size(c,1);
    end
    i=i+1;
end
LD=sortrows(NLD,3);
% end the data is represented in standard format
%code for  bus-injection to branch-current matrix
bibc=zeros(size(LD,1),size(LD,1));
for i=1:size(LD,1)
    if LD(i,2)==1
      bibc(LD(i,3)-1,LD(i,3)-1)=1;
    else
       bibc(:,LD(i,3)-1)=bibc(:,LD(i,2)-1);
       bibc(LD(i,3)-1,LD(i,3)-1)=1;
    end
end
S=complex(BD(:,2),BD(:,3));% complex power
Vo=ones(size(LD,1),1);% initial bus votage% 10 change to specific
data value
S(1)=[];
VB=Vo;
iteration=1000;
for i=1:iteration
     %backward sweep
    I=conj(S./VB);% injected current
    Z=complex(LD(:,4),LD(:,5));%branch impedance
```

```
    ZD=diag(Z);%makeing it diagonal
    IB=bibc*I;  %branch current
    %forward sweep
    TRX=bibc'*ZD*bibc;
    VB=Vo-TRX*I;
end
Vbus=[1;VB];
%display(Vbus);
%display(IB);
voltages=abs(Vbus);
VI=abs(sqrt(sum(Vbus.^2-1)));
```