A TECHNIQUE FOR OPTIMAL PLACEMENT OF DISTRIBUTED GENERATORS IN POWER SYSTEM NETWORKS

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A TECHNIQUE FOR OPTIMAL PLACEMENT OF DISTRIBUTED GENERATORS IN POWER SYSTEM NETWORKS

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ABSTRACT

The modern day societies are becoming more and more dependent on electrical energy. It is the most important part of our day to day life whose demand is increasing continuously. Even with today's advanced power system technologies the losses in the system are very high which are needed to be reduced for higher efficiencies and better receiving end voltages. This is experienced even more in distribution system where there is a direct impact on customer, owing to long radial lines. High *R/X* ratio of radial network further aggravates the issues. Infelicitous allocation of distributed generators in terms of its bus location may also lead to rise in fault currents, causes voltage variations, intervene in voltage-control processes, increase losses, system capital and operating costs etc. Optimal placement of distributed generators can address these issues significantly by reducing active power losses and enhancing voltage profile in a cost effective manner. Moreover, installation and placement of DG units is not straight-forward and need to be precisely alluded especially for load varying conditions with different variables like power loss, voltage profile, generation cost, load factor and reliability. A lot of complexity arises during optimization of these non-commensurable variables with different types of equality and inequality constraints.

In this research, multi-objective optimal placement problem is decomposed into minimization of total active power losses, maximization of qualitative bus voltage profile index enhancement and minimization of total generation cost of a power system network for static and probabilistic dynamic load characteristics with different network constraints. Optimum utilization factor for installed generators and available loads is scaled from the analysis of yearly load-demand curve of a network. The developed algorithm of *N*-bus system is implemented in IEEE-6 and IEEE-14 bus standard test system to demonstrate the effectiveness of the proposed methods in different loading conditions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABC	Artificial Bee Colony
AC	Alternating Current
ACOPF	Alternating Current Optimal Power Flow
AI	Artificial Intelligence
ANSI	American National Standards Institute
BBO	Biogeography Based Optimization
DE	Differential Evolution
DG	Distributed Generation
EPSO	Evolutionary Particle Swarm Optimization
GA	Genetic Algorithm
IC	Internal Combustion
IEEE	Institute of Electrical and Electronics Engineers
IPSO	Improved Particle Swarm Optimization
MATLAB	Matrix Laboratory
NBPSO	Binary Particle Swarm Optimization
NPI	Network Performance Index
OLTC	On-Load Tap Changer
PF	Power Flow
PSAT	Power System Analysis Toolbox
PSO	Particle Swarm Optimization
PV	Photo Voltaic
RCGA	Real-Coded Genetic Algorithm
RES	Renewable Energy Sources
SGA	Synthetic Genetic Array
SQP	Sequential Quadratic Programming
SSSC	Static Synchronous Series Compensator
STATCOM	Static Synchronous Compensator
THD	Total Harmonic Distortion

LIST OF SYMBOLS

B_{ik}	susceptance between the bus *i* and *k*
d	bus voltage deviation index
f	voltage quality factor
$F(x)$	objective function
F_{cost}	system generation cost function
F_{Loss}	system active power loss function
G_{ik}	conductance between the bus *i* and *k*
I_i	bus current of i^{th} bus
I_{ik}	thermal current through bus *i* and *k*
P_d	total active power demand
P_{DG}	distributed generator active power
P_i	injected real power
P_{Loss}	active power loss
P_{sys}	system active power
Q_d	total reactive power demand
Q_{DG}	distributed generator reactive power
Q_i	injected reactive power
Q_{Loss}	reactive power loss
Q_{sys}	system reactive power
R	circuit resistance value
S_i	total bus injected power
V_{Bus}	bus voltage index
V_i	bus voltage of i^{th} bus
X	circuit reactance value
Y_{ik}	admittance between the bus *i* and *k*
δ_{ik}	bus voltage angle between the bus *i* and *k*
θ_{ik}	admittance angle between the bus *i* and *k*

CHAPTER 1

INTRODUCTION

1.1 Introduction

The modern power distribution network is constantly being faced with an ever growing load demand, this increasing load is resulting into increased burden and reduction of voltage. The distribution network also has a typical feature that the voltage at nodes reduces during movement away from substation. This decrease in voltage is mainly due to inappropriate placement of new distributed generators. Even in certain industrial area critical loading, it may lead to voltage collapse. Thus to improve the voltage profile and to avoid voltage collapse optimal placement of distributed generators is required. The *R/X* ratio for distribution levels is low compared to transmission levels, causing high power losses and a drop in voltage magnitude along radial distribution lines [1-2]. It is well known that loss in a distribution networks are significantly high compared to that in a transmission networks. Such non-negligible losses have a direct impact on the financial issues and overall efficiency of distribution utilities. The need of improving the overall efficiency of power delivery has forced the power utilities to reduce the losses at distribution level. Many arrangements can be worked out to reduce these losses like optimal distributed generator placement, network reconfiguration, shunt capacitor placement for reactive power compensation etc. [3]. The distributed generators supply part of active power demand, thereby reducing the current and MVA in lines. Installation of distributed generators on distribution network will help in reducing energy losses, peak demand losses and improvement in the networks voltage profile, networks stability and power factor of the networks [4].

Optimization is a process by which we try to find out the best solution from set of available alternative. In Distributed generation (DG) allocation problem, DG locations must be optimized in such a way that it provides most economical, efficient, technically sound distribution system. Optimal placement of DGs is basically a complex combinatorial optimization issue which requires concurrent optimization of multiple objectives, for instance minimizations of real and reactive power losses, node voltage deviation, carbon emanation, line loading, and short circuit capacity and maximization of network reliability etc. The goal is to determine the optimal location of DG units in a distribution network.

The optimization is carried out under the constraints of maximum DG sizes, thermal limit of network branches, and voltage limit of the nodes [5]. In most of the planning models, the optimal distribution network is determined based on a deterministic load demand which is usually obtained from a load forecast. Also the placement of the DG units mainly the renewable energy sources placement, is affected by several factors such as wind speed, solar irradiation, environmental factors, geographical topography, political factors, etc [6]. The most essential uncertainty to account for the time-varying characteristics of both generation and demand of power are the increasing penetrations of different distributed generators at present load growth.

1.2 Literature Review

During the present years, demand for power has been increasing drastically. But the power generation stations and transmission system expansion is limited severely due to the limited availability of resources. DG has become a research topic for the past twenty years to mitigate the power generation crisis. Different researchers have proposed different ways for solving the problem of voltage improvement and loss minimization in distribution systems for optimal placement of Distributed Generation. In the recent past, much effort has been contributed to solving the optimal DG placement problem, utilizing different algorithms and considering different objectives. The DG placement problem could be formulated as an optimization problem. Various algorithms are used to solve the problem. The methods used to solve this problem are analytical, computational, artificial intelligence and some hybrid techniques.

Though the analytical methods suffer from many draw backs, they are still used in optimizing the location and size of DGs in distribution systems. This is because they are easy to work with and their logical analysis can easily be followed. Graham et al. applied loss sensitivity factor method based on the principle of linearization of the original nonlinear equation (loss equation) around the initial operating point, which helps to reduce the amount of solution space. Optimal placement of DG units is determined exclusively for the various distributed load profiles to minimize the total losses. They iteratively increased the size of DG unit at all buses and then calculated the losses; based on loss calculation they ranked the nodes. Top ranked nodes are selected for DG unit placement [7]. A comparative analysis of voltage control strategies in distribution networks with DGs is presented along with several voltage control strategies that incorporated existing voltage control devices and reactive power compensators with various degrees of integration where, results showed that the coordinated control strategy integrating distribution and generation plants was the most effective among the proposed control strategies and can provide an effective way to manage network voltage against DG penetration [8]. G. Naik et al. presented a simple method for real power loss reduction, voltage profile improvement and substation capacity release. The proposed method was based on voltage sensitivity index analysis and power flow analysis which was done using the forward-backward sweep method. The forward-backward sweep based algorithm had the advantage of low memory requirements, computational efficiency and robust convergence characteristic [9]. L. I. Dulua et al. presented a way to reduce power loss of distribution networks with DG using mathematical approach. The proposed method was based on power loss index analysis and load flow analysis which was done using the newton-raphson extended method. The optimization is performed for two cases: when the distributed generator is connected to the system, and when the distributed generator is not connected to the system. In the research paper, IEEE-5 bus system was shown analytically based on the minimization of the network power losses at minimum cost [10].

Another class of techniques used for optimizing the location and size of DGs in a power system is the computational methods. Though these methods are fast compared to the other classes of techniques their drawback is that they are complex and reproduction of their results may be difficult or sometimes impossible. W. El-khattam et al. used a heuristic iterative search method to minimize the cost of investment and operation of DGs, loss and energy required by customers to minimize DG investment, operation losses and energy purchased from the main grid [11]. An D.T. Le et al. addressed the issue of optimizing DG planning in terms of DG size and location to reduce the amount of line losses in the distribution networks. Their optimization methodology, which was based on the sequential quadratic programming (SQP) algorithm, assessed the compatibility of different generation schemes upon the level of power loss reduction and DG cost [12]. A. Yadev et al. presented a way to reduce power loss and improvement of voltage profile in a distribution networks with DG using computational approach. This paper also discusses the key issues related to optimal placement and size of distributed generation [13].

The analytical and the computational optimization methods are being phased out by the most promising artificial intelligence (AI) methods. This is because among other benefits the artificial intelligence techniques are not gradient based and thus are not prone to being trapped in local minimum. The results from the artificial intelligence optimization algorithms are also easily reproducible. Genetic Algorithm (GA) being one of the most common artificial intelligence optimization techniques has been used in several literatures. GA has been used by several authors to optimize the location and size of DGs in power systems [14-15]. Particle swarm optimization (PSO) techniques have also been used in several literatures by different authors in the optimization of DG location and size in a power system with the aim of reducing system power losses and improving voltage profile [16-18]. Researchers have come up with several hybrids incorporating different optimization techniques. The most common hybrids are those combining an artificial intelligence method to another artificial intelligence technique or to either an analytical or computational method. From the literature given here it will be clear that most of the hybridization result to better solutions than either of the methods if considered separately [19-22]. L. I. Dulua described the optimal location of a 2.3 MW DG in a IEEE 14 bus test system based on the power losses. The DG optimal location is determined considering the power losses at each bus where the DG is connected. The power losses at each bus will be determined with the Neplan software, using the newton-raphson extended method [23]. N. Singh et al. focuses on testing various indices and using effective techniques for the optimal placement and sizing of the DG unit by minimizing power losses and voltage deviation. A 33-bus radial distribution system has been taken as the test system. The feasibility of the work lies on the fast execution of the programs as it is equipped with the real time operation of the distribution system and it is found that execution of the DG placement is quite fast and feasible with the optimization techniques used in this work [24]. W. S. Warid et al. proposed a sensitivity-based methodology is for the optimum placement of different types of DG unit in meshed power systems. A high correlation is reported between the sorting based on each loss sensitivity and sorting estimated according to the loss reduction rates obtained by placing the relevant type of DG. Consequently, these sensitivities are considered credible indicators for the placement of DG types. Reliable and realistic results are achieved by incorporating the sorting based on loss sensitivities and the ranking based on the effectiveness in loss reduction obtained by allocating three common types and frequently used sizes of DG units [25].

DG technologies under smart grid concept forms the backbone of today’s world electric distribution networks [26]. These DG technologies are classified renewable energy sources (RES) and fossil fuel-based sources. RES based DGs are wind turbines, photovoltaic, biomass, geothermal, small hydro, etc. Fossil fuel based DGs are the internal combustion (IC) engines, combustion turbines and fuel cells [27]. Environmental, economic and technical factors have a huge role in DG development. Presence of DG in distribution networks is a momentous challenge in terms of technical and safety issues [28]. Evaluation of the technical impacts of DG in the power networks is very critical and laborious work. Thus, the generators are needed to be connected in distributed systems in such a manner that it avoids degradation of power quality and reliability. Inadequate allocation of DG in terms of its location and capacity may lead to increase in fault currents, causes voltage variations, interfere in voltage-control processes, diminish or increase active power losses, increase system capital and operating costs, etc. [29-30]. In most of the techniques generation cost is ignored, voltage quality has no impact during optimization and only time-invariant loads are considered while ensuring optimal placement. Moreover, installing DG units is not straightforward, and thus the placement of DG units should be carefully addressed with all its factor specially for load varying conditions. Investigation of this optimization problem is the major motivation of the present research.

1.3. Thesis Objective

The objective of the research work is to develop a technique for optimal placement of distributed generators in power system network to minimize the power losses and maximize the enhancement of the bus voltage profile in a cost effective manner for time-invariant and time-variant loads.

1.4. Thesis Outcome

The outcome of the research work is a technique that ensures minimization of power losses and maximization of bus voltage profile improvement at minimum generation cost for time-invariant as well as time-variant loads through optimal placement of distributed generators in power system networks.

1.5. Thesis Outlines

The research carried out in this report has been summarized in five chapters:

Chapter 1 introduces to the research study, motivation, objectives including system active power loss reduction phenomenon, voltage profile improvement and cost minimization aspects with recent literature review and the outline of the research is also given in this chapter.

Chapter 2 highlights the distribution network structure of the DG including its definition, different types, benefits and impacts on the power system network to mitigate the effect of power loss reduction and poor voltage profile.

Chapter 3 dwells on problem formulation of the multi-objective function of this research and explains the load flow technique using gauss-seidal iteration method in detail giving it parameters, implementation steps and flow charts to find out the optimal location for DG placement.

Chapter 4 briefly describes how to identify the candidate nodes for distributed generator placement, objective function for overall loss minimization, voltage profile maximization in a cost effective manner of distribute networks finding results and discussion pertaining to various test cases.

The conclusions made from the results obtained and the beneficiaries of the research work including the recommendations made for furthering this research work are detailed in **Chapter 5**.

CHAPTER 2

DISTRIBUTED GENERATION: AN OVERVIEW

2.1 Introduction

The objective of power system operation is to meet the demand at all the locations within the power network as economically and reliably as possible. The traditional electric power generation systems utilize the conventional energy resources, such as fossil fuels, hydro, nuclear etc. for electricity generation. The operation of such traditional generation systems is based on centralized control utility generators, delivering power through an extensive transmission and distribution system, to meet the given demands of widely dispersed users. Nowadays, the justification for the large central-station plants is weakening due to depleting conventional resources, increased transmission and distribution costs, deregulation trends, heightened environmental concerns, and technological advancements. Distribution system provides a final link between the high voltage transmission system and the consumers. A radial distribution system has main feeders and lateral distributors. The main feeder originates from substation and passes through different consumer loads. Laterals are connected to individual loads [31]. Generally radial distribution systems are used because of their simplicity. Power loss in a distribution system is high because of low voltage and hence high current.

2.2 DG Definition

DG is a new approach in the power industry. In fact, it is so new, neither a standard definition nor a standard name for it have been agreed upon. Nevertheless, various definitions and names have been used in the literature. Some researchers define DG by rating DG units, whereas others define DG in terms of the technology used. DG also appears under different names, depending on the country. For instance, in some parts of North America, the term Dispersed Generation is used, while in South America, Embedded Generation has been coined. Meanwhile, in Europe and some Asian countries, DG stands for Decentralized Generation. After studying and analyzing several research papers a generalize definition for DG, suggesting that the most appropriate definition would be “an electric power source connected directly to the distribution network or on the customer site of the meter” [3]. However, this definition does not mention any capacity criterion or the technologies used to build and run these sources. Therefore, two additional categories are suggested in classifying as well as defining DG. The first category classifies DG based on its capacity, and the second category classifies DG based on its technology.

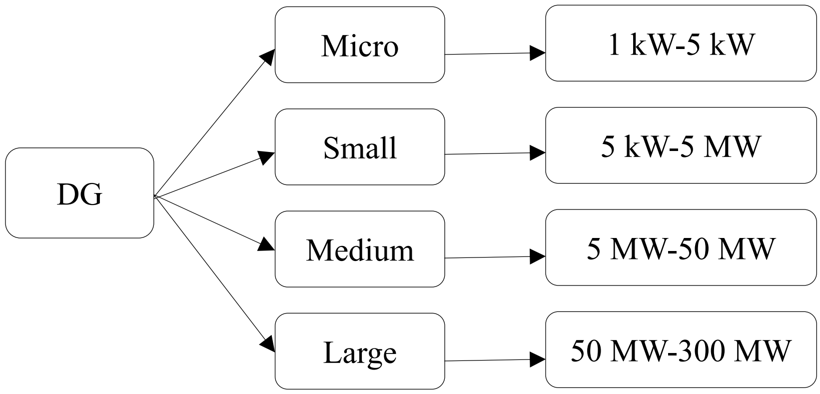

Fig. 2.1: DG based on capacity

2.2.1 DG based on capacity

Regarding to the capacity of DG units, there are different definitions for the generation size range according to some institutes and literatures is depicted in Fig. 2.1 [3]. However, the rating definitions of DG units are also depending on the governmental legislation.

2.2.2 DG based on technology

In the literatures the researchers classifying the DG technologies and types based on different related issues, such as generation type, energy source, fuel type, combustion, and generation model. These issues and their related DG is depicted in Fig. 2.2 [11]. Some major DG technologies will be briefly discussed as follows:

2.2.2.1 Photovoltaic

Photovoltaic (PV) is a technology converting solar radiation into electrical energy. PV cell consists of two or more thin layers of semi-conductor material, mostly commonly silicon. When the silicon is exposed to light afterwards electrical charges are generated as a direct current. PV equipment has no moving parts and as a result requires minimal maintenance. It generates electricity without producing emissions of greenhouse gases [32].

2.2.2.2 Wind turbine

Wind energy is not a new form; it has been used for several decades. A wind turbine consists of a rotor, turbine blades, generator, drive or coupling device, shaft, and the nacelle (the turbine head) that contains the gearbox and the generator drive. Modern wind turbines can provide clean electricity as individuals or as wind farms.

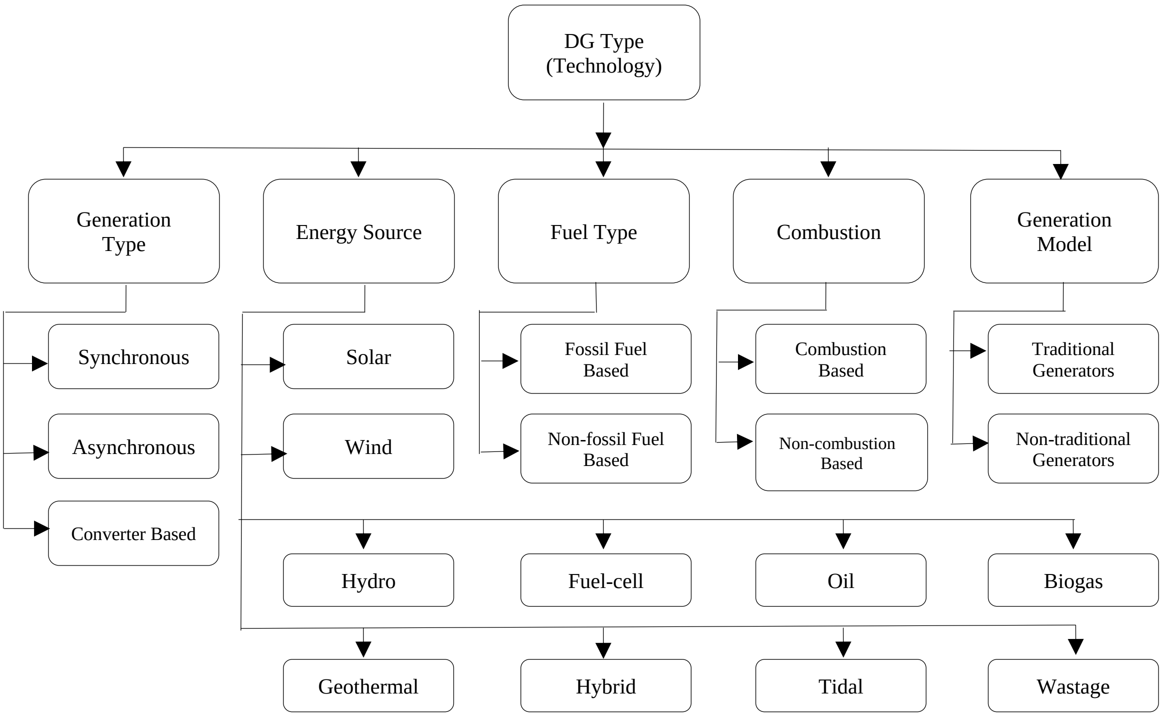

Fig. 2.2: DG based on technology

2.2.2.3 Reciprocating engines

Reciprocating engines are ones in which pistons move back and forth in cylinders. Reciprocating engines are a subset of internal combustion engines, which also include rotary engines. Smaller engines are primarily designed for transportation and can be converted to power generation with little modification. For DG applications, reciprocating engines offer low costs and good efficiency, but the maintenance requirements are high, and diesel-fueled units have high emissions.

2.2.2.4 Micro turbines

Simple micro turbines consist of a compressor, combustor, turbine and generator. The compressors and turbines are typically radial-flow designs, and resemble automotive engine turbochargers. Most designs are single-shaft and use a high-speed permanent magnet generator producing variable voltage, variable frequency alternating current (AC) power. An inverter is employed to produce 50 Hz AC power. Most micro turbine units are currently designed for continuous-duty operation and are recuperated to obtain higher electric efficiencies.

2.2.2.5 Fuel cell

Fuel cells are systems where electricity and heat are generated by electrochemical combination of hydrogen and oxygen where water is generated as a 'waste' product. The FC thus is a system capable of producing electricity without any mechanical process, resulting in higher efficiencies than regular thermo-mechanical systems and quieter operation [33].

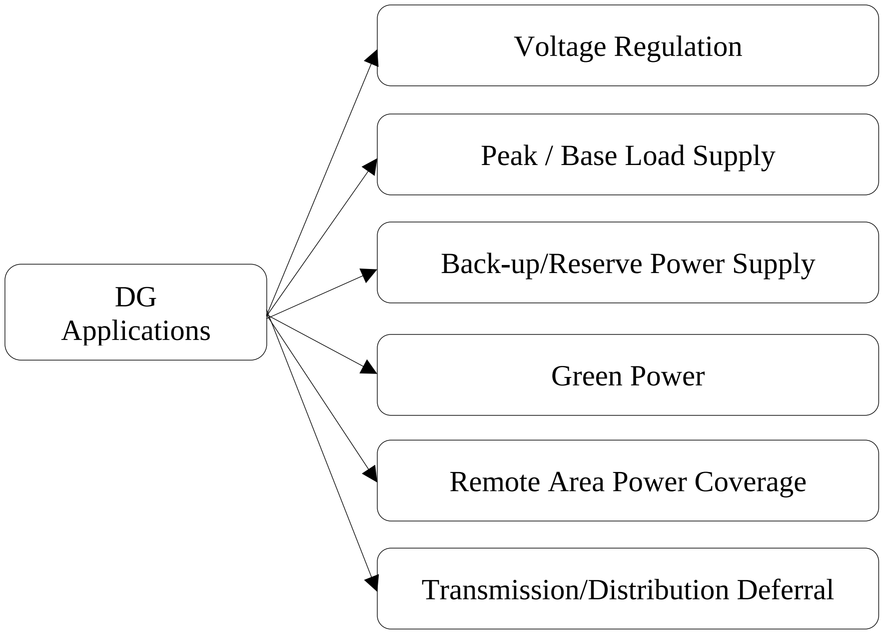

Fig. 2.3: DG in different applications

2.3 Applications of DG

There are many different potential applications of DG technologies; for example, some customers use DG to reduce demand charges imposed by their electric utility, while others use it to provide primary backup power or reduce environmental emissions. DG can also be used by electric utilities to enhance their distribution systems. Fig. 2.3 shows a list of those of potential interest to electric utilities and their customers [34].

2.4 Impacts of DG on Distribution Networks

As the penetration of DG into the grid is high, the supplied power from DG units will not only affect the power flow in the distribution network, but also the whole transmission network. Therefore, the interconnection of DG to the grid may have different implications on the distribution network [35]. In this section, different impacts in Fig. 2.4 of DG integration on power distribution network is discussed [36].

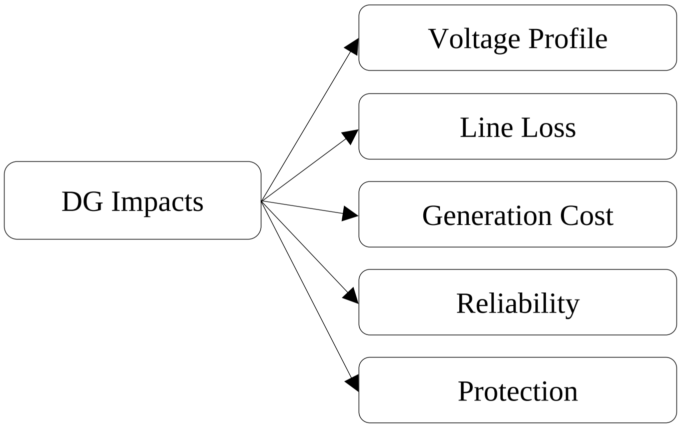

Fig. 2.4: DG impacts on distribution networks

2.4.1 Voltage profiles

Voltage profile is extremely important for the end users because it's a basic demand for electrical equipment's running near the rated voltage. DG can provide voltage support to raise the voltage at the end of the feeder. The impact of DG on the voltage profile can be positive or negative depending mainly on the type of DG, amount of power DG supplies back to the system, its location and distribution network characteristics [37-38]. With the existence of DG units in distribution networks, the following methods can be used for maintaining the proper voltage profiles [39]:

- Reinforcement of the network,
- DG reactive power control,
- DG active power control,
- Installation of voltage regulators,
- Use of compensators.

Based on the previous methods, different control strategies have been reported in the literatures. For example, in [40] a coordination between the on-load tap changer (OLTC), switched capacitors at substation, switched capacitor at feeder, and synchronous machine based DG is used for voltage and reactive power control in a distribution network. In [41] the voltage regulation of distribution systems is addressed with the presence of DG. The OLTC voltage set-point is modified based on a command governor approach to determine the OLTC voltage reference that allows the fulfillment of prescribed operating constraints despite the occurrence of adverse conditions.

2.4.2 Power/Energy losses

It is obvious that the network losses depend on the power flow of the system. As DG is integrated, it has an impact on the power flow of the distribution network; the losses of such network will be in turn affected as well. Different studies are presented in the literatures for providing how the influence of DG interconnection on the system losses is. The impact of different DG technologies, penetration, and concentration levels on the energy losses of distribution networks based on different load flow methodologies was investigated in some of the research [42]. A sensitivity based methodology is also presented for evaluation the influence of DG integration on the power loss. The evaluation process is conducted for different penetration levels, different numbers of DG units, and different operating modes of DG.

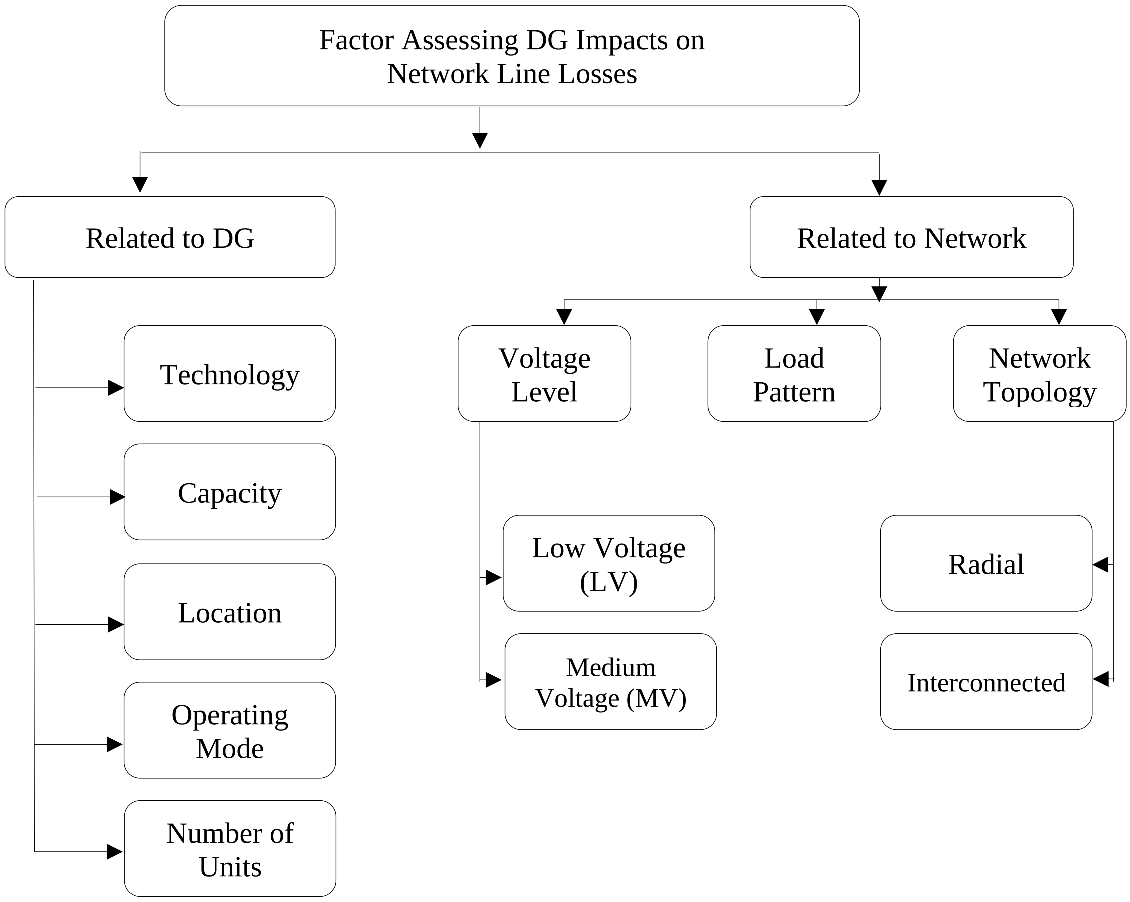

Fig. 2.5: Different factors assessing the DG impact on power/energy losses

Some researchers also investigated the impact of DG units on the power loss using three phase models for all the components in the distribution network including the DG unit. Based on the previous studies in this area [43-44] it can be concluded that the impact of

DG on power/energy loss can be positive or negative. Moreover, this influence depends on different factors. These factors can be broken into two groups which is depicted in Fig. 2.5 [45]. The first group is related to the DG unit itself and the second group is related to the distribution network where the DG is intended to be interconnected.

2.4.3 System generation cost

Energy costs are a major factor in today's business landscape whether you are running a hotel or managing an industrial facility. Equipment and processes are becoming more energy-intensive, and energy costs themselves are rising at record rates. You need to make sure that you don't impact productivity or customer satisfaction, but the cost of energy is a growing challenge in your ability to meet these needs. Whenever DG is integrated, it has an impact on the total cost on basis of the type of DG. This total cost of the system is related with the running cost and instalment cost of DG.

2.4.4 Reliability

A widely accepted definition for reliability involved two elements: adequacy, the ability to satisfy market demand at all times, and security, the ability to withstand sudden disturbances such as short circuits or unanticipated loss of system elements [46]. If the DG unit is used as a standby power supply, therefore it can enhance the power supply system reliability. However, if there is a parallel operation between DG and power network, the reliability of power supply system is possible to be weakened. There are several ways where DG can improve the reliability of the distribution networks such as [47]:

- Aggregating backup assets for sale to grid.
- Utility provision of premium power.
- Adding generation capacity at the customer site for continuous power and backup supply.
- Freeing up additional system generation, transmission and distribution capacity.
- Relieve transmission and distribution bottlenecks.
- Supporting power system maintenance or restoration operations with generation of temporary backup power.

2.4.5 Power quality

Power quality is identified in a quite different way, depending on one's frame of reference. The utility may define power quality as reliability of its system. A manufacturer of load equipment may define power quality as those characteristics of the power supply that enable the equipment to work properly. As the DG is introduced the distribution networks an interaction between the power quality problem caused by the DG itself and power quality problems come from the distribution network and affect the DG unit. The main power quality issues affected by DG are [48]:

- **Sustained interruptions:** Many generators are designed to provide backup power to the load in case of power interruption. However, DG has the potential to increase the number of interruptions in some cases.
- **Voltage regulation:** This is the most limiting factor for how much DG can be accommodated on a distribution feeder without making changes.
- **Harmonics:** There are harmonics concern with both rotating machines and inverters, although concern with inverters is less with modern technologies.
- **Voltage sags:** This is a special case because DG may or may not affect.
- **Voltage flickers:** Voltage flicker is the rapid and repetitive change of voltage that causes visible fluctuations in the light output. Generally, flicker can be caused by load fluctuations as well as source fluctuations. DG units have the potential to cause unwanted fluctuations and cause noticeable voltage flicker in the local power grid. Step changes in the outputs of the DG units with frequent fluctuations and the interaction between DG and the voltage controlling devices in the feeder can result in noticeable lighting flicker [49].

2.4.6 Distribution System Protection

The distribution networks are traditionally designed to be operated in radial where the power flows in unidirectional. As the DG units are integrated into the network, it will be converted from simple systems into complex networks, which needs essential modifications in protection systems. Different typical feeder protection problems, which can be raised by integration of high penetration level of DG, can be stated as follows:

- Change of the short circuit current level.
- Fast tripping of feeders.
- Preventing the operation of feeder protection.
- Unwanted islanding.

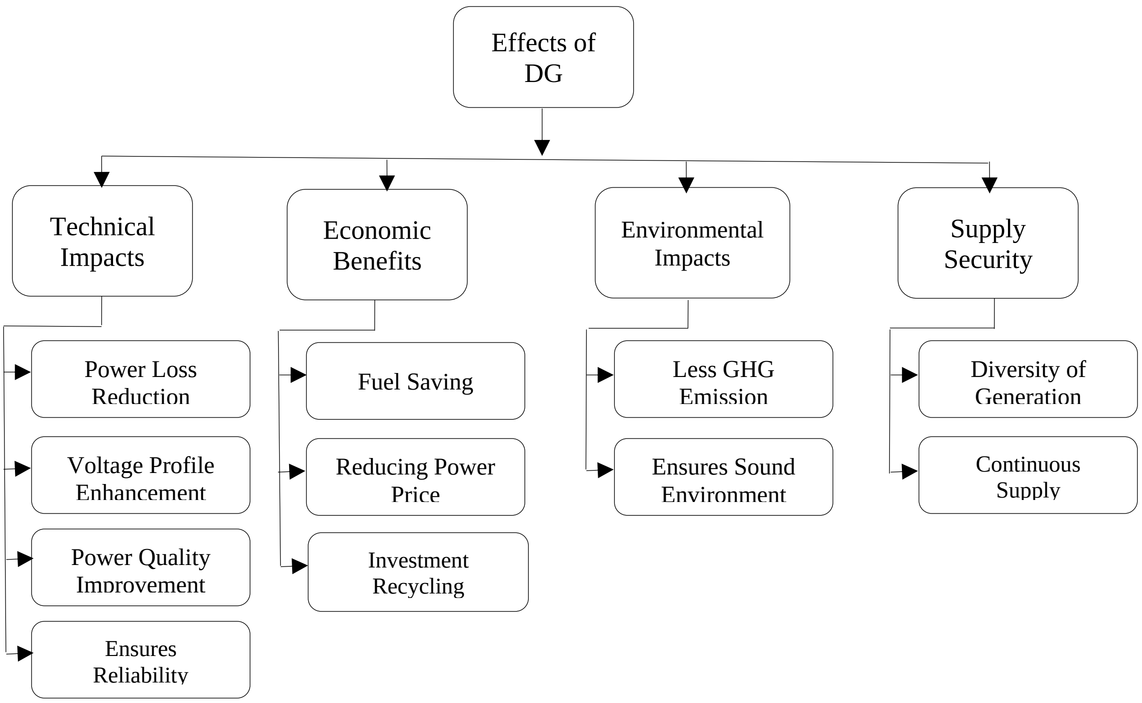

Fig. 2.6: Effects of DG in power system network

2.5 Effects of DG

Invaluable benefits can be drawn through the interconnection of DG units into electric power networks. An overview on these benefits is depicted in Fig. 2.6 [50]. The benefits of DG can be broken as follows:

2.5.1 Economic benefits

By integrating the DG units closer to the customer, a potential for avoidance or deferral of the need for building new transmission and distribution lines, upgrade the existing power supply system and reduce transmission and distribution capacity during network planning can be exist. Thus, DG can be a least-cost planning alternative. Some economic benefits of DG can be discussed as follows:

- DGs can be assembled easily anywhere as modules which have different advantages as they can be installed in a very short period at any location. Each module can be operated immediately and separately after its installation independent of other modules arrival and not affected by other module operation failure.
- Total capacity of DG can be increased or decreased by adding or removing more modules, respectively.

- DGs are not restricted by the centralization of the power as they can be placed anywhere. Thus, DG location flexibility has a great effect on energy prices. However, renewable DGs technology such as hydro, wind, and solar units require certain geographical conditions.
- DGs are well sized to be installed in small increments to provide the exact required customer load demand.
- Some DG technologies provide cogeneration possibilities, which allow site recovery of heat and / or hot water. This has the potential to rise up the energy efficiency to around 90%. In rural villages, the recovered heat can be used for hot water, space heating, industrial processes and even space cooling [50].
- DGs can reduce the wholesale power price by supplying power to the grid, which leads to reduction of the demand required.
- Due to deregulation DG will have a great importance in generating power locally especially if the location margin pricing is applied for independent transmission operators and regional transmission organizations. Location margin pricing can give an indication of where DG should be installed.
- DG increase the system equipment’s lifetimes and provide fuel savings.
- Installing DG reduce the construction schedules of developing plants. Hence, the system can track and follow the market’s fluctuations and/or the peak load-demand growth.
- Depending on the nature of fuel used, electricity prices are often lower than power from central plants.
- General uncertainty in electricity markets favors small generation schemes. One of the acknowledged consequences of the introduction in competition and choice in electricity is the increased risk faced by all receivers in the electricity supply chain from generators through transmission and distribution businesses to retailers. It is well known that the capital outlay required to establish new power stations can be very high.
- DG helps to resolve load pocket problems when load grows but transmission lines cannot feasibly be added. DGs benefits are maximized when DG is located in congested areas to relieve congestion.

- DG decreases the overall costs of producing, delivering power and promotes the development and wider use of renewable energy, which can improve the environment and offers new jobs.

2.5.2 Technical impacts

DG can provide different technical benefits based on different factors, e.g. location and technology. The following are some of the technical benefits [51]:

- Improving availability and reliability of the power supplying network
- Voltage support and improved power quality.
- Power-loss reduction.
- Reduce power flow inside the transmission network to fit certain constraints and improve its voltage profile.
- DGs can help in “peak load saving” and load management programs,
- DGs capacities vary from micro to large size so they can be installed on medium and/or low voltage distribution network which give flexibility for sizing and sitting of DGs into the distribution network.
- Other benefits of DG include providing ancillary services, and adding self-generation to customer options.
- DG could prove invaluable for developing countries. Thus, micro power is an attractive option for those countries. DG such as grid-free renewable may be particularly suitable for remote areas.

2.5.3 Environmental impacts

Electric power generation is responsible for about 40% of carbon dioxide emissions, a primary contributor to climate change. In principle, we now have the chance to modify not only the way we supply power but also, at least in significant part, the way we humans successfully restore our and the other critters’ environment. Recent DG technologies offer an environmentally source of electrical energy through limiting the greenhouse gas emissions. By 2050, a widespread installation of micro generation could reduce the household carbon emissions by approximately 15% [52]. Also, avoidance of the construction of new transmission circuits and large generating plants are also important environmental benefits.

2.5.4 Supply security impacts

DG can provide additional benefits regarding the security of supply which can be divided into two categories, energy security and system security. The term security of supply can be briefly described as the provision of an electricity supply that is continuous and of a defined quality (in terms of voltage and frequency). By introducing a higher number of smaller generators into the generation mix, the significance of individual larger power stations to security of supply is reduced and the ability of system operators to avoid system wide black out in the face of the loss of a number of generators should be enhanced. All varieties of renewable energy offer positive benefits to security of supply in this case they do not rely on imported primary fuel. An active distribution system should increase security of supply to local loads. Micro generation and micro combined heat and power in particular can reduce peak demand and can therefore reduce the overall stress on the transmission and distribution systems. In this way, micro generation can contribute towards security of supply.

2.6. Conclusion

This chapter reviews the definition of distributed generation as proffered by different bodies and authors in the field of electrical power system. It also gives detailed information about DG technologies that are available and the general benefits. The types of DG discussed above, as well as the advantages they offer and their technical impacts, will help to mitigate the effect of power loss reduction and poor voltage profile. The next chapter dwells on problem formulation of the multi-objective function of this research and explains the load flow technique using gauss-seidal iteration method in detail giving it parameters, implementation steps and flow charts to find out the optimal location for DG placement.

CHAPTER 3

DG OPTIMIZATION PROCESS

3.1 Introduction

The load flow of a power system gives the unfaltering state result through which different parameters of investment like currents, voltages, losses and so on can be figured. The load flow will be imperative for the investigation of distribution networks, to research the issues identified with planning, outline and the operation and control. A few provisions like ideal distributed generation placement in distribution networks and distribution automation networks, obliges rehashed load flow result. Numerous systems such gauss-seidal, newton-raphson are generally appeared for convey the load flow of transmission networks. The utilization of these systems for distribution networks may not be worthwhile in light of the fact that they will be generally focused around the general meshed topology of a normal transmission networks although most distribution networks structure are likely in tree, radial or weakly meshed in nature. R/X ratio of distribution networks is high respect to transmission system, which cause the distribution networks to be badly molded for ordinary load flow techniques [53]. Some other inborn aspects of electric distribution networks are like radial or weakly meshed structure, unbalanced operation and unbalanced distributed loads, large number of nodes and branches and has wide range of resistance and reactance values with distribution networks has multiphase operation. The effectiveness of the optimization problem of distribution networks relies on upon the load flow algorithm on the grounds that load flow result need to run for ordinarily. Thusly, the load flow result of distribution networks ought to have accuracy and time proficient qualities. A technique which can discover the load flow result of radial distribution networks specifically by utilizing topological normal for distribution system is utilized. In this strategy, the plan of tedious Jacobean matrix or admittance matrix, which are needed in customary techniques, is stayed away from [54-55].

3.2 DG Optimization Approach

The inclusion of DG to the distributed network may influence the stability of the power system, i.e., angle, frequency, and voltage stability. It may have an impact on the protection selectivity, and the frequency and voltage control of the system. Inappropriate selection of location and size of DG may increase system losses. By optimum allocation of DGs, utilities take advantage of reduction in system losses, improvement in voltage regulation and reliability of supply. DG could be considered as one of the viable options to ease some of the problems such as high power loss, low reliability, poor power quality and helps in meeting the energy demand of ever growing loads at lower cost. For a particular bus, as the size of DG is increased, the losses are reduced to a minimum value and if the size of DG is increased beyond the optimal DG size at that location, the losses start to increase. So, the size of distribution system in term of load (MW) will play an important role in selecting the size of DG. Similarly, location of DG plays an important role in minimizing the losses. The optimal and fast placement and assignment of DG units are one of the major challenges in the system design field and various techniques has already been used for this purpose with different objectives depicted in Fig 3.1.

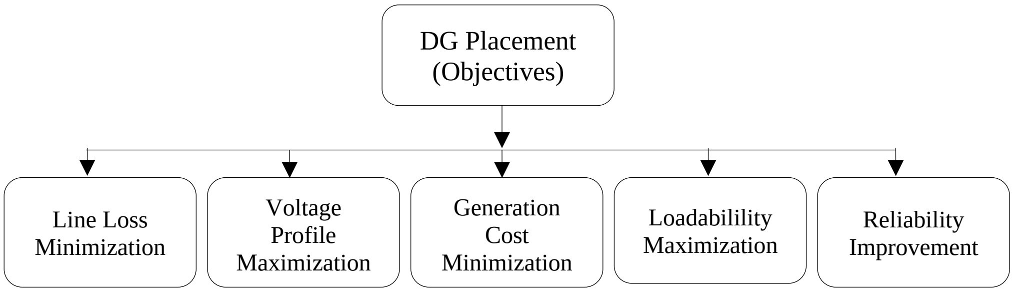

Fig. 3.1: Objectives for optimal placement of DG

Optimization of these non-commensurable variables or objectives are often complicated and is associated with a number of equality and inequality constraints. Several optimization techniques and algorithm have already proposed as discussed in literature review section like analytical approaches to reduce power losses and to improve voltage profile independently, simulation by monte-carlo software, neplan software to reduce only power losses and by meshed power network to reduce power losses and improve voltage profile. Majority analysis has done on developing algorithm for different bus construction to reduce power loss by PSO, network performance index and to improve voltage profile at minimum cost by immune algorithm. However, algorithm has also developed to optimize both power losses and voltage profile by bus injection to branch current and branch-current to bus voltage matrices, PSO, artificial neural network, GA, harmony search differential operator, matrix laboratory (MATLAB) and clonal selection. In most of the techniques generation cost is ignored and only time-invariant loads are considered while ensuring optimal placement.

3.3 Problem Statement Formulation

Many real-world problems involve simultaneous optimization of several objective functions. Generally, these functions are non-commensurable and often conflicting objectives. Multi-objective optimization with such conflicting objective functions gives rise to a set of optimal solutions, instead of one optimal solution. The reason for the optimality of many solutions is that no one can be considered to be better than any other with respect to all objective functions.

3.3.1 Objective function

In this research, different types objective functions are optimized simultaneously as multi-objective optimization problem and is associated with a number of equality and inequality constraints for the DG placement and sizing problem in the power system network.

$$\text{Optimize } F(x) = [\min F_{Loss}(x) \times \max f\, V_{bus}(x)] \times \min F_{cost}(x) \tag{3.1}$$

Where, $F_{Loss}(x)$ = Power System active power loss

$V_{bus}(x)$ = Improved Bus Voltage Index &

$F_{cost}(x)$ = total cost of distributed generation systems

f = voltage quality factor

3.3.1.1 Minimization of system active power loss

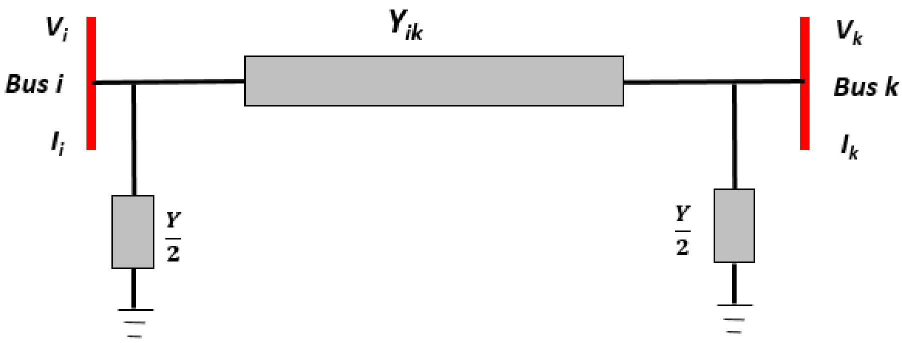

Fig. 3.2: Bus connection diagram

For the formulation of the real and reactive power entering a bus following quantities are required to be defined in Fig 3.2. Let the voltage at the i^{th} bus be denoted by [56],

$$V_i = |V_i|\angle\delta_i = |V_i|(\cos\delta_i + j\sin\delta_i) \tag{3.2}$$

Also let us define the self-admittance at bus- i as,

$$Y_{ii} = |Y_{ii}|\angle\theta_{ii} = |Y_{ii}|(\cos\theta_{ii} + j\sin\theta_{ii}) = G_{ii} + jB_{ii} \tag{3.3}$$

Similarly, the mutual admittance between the buses *i* and *j* can be written as,

$$Y_{ij} = |Y_{ij}|\angle\theta_{ij} = |Y_{ij}|(cos\ \theta_{ij} + j\ sin\ \theta_{ij}) = G_{ij} + jB_{ij} \tag{3.4}$$

Let, the power system contains a total number of *n* buses. The current injected at bus- *i* is given as,

$$I_i = Y_{i1}V_1 + Y_{i2}V_2 + Y_{i3}V_3 + \cdots\cdots + Y_{in}V_n = \sum_{k=1}^{n} Y_{ik}V_k \tag{3.5}$$

It is to be noted, if the current entering a bus to be positive and that leaving the bus to be negative. As a consequence, the power and reactive power entering a bus will also be assumed to be positive. The complex power at bus- *i* is then given by,

$$P_i - jQ_i = V_i^* I_i = V_i^* \sum_{k=1}^{n} Y_{ik}V_k$$

$$= |V_i|(cos\ \delta_i - j\ sin\ \delta_i) \sum_{k=1}^{n}|Y_{ik}V_k|(cos\ \theta_{ik} + j\ sin\ \theta_{ik})\ (cos\ \delta_k + j\ sin\ \delta_k)$$

$$= \sum_{k=1}^{n}|Y_{ik}V_iV_k|(cos\ \theta_{ik} + j\ sin\ \theta_{ik})\ (cos\ \delta_k + j\ sin\ \delta_k)\ (cos\ \delta_i - j\ sin\ \delta_i)$$

$$= \sum_{k=1}^{n}|Y_{ik}V_iV_k|(cos\ \theta_{ik} + j\ sin\ \theta_{ik})\ (cos\ \delta_k + j\ sin\ \delta_k)\ (cos\ \delta_i - j\ sin\ \delta_i)$$

$$= \sum_{k=1}^{n}|Y_{ik}V_iV_k|\{cos\ (\theta_{ik} + \delta_k - \delta_i) + j\ sin(\theta_{ik} + \delta_k - \delta_i)\} \tag{3.6}$$

Therefore, the real and reactive power ca be written as,

$$P_i = \sum_{k=1}^{n}|Y_{ik}V_iV_k|cos\ (\theta_{ik} + \delta_k - \delta_i) \tag{3.7}$$

$$Q_i = - \sum_{k=1}^{n}|Y_{ik}V_iV_k|\ sin(\theta_{ik} + \delta_k - \delta_i) \tag{3.8}$$

The active power loss of the line section connecting buses *i* and *k* can be computed from per-unit system,

$$S_{ik} = P_{ik} + j\ Q_{ik} = V_i\ I_{ik}^* \tag{3.9}$$

Where, $I_{ik} = \left[\frac{P_{ik} + jQ_{ik}}{V_i}\right]^*$

Taking only the magnitude,

$$|I_{ik}| = \frac{\sqrt{{P_{ik}}^2 + {Q_{ik}}^2}}{|V_i|}$$

$$|I_{ik}|^2 = \frac{{P_{ik}}^2 + {Q_{ik}}^2}{|V_i|^2}$$

$$|I_{ik}|^2 \times R_{ik} = \frac{{P_{ik}}^2 + {Q_{ik}}^2}{|V_i|^2} \times R_{ik}$$

$$P_{ik_{Loss}} = \frac{{P_{ik}}^2 + {Q_{ik}}^2}{|V_i|^2} \times R_{ik} \tag{3.10}$$

The total active power loss of the N number of bus sections can be expressed as

$$\text{Min } F_{Loss} = P_{T_{Loss}} = \sum_{i,\ k;i\neq k} P_{ik_{Loss}} \tag{3.11}$$

3.3.1.2 Voltage profile maximization

The complex power at bus- i is then given by [56]

$$P_i - jQ_i = V_i^* I_i = V_i^* \sum_{k=1}^{n} Y_{ik} V_k$$

$$= V_i^* [Y_{i1}V_1 + Y_{i2}V_2 + Y_{i3}V_3 + \cdots + Y_{ii}V_{i} + \cdots + Y_{in}V_n]$$

$$V_i = \frac{1}{Y_{ii}} \left[\frac{P_i - jQ_i}{V_i^*} - Y_{i1}V_1 - Y_{i2}V_2 - Y_{i3}V_3 - \cdots - Y_{in}V_n \right] \quad (3.12)$$

In the Gauss-Seidel load flow, usually the initial voltage of the i^{th} bus by $V_i^{(0)}$, $i = 2, \ldots , n$ is denoted. This will read as the voltage of the i^{th} bus at the 0^{th} iteration, or initial guess. Similarly this voltage after the first iteration will be denoted by $V_i^{(1)}$. In this Gauss-Seidel load flow the load buses and voltage controlled buses are treated differently. However, in both these type of buses complex power equation given in (3.7) is used for updating the voltages.

$$\text{Max } V_{Bus} = \sum_{i=1}^{N_{bus}} V_i$$

$$\text{Max } V_{Bus} \text{ Index} = \frac{\sum_{i=1}^{N_{bus}} V_i}{N} \quad (3.13)$$

By using standard deviation of the given system,

$$V_{Bus} \text{ deviation index, } d = \sqrt{\frac{\sum (V_{index} - \bar{V})^2}{N}} \quad (3.14)$$

Bus voltage Quality Factor, $f = 1 - d$

3.3.1.3 Generation cost optimization

The total costs include the fixed costs during initial investment and variable costs like the cost of maintenance and utilization of DG systems. The following equation can be used to express the total cost of a generation system [57].

$$\text{Min } F_{cost} = aP + bP^2 + cP^3 + d \quad (3.15)$$

Where a, b, c is considered as the coefficient for variable cost and d is the fixed cost of the system.

3.3.2 System constraints

The objective function is associated with a number of equality and inequality constraints for the DG placement and sizing problem in the distribution network.

i. **Network active & reactive power balance**

   To maintain balance between generation power of the network and its power consumption, the following relations should be established [57]:

$$P_{sys} + P_{DG} = P_d + P_{Loss} \quad (3.16)$$

$$Q_{sys} + Q_{DG} = Q_d + Q_{Loss} \quad (3.17)$$

Where, P_{sys} and Q_{sys} are active and reactive powers, respectively which are injected to the desired distribution network by sub-transmission network. P_{DG} and Q_{DG} are active and reactive powers of DGs. P_d and Q_d are total power demand of network loads. P_{Loss} and Q_{Loss} are both active and reactive power losses of the network.

ii. Bus voltage limits

The voltage at various buses should be maintained within the acceptable limits by following condition.

$$V_i^{min} \leq V_i \leq V_i^{max} \quad (3.18)$$

iii. Thermal limits

The current at various branches should be maintained within the acceptable limits by following equation.

$$I_{ij} \leq I_{ij}^{max} \quad (3.19)$$

iv. Power limits of DG

The active and reactive power limits of DG at the all buses are maintained within the acceptable limits of the individual bus by following equations.

$$P_{DG}^{min} \leq P_{DG} \leq P_{DG}^{max} \quad (3.20)$$

$$Q_{DG}^{min} \leq Q_{DG} \leq Q_{DG}^{max} \quad (3.21)$$

3.3.3 Optimal condition

The optimal condition for the system can be represent by following equations.

$$\sum P_{Loss} \text{ (with DG)} < \sum P_{Loss} \text{ (without DG)} \quad (3.22)$$

$$\sum V_{Bus} \text{ (with DG)} > \sum V_{Bus} \text{ (without DG)} \quad (3.23)$$

$$\sum \text{Total Cost (with DG)} < \sum \text{Total Cost (without DG)} \quad (3.24)$$

3.4 Optimization Process

Distribution system are critical links to the utility and the consumer. The ever-increasing need for electrical power generation, steady progress in power deregulation and tight constraints over the construction of new transmission lines for long distance power transmission have created increased interest in distributed power generation. Optimal placement of DG units in distribution system reduce the energy losses, improve the voltage profile, release the transmission capacity, decrease equipment stress, and improve the system reliability. Many techniques have been developed to solve the problem of sizing of multiple distributed generation units in distribution system. Their objective is to reduction of power loss, improvement of system voltage profile, minimization of cost and maximization of generation capacity. In this thesis, an algorithm is developed to locate optimal place of DG units in any power system bus network. The algorithm ensures minimization of power losses and maximization of buses voltage profile improvement at minimum generation cost, for time-variant and time-invariant loading conditions.

3.4.1 Preparation of data for load flow

Load-flow studies are probably the most common of all power system analysis calculations. They are used in planning studies to determine if and when specific elements will become overloaded. Major investment decisions begin with reinforcement strategies based on load-flow analysis. In operating studies, load-flow analysis is used to ensure that each generator runs at the optimum operating point; demand will be met without overloading facilities; and maintenance plans can proceed without undermining the security of the system.

3.4.1.1 Bus selection

For load flow studies it is assumed that the loads are constant and they are defined by their real and reactive power consumption. It is further assumed that the generator terminal voltages are tightly regulated and therefore are constant. The main objective of the load flow is to find the voltage magnitude of each bus and its angle when the powers generated and loads are pre-specified. To facilitate this, classification of the different buses in power system shown are discussed below [56].

In Load buses buses no generators are connected and hence the generated real power P_{Gi} and reactive power Q_{Gi} are taken as zero. The load drawn by these buses are defined by real power $-P_{Li}$ and reactive power $-Q_{Li}$ in which the negative sign accommodates for the power flowing out of the bus. This is why these buses are sometimes referred to as *PQ* bus. The objective of the load flow is to find the bus voltage magnitude $|V_i|$ and its angle δ_i.

Voltage controlled buses are the buses where generators are connected. Therefore, the power generation in such buses is controlled through a prime mover while the terminal voltage is controlled through the generator excitation. Keeping the input power constant through turbine-governor control and keeping the bus voltage constant using automatic voltage regulator, we can specify constant P_{Gi} and $|V_i|$ for these buses. This is why such buses are also referred to as *PV* buses. It is to be noted that the reactive power supplied by the generator Q_{Gi} depends on the system configuration and cannot be specified in advance. Furthermore, we have to find the unknown angle δ_i of the bus voltage.

Usually slack or swing bus is numbered 1 for the load flow studies. This bus sets the angular reference for all the other buses. Since it is the angle difference between two voltage sources that dictates the real and reactive power flow between them, the particular angle of the slack bus is not important. However, it sets the reference against which angles of all the other bus voltages are measured. For this reason, the angle of this bus is usually chosen as 0° and it is assumed that the magnitude of the voltage of this bus is known.

3.4.1.1 Line data modeling

Transmission lines are characterized by a series resistance, inductance, and shunt capacitance per unit length. These values determine the power-carrying capacity of the transmission line and the voltage drop across it at full load. AC resistance of a conductor is always higher than its DC resistance due to the skin effect forcing more current flow near the outer surface of the conductor. The higher the frequency of current, the more noticeable skin effect would be. A current-carrying conductor produces concentric magnetic flux lines around the conductor. If the current varies with the time, the magnetic flux changes and a voltage is induced.

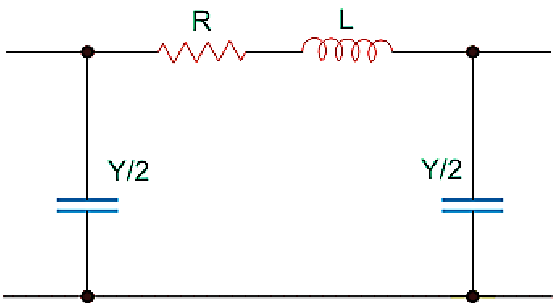

Fig. 3.3: Generalize transmission line (π model)

Therefore, an inductance is present, defined as the ratio of the magnetic flux linkage and the current. The magnetic flux produced by the current in transmission line conductors produces a total inductance whose magnitude depends on the line configuration. Since a voltage V is applied to a pair of conductors separated by a dielectric (air), charges q of equal magnitude but opposite sign will accumulate on the conductors to form shun capacitance. Wire manufacturers usually supply tables of resistance, inductance and shunt capacitance effect per unit length at common frequencies (50 and 60 Hz). Therefore, these data can be determined from manufacturers data sheets. A transmission line is represented in Fig 3.3 as a nominal π model. Where, $R + jX$ is the line impedance and $Y/2$ is called the half line charging admittance.

3.4.1.2 Causes of load variation

The operation of power systems has been complicated by the rapid diversification of loads. Analyzing load characteristics becomes necessary to different utilities in energy management systems to ensure the reliability of power systems. Usually all the needed load data is not available directly and the load values must be estimated and forecasted using other available information. The load calculations for different locations in the radially operated distribution network are rather straightforward when the customers' loads are known. The load modelling and forecasting is based on knowledge of several factors influencing the customer's load. The most important factors are [58]:

3.4.1.2.1 Customer factors

The customer factors of electricity consumption are primarily the number, type and size of the electrical equipment of the customer. While the electrical equipment and installations vary from customer to customer there are recognized types of customers which have similar properties. Such customer types are for example: residential, electric heating, agriculture, small industry and service.

3.4.1.2.2 Time factors

The electric load varies with time depending on human and economic activity. There is more load in the day time and less load at night. Also the load varies between week days and usually the load is lower at weekend than on week days. The cyclic time dependency leads to analyzing the loads: on hour of day basis, day of week basis and time of year basis.

3.4.1.2.3 Climate factors

The weather factors like out-door temperature, wind speed, sun radiation etc. influence the load. The outdoor temperature mainly influences customers with electric heating. The temperature varies over a wide range in the winter (about 20 degrees C change in a few days is normal). This causes a lot of variation in temperature dependent loads, especially electric heating. Temperature is not the only factor, as the demand for heating energy is also dependent on sun radiation, wind speed and humidity. Also the automatic control of different heating equipment reacts to the temperature changes in different ways. However, in practice only the outdoor temperature is taken into account as knowledge of the values of the other factors is limited.

A graphical plot showing the variation in demand for energy of the consumers on a source of supply with respect to time is known as the load curve. If this curve is plotted over a time period of 24 hours, it is known as daily load curve. If its plotted for a week, month, or a year, then its named as the weekly, monthly or yearly load curve respectively. The load duration curve reflects the activity of a population quite accurately with respect to electrical power consumption over a given period of time. Load variation of Bangladesh in off-day and working day is depicted in Fig 3.4.

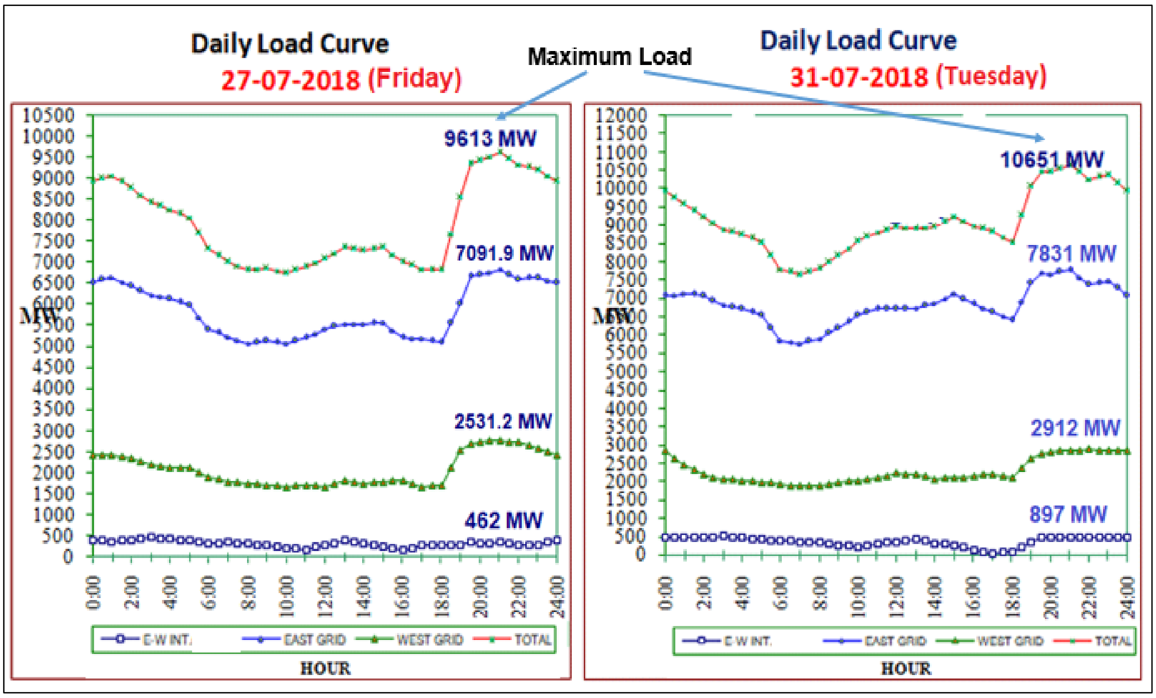

Fig. 3.4: Load variation in off-day and working day [59].

3.4.2 Load flow analysis

A power flow study or load-flow study is a steady-state analysis whose target is to determine the voltages, currents, and real and reactive power flows in a system under a given load conditions. The purpose of power flow studies is to plan ahead and account for various hypothetical situations. For example, if a transmission line is taken off line for maintenance, can the remaining lines in the system handle the required loads without exceeding their rated values. The basic power flow equations (3.7) and (3.8) are nonlinear. In an n-bus power system, let the number of PQ buses be n_p and the number of PV (generator) buses be n_g such that $n = n_p + n_g + 1$. Both voltage magnitudes and angles of the PQ buses and voltage angles of the PV buses are unknown making a total number of $2n_p + n_g$ quantities to be determined. Amongst the known quantities are $2n_p$ numbers of real and reactive powers of the PQ buses, $2n_g$ numbers of real powers and voltage magnitudes of the *PV* buses and voltage magnitude and angle of the slack bus. Therefore, there are sufficient numbers of known quantities to obtain a solution of the load flow problem. However, it is rather difficult to obtain a set of closed form equations from (3.7) and (3.8). Therefore, algorithm has to resort to obtain iterative solutions of the load flow problem.

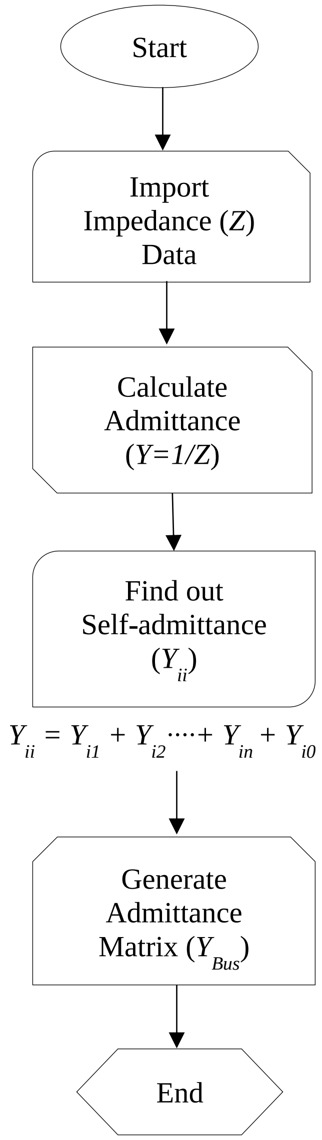

Fig. 3.5: Flowchart for *Y*-bus matrix formulation

3.4.2.1 *Y* bus matrix formulation

The detail algorithm for formulation of admittance matrix is as follows and flowchart is depicted in Fig. 3.5.

Step 1: Read the values of number of buses and the number of lines of the given system.

Step 2: Read the self-admittance of each bus and the mutual admittance between the buses.

Step 4: The off-diagonal term called the transfer admittance, Y_{ij} which is the negative of the admittance connected from bus *i* to bus *j*.

Step 5: Check for the end of bus count and print the computed *Y*-bus matrix.

Step 6: Stop the program and print the results.

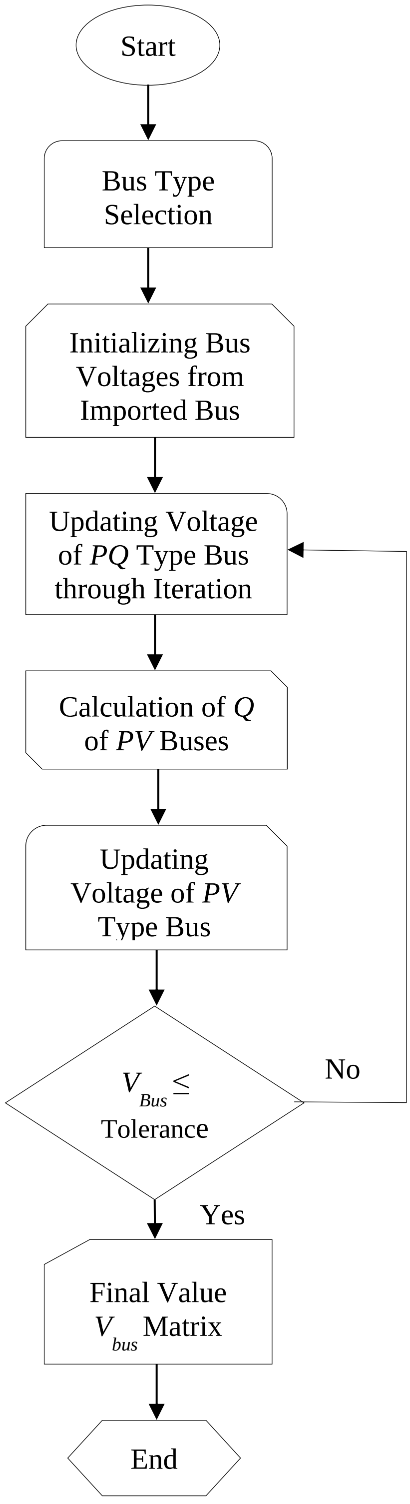

Fig. 3.6: Flowchart for bus voltage profile calculation

3.4.2.2 Bus voltage calculation

The detail algorithm for bus voltage calculation is as follows and flowchart is depicted in Fig. 3.6.

Step 1: Read the input data.

Step 2: Choose the initial voltage profile $1+j0$ to all load buses and $j0$ for generator buses except slack bus.

Step 3: Set the iteration count $p = 0$ and bus count $i = 1$.

Step 4: Check the slack bus, if it is the generator bus then go to next step otherwise go to next step 6.

Step 5: Before the check for the slack bus if it is slack bus then go to step 10 otherwise go to next step.

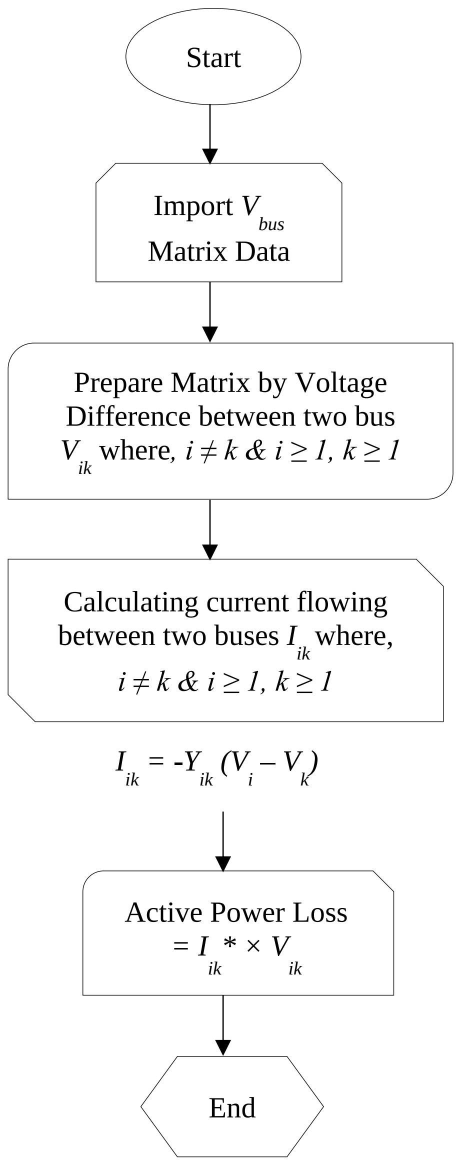

Fig. 3.7: Flowchart for line loss calculation

Step 6: Check the reactive power of the generator bus within the given limit.

Step 7: If the reactive power violates a limit then treat the bus as load bus.

Step 8: Calculate the phase of the bus voltage on load bus

Step 9: Calculate the change in bus voltage of the repeat step mentioned above until all the bus voltages are calculated.

Step 10: Stop the program and print the results.

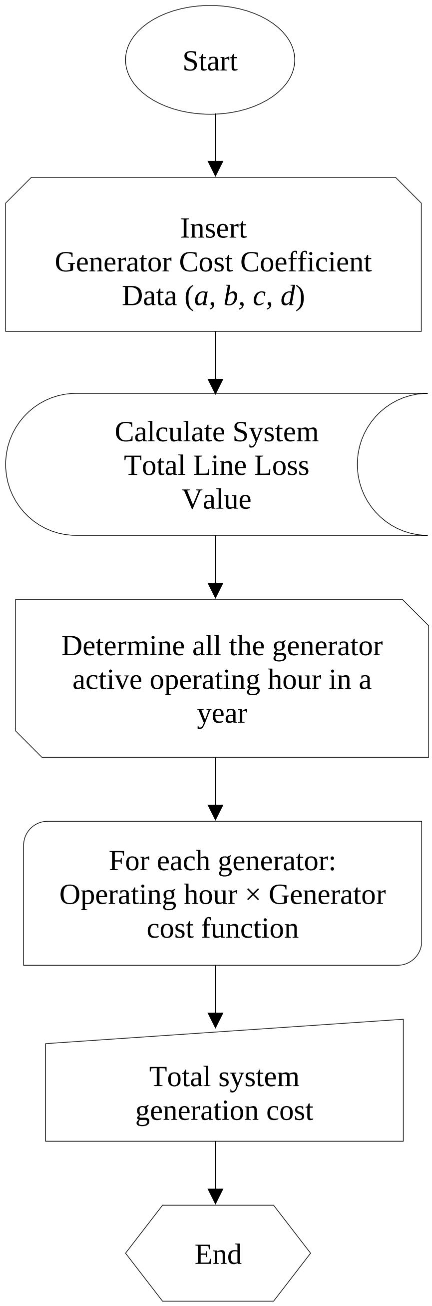

Fig. 3.8: Flowchart for total cost calculation

3.4.2.3 Power loss calculation

The detail algorithm for power loss calculation is as follows and flowchart is depicted in Fig. 3.7.

Step 1: Read the input bus voltage data.

Step 2: Prepare matrix by voltage difference between two buses.

Step 3: Calculate current flowing between the line of two buses.

Step 4: Find out active power loss.

Step 5: Stop the program and print the results.

3.4.2.4 Calculation of system generation cost

The detail algorithm for system generation cost is as follows and flowchart is depicted in Fig. 3.8.

Step 1: Insert the cost function for the all generator of the network.

Step 2: Insert the coefficients value for the all generator.

Step 3: Calculate line losses for each of the connection.

Step 4: Calculate total cost of the system using generator active hour.

Step 5: Find minimum value of the cost.

Step 5: Stop the program and print the results.

3.4.3 System optimization

The detail algorithm for optimization of loss and voltage with cost is as follows and flowchart is depicted in Fig. 3.9.

Step 1: Insert the DG in possible connections.

Step 2: Calculate bus voltage profile, line loss and generation cost for each of the connection.

Step 3: Find out change in voltage improvement, line loss minimization and generation cost for each of the connection.

Step 4: If bus voltage improvement is same, voltage quality is also ensured from standard deviation.

Step 5: Insert optimal factor value and take the minimum cost value.

Step 6: Stop the program and print the results.

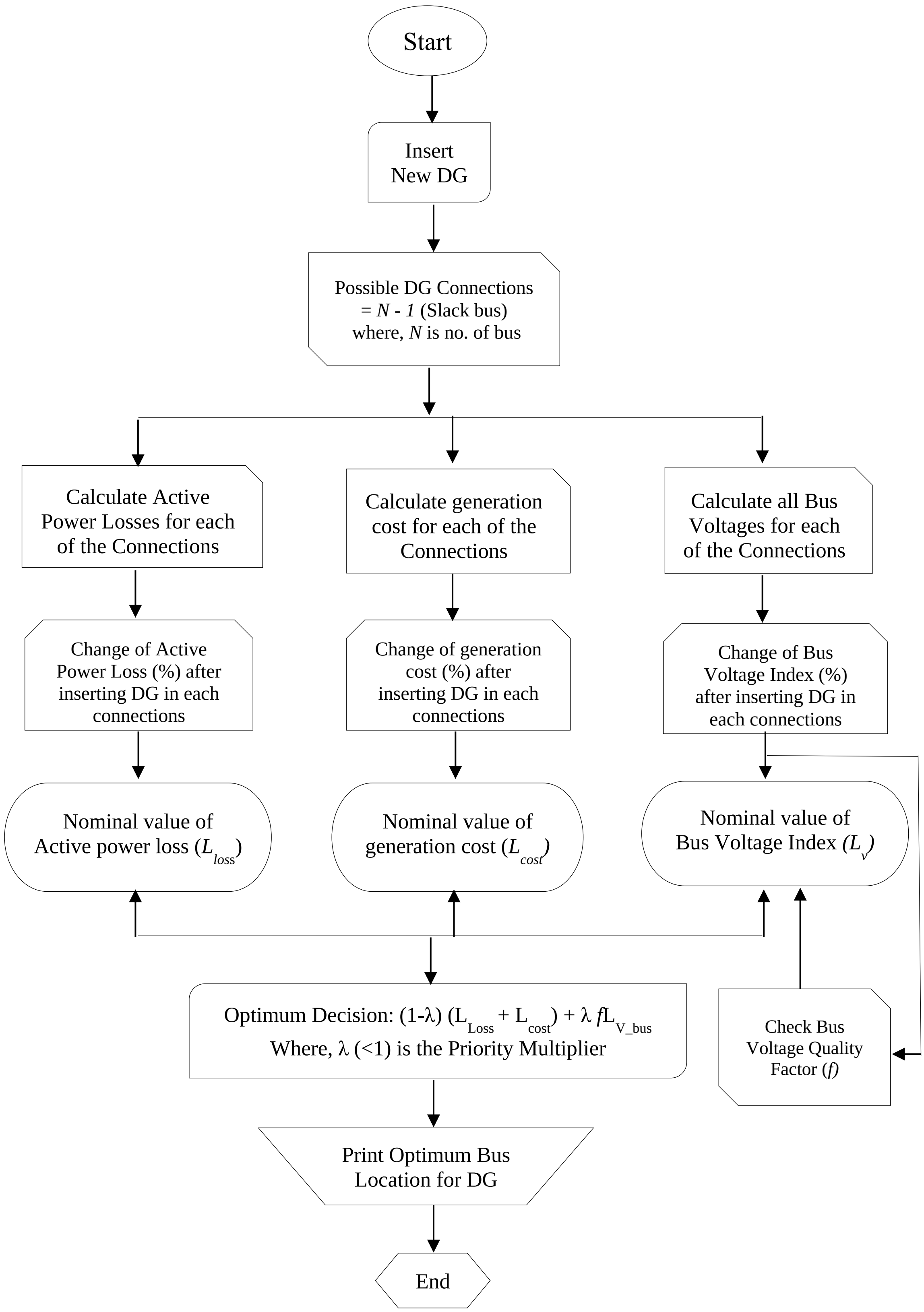

Fig. 3.9: Flowchart for optimization of DG placement

3.5 Optimal Location for DG

DG can be placed in optimal bus connection on basis of the analysis in voltage improvement maximization function, power loss and total generation cost minimization function from the above discussions. The algorithm is developed in MATLAB software which has versatile application in engineering field. Bus voltage, power loss and generation cost found without connecting DG are considered as the base value for each index during optimization. New DG is being connected to all the possible bus location except the slack bus and all the new bus voltage, power loss and generation cost are again calculated. Then a heuristics approach results the optimal bus location where minimum power loss and maximum bus voltage at a minimum generation cost can be achieved.

3.6. Conclusion

This chapter deals with the multi-objective problem formulation, the formulations of the system index factors for optimization. The constraints to which the multi-objective function is subjected to are also defined here. Generally, both real and reactive power flow and power loss are formulated using the gauss-seidal iteration load flow technique, while the multi-objective optimization is formulated taking into consideration of real power loss reduction index, qualitative voltage profile improvement index and system total generation cost index. Both equality and inequality constraints are also defined. In chapter four, the results obtained are presented and analyzed in terms of tables and graphs. A detailed discussion about the obtained results for different test bus system is also synthesized on the chapter.

CHAPTER 4

TEST SYSTEM RESULTS AND ANALYSIS

4.1 Introduction

Multi-objective optimal placement problem is decomposed into minimization of total active power losses, maximization of bus voltage profile enhancement and minimization of total generation cost of a power system network. At the first stage, candidate distributed generator is placed in all available buses independently except slack bus to calculate change of bus voltage profiles through gauss-seidal iteration method. The loss factor is calculated to determine the amount of power loss in a particular line with respect to the change of bus voltage profiles. Similarly, cost factor is estimated to calculate the total generation cost with respect to the change of line losses. In the second stage, heuristics approach is used through lagrangian multiplier function to find out optimal bus location for integration of distributed generators at not only time-invariant but also probabilistic time-variant loading conditions. Here, optimum utilization factor for installed generators and loads is scaled by the analysis of yearly load-demand curve of a network. The developed algorithm of N-bus system in MATLAB (R2016a-version 9.0) is implemented on different standard test system by IEEE-6 bus and IEEE-14 bus systems.

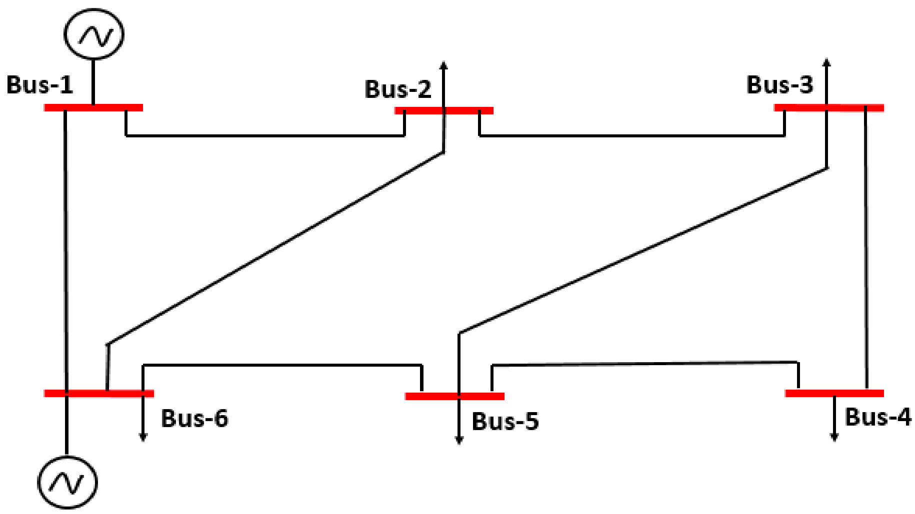

Fig. 4.1: IEEE-6 bus system diagram [60]

4.2 IEEE-Six (6) Bus System Analysis

For the load flow studies, IEEE-6 bus consider the system of Fig. 4.1 is considered, which has 2 generator and 4 load buses. Bus-1 is selected as the slack bus while taking bus-6 as the *PV* bus. Buses 2, 3, 4 and 5 are corresponding *PQ* buses. The line impedances and the line charging admittances are given in Table 4.1.

Table 4.1: Bus system line data [60]

Line (bus to bus)	Impedance (Per unit)	Line Charging (*Y*/2)
1-2	0.025 + *j* 0.10	*j* 0.030
1-6	0.047 + *j* 0.25	*j* 0.020
2-3	0.050 + *j* 0.25	*j* 0.025
2-6	0.045 + *j* 0.25	*j* 0.023
3-4	0.040 + *j* 0.20	*j* 0.020
3-5	0.048 + *j* 0.24	*j* 0.015
4-5	0.080 + *j* 0.42	*j* 0.010
5-6	0.100 + *j* 0.50	*j* 0.050

The known bus voltage magnitudes, their angles, operating time & the power generated by generator bus and DG system are given in Table 4.2 and 4.3.

Table 4.2: Bus voltage magnitudes and generated power data

Bus No.	Bus Voltage		Power Generated	
	Magnitude (pu)	Angle (deg)	*P* (MW)	*Q* (MVAR)
1	1.05	-	30	-
6	1.02	-	20	-
DG	1.00	-	2	

Table 4.3: Generator operating time data

Generator	Max (MW)	Min (MW)	Up Time (Hr)	Down Time (Hr)	Priority Order
Gen-1	30	10	6	3	2
Gen-2	20	8	5	2	1
DG	2	0.5	2	1	3

The power consumed at each load bus are considered in both time invariant usually maximum load and probabilistic time variant loading conditions in Table 4.4 and Table 4.5 respectively. Yearly probabilistic load variation for the above system is assumed as the worst possible case where maximum load data is mark out as the time-invariant load.

Table 4.4: Time invariant loads at all load connected buses

Bus No.	Max Load	
	P (MW)	*Q* (MVAR)
1	-	-
2	9.9	2.2
3	9.5	2.8
4	9.7	2.7
5	9.6	3.1
6	9.4	2.7

Table 4.5: Probabilistic time variant loads at all load connected buses

Hour Yearly	Load Variation									
	Bus-2		Bus-3		Bus-4		Bus-5		Bus-6	
	P (MW)	Q (MVR)	P (MW)	Q (MVR)	P (MW)	Q (MVR)	P (MW)	Q (MVR)	P (MW)	Q (MVR)
1 - 425	6.8	1.1	6.3	1.9	7.5	1.5	5.8	2.6	9.8	1.6
426 - 975	7.1	1.4	9.5	1.6	6.7	0.6	9.4	2.9	8.7	1.9
976 - 1375	3.8	0.6	3.6	2.4	3.2	1.5	3.7	1.7	4.3	1.1
1376 - 1800	9.8	2.1	9.5	2.4	9.2	2.1	9.2	2.5	9.8	1.1
1801 - 2320	9.6	1.6	9.1	2.5	8.1	1.4	9.8	2.1	9.7	2.1
2321 - 2870	4.7	1.1	4.2	1.9	5.7	1.9	5.8	1.6	7.7	1.6
2871 - 3590	7.8	1.2	6.6	1.8	6.7	1.6	6.4	1.9	8.2	1.7
3591 - 4120	9.9	2.1	9.9	1.9	9.7	1.8	9.9	1.7	9.5	2.6
4121 - 4570	9.4	2.2	9.5	2.8	8.7	2.4	9.5	3.1	9.8	0.7
4571 - 5100	8.7	1.1	9.6	1.9	9.4	1.8	8.1	1.7	9.6	1.6
5101 - 5580	9.6	1.7	9.6	2.1	8.4	2.7	9.4	1.9	9.2	2.2
5581 - 6025	5.8	1.4	7.8	1.6	8.1	1.7	8.9	1.8	8.8	1.9
6026 - 6560	5.4	1.3	9.9	1.7	6.4	1.1	8.2	2.4	7.2	1.8
6561 - 7170	3.7	0.7	4.5	2.1	2.4	0.4	4.5	2.1	3.2	1.4
7171 - 7510	8.5	1.5	9.9	1.5	9.5	1.9	9.6	3.1	9.1	2.2
7511 - 8110	9.2	1.8	9.9	1.2	9.5	1.3	8.8	2.2	9.1	2.3
8111 - 8520	7.4	2.2	9.2	2.1	6.8	1.4	9.6	2.1	9.4	2.7
8521 - 8760	5.1	1.5	5.3	1.5	5.5	1.8	5.1	1.7	6.7	2.2

Considering 2 MW capacity DG need to be connected with the given system which has some possible connection in the system depicted in Fig. 4.2. But to find the optimal location for connection developed algorithm is used.

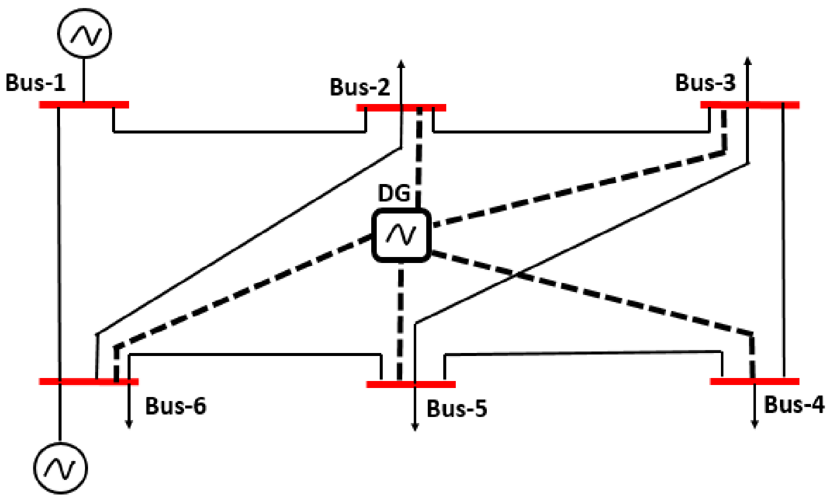

Fig. 4.2: Possible connection for new DG

4.2.1 Load flow analysis

Y bus matrix is formed in Table 4.6 using the data of Table 4.1. It is to be noted here that the sources and their internal impedances are not considered while forming the *Y* bus matrix for load flow studies which deal only with the bus voltages.

Table 4.6: Generated *Y*-bus matrix

Y	**1**	**2**	**3**	**4**	**5**	**6**
1	3.0792 - *j*13.2252	-2.3529 + *j*9.4117	0.0	0.0	0.0	-0.7263 + *j*3.8634
2	-2.3529+ *j*9.4117	3.8195 - *j*17.0523	-0.76923 + *j*3.8461	0.0	0.0	-0.6974+ *j*3.8744
3	0.0	-0.7692 + *j*3.8461	3.3974 - *j*9.4321	-0.9615 + *j*4.8076	-1.6667 + *j*0.8333	0.0
4	0.0	0.0	-0.9615 + *j*4.8076	1.3991 - *j*7.0752	-0.4376 + *j*2.2975	0.0
5	0.0	0.0	-1.6667 + *j*0.8333	-0.4376 + *j*2.2975	2.4889 - *j*4.9840	-0.3846 + *j*1.9230
6	-0.7263 + *j*3.8634	-0.6974 + *j*3.8744	0.0	0.0	-0.3846 + *j*1.9230	1.8083 - *j*9.5659

The bus voltage magnitudes, their angles, the power generated and consumed at each bus are given in Table 4.2 where, load buses have no voltage values. In the Table 4.7 some of the voltages and their angles are given in boldface letters. This indicates that these are initial data used for starting the load flow program. The power and reactive power generated at the slack bus and the reactive power generated at the *PV* bus are unknown. Therefore, each of these quantities are indicated by a dash (-). Since, initial estimate is not required of these quantities for load flow calculations. Also note from Fig. 4.1 that the slack bus does not contain any load while the *PV* bus at 6 bus number has a local load and this is indicated in the load column. It is to be noted that the real and reactive powers are given respectively in MW and MVAR. However, they are converted into per unit quantities during calculation, where a base of 100 MVA is chosen.

Table 4.7: Initial data for buses

Bus Type	Bus No.	Bus voltage		Power generated	
		Magnitude (pu)	Angle (deg)	*P* (MW)	*Q* (MVAR)
Slack	1	1.05	0	30	-
PQ Bus	2	**1**	**0**	0	0
	3	**1**	**0**	0	0
	4	**1**	**0**	0	0
	5	**1**	**0**	0	0
PV Bus	6	1.02	**0**	20	-
DG	-	1.00	**0**	2	-

Acceleration factor is used with a value less than 2 for the convergence to occur. It is seen that the algorithm converges in the least number of iterations when λ is 0.4 and the maximum number of iterations are required when λ is 2. In fact, the algorithm starts to diverge if larger values of acceleration factor are chosen. The system data after the convergence of the algorithm is given at Table 4.8 to 4.11 for all possible connections.

Table 4.8: Updated bus voltage after DG insertion (time invariant loads)

DG Placement	Bus Voltage (pu)						Bus Index	*f*
	V_1	V_2	V_3	V_4	V_5	V_6		
Without DG	1.05∠0	1.041 ∠-1.56	1.035 ∠-4.62	1.031 ∠-5.54	1.029 ∠-4.81	1.02 ∠-0.88	1.034	0.65
Bus-2	1.05∠0	1.0372 ∠-1.42	1.018 ∠-4.45	1.009 ∠-5.2	0.9997 ∠-4.12	1.02 ∠-0.74	1.022	0.52
Bus-3	1.05∠0	1.037 ∠-1.49	1.02 ∠-4.42	1.01 ∠-5.2	0.9997 ∠-4.31	1.02 ∠-0.81	1.031	0.62
Bus-4	1.05∠0	1.0375 ∠-1.46	1.019 ∠-4.35	1.01 ∠-5.0	0.9997 ∠-4.09	1.02 ∠-0.76	1.0348	0.65
Bus-5	1.05∠0	1.0372 ∠-1.46	1.017 ∠-4.39	1.00 ∠-5.15	0.9998 ∠-3.95	1.02 ∠-0.73	1.030	0.61
Bus-6	1.05∠0	1.041 ∠-1.51	1.035 ∠-4.54	1.03 ∠-5.45	1.03 ∠-4.7	1.02 ∠-0.72	1.0360	0.66

Table 4.9: Line losses after DG insertion (time invariant loads)

DG Placement	Bus to Bus Line Losses (MW)								Total
	1-2	1-6	2-3	2-6	3-4	3-5	4-5	5-6	
Without DG	0.210	0.083	0.238	0.041	0.028	0.0073	0.0076	1.93	0.8104
Bus-2	0.193	0.078	0.255	0.031	0.026	0.0638	0.0210	0.152	0.8219
Bus-3	0.209	0.081	0.237	0.032	0.030	0.0069	0.0178	0.162	0.8396
Bus-4	0.203	0.079	0.234	0.033	0.019	0.0666	0.0167	0.148	0.8007
Bus-5	0.205	0.078	0.241	0.032	0.024	0.0647	0.0233	0.139	0.8097
Bus-6	0.198	0.078	0.235	0.045	0.028	0.0065	0.0080	0.198	0.7961

Table 4.10: Updated bus voltage after DG insertion (time variant loads)

DG Placement	Bus Voltage (pu)						Bus Index	*f*
	V_1	V_2	V_3	V_4	V_5	V_6		
Without DG	1.05∠0	1.045 ∠-1.00	1.047 ∠-3.12	1.046 ∠-3.72	1.042 ∠-3.21	1.02 ∠-0.25	1.04	0.60
Bus-2	1.05∠0	1.0399 ∠-0.88	1.024 ∠-2.93	1.016 ∠-3.33	0.9999 ∠-2.27	1.02 ∠-0.11	1.024	0.42
Bus-3	1.05∠0	1.04 ∠-0.93	1.024 ∠-2.94	1.02 ∠-3.38	0.9999 ∠-2.42	1.02 ∠-0.15	1.025	0.43
Bus-4	1.05∠0	1.0399 ∠-0.91	1.024 ∠-2.88	1.016 ∠-3.21	0.9999 ∠-2.25	1.02 ∠-0.11	1.0435	0.66
Bus-5	1.05∠0	1.0398 ∠-0.94	1.023 ∠-2.97	1.015 ∠-3.38	0.9999 ∠-2.33	1.02 ∠-0.14	1.0248	0.43
Bus-6	1.05∠0	1.045 ∠-0.98	1.047 ∠-3.08	1.046 ∠-3.68	1.042 ∠-3.15	1.02 ∠-0.18	1.043	0.65

Table 4.11: Line losses after DG insertion (time variant loads)

DG Placement	Bus to Bus Line Losses (MW)								Total
	1-2	1-6	2-3	2-6	3-4	3-5	4-5	5-6	
Without DG	0.085	0.067	0.115	0.057	0.012	0.0047	0.0044	0.128	0.4719
Bus-2	0.086	0.066	0.125	0.041	0.011	0.1151	0.0261	0.0712	0.5401
Bus-3	0.091	0.066	0.121	0.041	0.112	0.1138	0.0245	0.0767	0.5461
Bus-4	0.088	0.065	0.117	0.042	0.009	0.1159	0.0244	0.0698	0.4621
Bus-5	0.093	0.066	0.125	0.041	0.011	0.1141	0.0259	0.0729	0.4683
Bus-6	0.081	0.066	0.114	0.058	0.012	0.0044	0.0045	0.1295	0.4696

4.2.2 Cost analysis

The IEEE-6 system has 3 generator including DG, all the cost coefficient values are given in Table 4.12.

Table 4.12: Data for cost co-efficient's value [10]

Generator	***a***	***b***	***c***	***d***
Gen-1 (30 MW)	21.5	13.8	1.9	206
Gen-2 (20 MW)	27.62	15.4	2.2	281
DG (2 MW)	22.21	18.31	15.23	505

Total system cost for time invariant loads can be calculated by using data of Table 4.4 and their corresponding line losses. But for time variant loads generator operating hour is calculated from overall loading hour of a year which is shown in Table 4.13.

Table 4.13: Calculation of generator operating time in a year

Yearly Hour			Total 6 Bus *P* (MW)	Total 6 Bus *Q* (MVR)	Active Gen	Gen-1 (Hr)	Gen-2 (Hr)	DG (Hr)
1	-	425	36.2	8.7	G1+G2	425	425	-
426	-	975	41.4	8.4	G1+G2	550	550	-
976	-	1375	18.6	7.3	G2	9	400	2
1376	-	1800	51.5	10.2	G1+G2+DG	425	425	425
1801	-	2320	50.3	9.7	G1+G2+DG	520	520	520
2321	-	2870	28.1	8.1	G1	550	7	1
2871	-	3590	35.7	8.2	G1+G2	720	720	2
3591	-	4120	51.8	10.1	G1+G2+DG	530	530	530
4121	-	4570	50.9	11.2	G1+G2+DG	450	450	450
4571	-	5100	50.4	8.1	G1+G2+DG	530	530	530
5101	-	5580	50.2	10.6	G1+G2+DG	480	480	480
5581	-	6025	41.4	8.4	G1+G2	445	445	1
6026	-	6560	39.1	8.3	G1+G2	535	535	0
6561	-	7170	18.3	6.7	G2	9	610	2
7171	-	7510	50.6	10.2	G1+G2+DG	340	340	340
7511	-	8110	50.5	8.8	G1+G2+DG	600	600	600
8111	-	8520	43.4	10.5	G1+G2	410	410	1
8521	-	8760	27.7	8.7	G1	240	2	-
Total						7768	7979	3884

Using above coefficient's in cost functions the total system cost is depicted in Fig. 4.3.

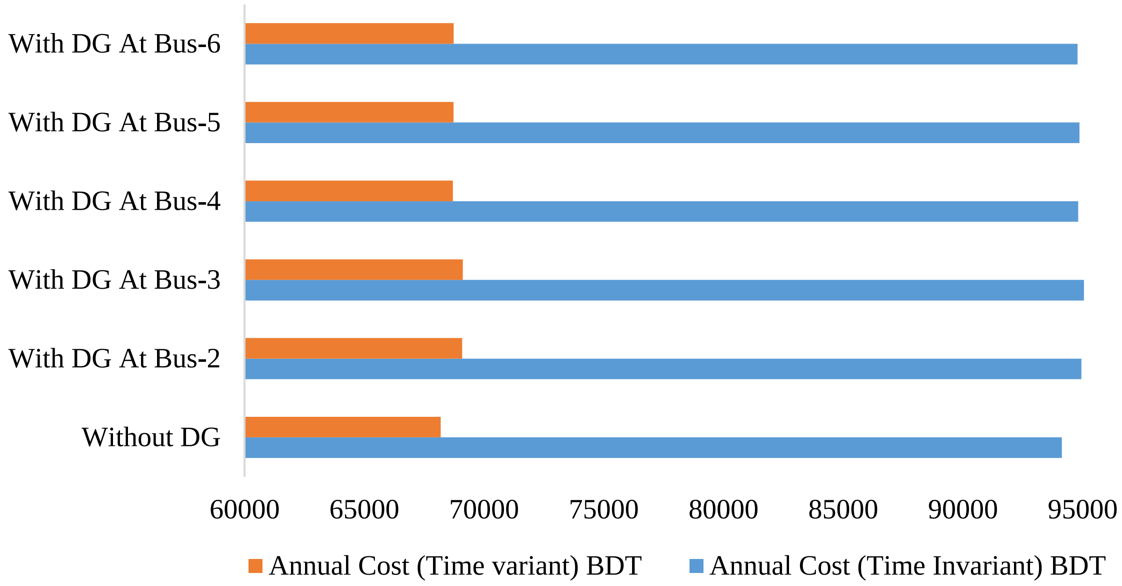

Fig. 4.3: Total system cost in a year in different bus locations

4.2.3 Comparison in loading conditions

Two types of loading condition have different bus voltage profile, line loss and cost values which are summarized at Table 4.14 to 4.15 and Fig. 4.3.

Table 4.14: Comparison in bus voltage profile

DG Placement	Total Bus Voltage Index (pu)					
	Without DG	Bus-2	Bus-3	Bus-4	Bus-5	Bus-6
Time-invariant Loads	1.034	1.022	1.031	1.0348	1.03	1.036
Time-variant Loads	1.04	1.024	1.025	1.043	1.0248	1.043

Table 4.15: Comparison in line to line losses

DG Placement	Total Line Losses (MW)					
	Without DG	Bus-2	Bus-3	Bus-4	Bus-5	Bus-6
Time-invariant Loads	0.8104	0.8218	0.8396	0.8006	0.8097	0.7961
Time-variant Loads	0.4719	0.5401	0.5461	0.4621	0.4683	0.4696

4.2.4 Optimal location

From the above discussion it is clear that, with time invariant loads Bus-6 is found as the optimal place while for probabilistic time variant loads it is Bus-4 shown in Table 4.16. As power system network is one of the major unpredictable scenario which vary in different time to time. Decision for time invariant system will affect the system during different loading conditions. So final decision for optimal placement will be on basis of time variant systems depicted in Fig. 4.4 as it will ensure 0.87% less power loss, 0.11% more bus voltage improvement and 0.01% less generation cost from time invariant loading conditions.

Table 4.16: Decision of optimal bus location of DG (IEEE-6 bus)

DG Placement	Time invariant Loads				Time Variant Loads			
	Total Change in %			Decision	Total Change in %			Decision
	Loss (MW)	Voltage (pu)	Cost (BDT)		Loss (MW)	Voltage (pu)	Cost (BDT)	
Without DG	0.8104	1.034	94132.5		0.4719	1.04	68195.7	
Bus-2	(+)1.41	(-)1.13	(+)0.87		(+)14.5	(-)1.62	(+)1.31	
Bus-3	(+)3.60	(-)0.29	(+)0.99		(+)15.7	(-)1.60	(+)1.35	
Bus-4	(-)1.21	(+)0.05	(+)0.73		(-)2.08	(+)0.16	(+)0.74	Selected
Bus-5	(-)0.09	(-)0.35	(+)0.79		(-)0.76	(-)1.62	(+)0.78	
Bus-6	(-)1.76	(+)0.16	(+)0.75	Selected	(-)0.49	(+)0.16	(+)0.79	

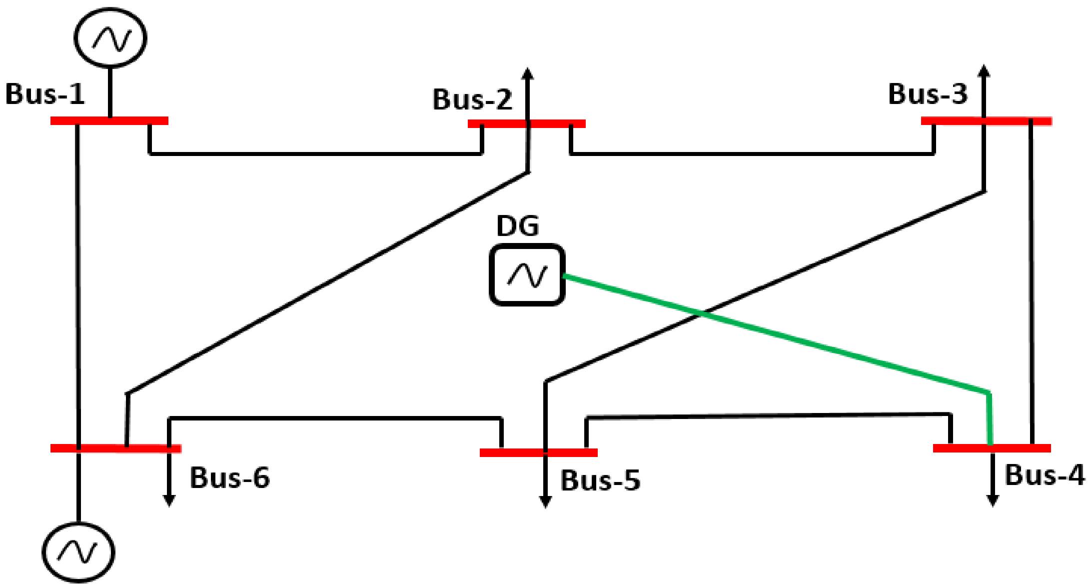

Fig. 4.4: Final optimal DG location (IEEE-6 bus)

4.4 IEEE-14 Bus System Analysis

For the load flow studies, another different IEEE-14 bus system of Fig. 4.5 is considered, to verify the results which has 3 generator and 11 load buses. Bus-1 is selected as the slack bus while taking bus-13 and bus-14 as the *PV* bus, except all are *PQ* buses. The line impedances and the line charging admittances are given in Table 4.17.

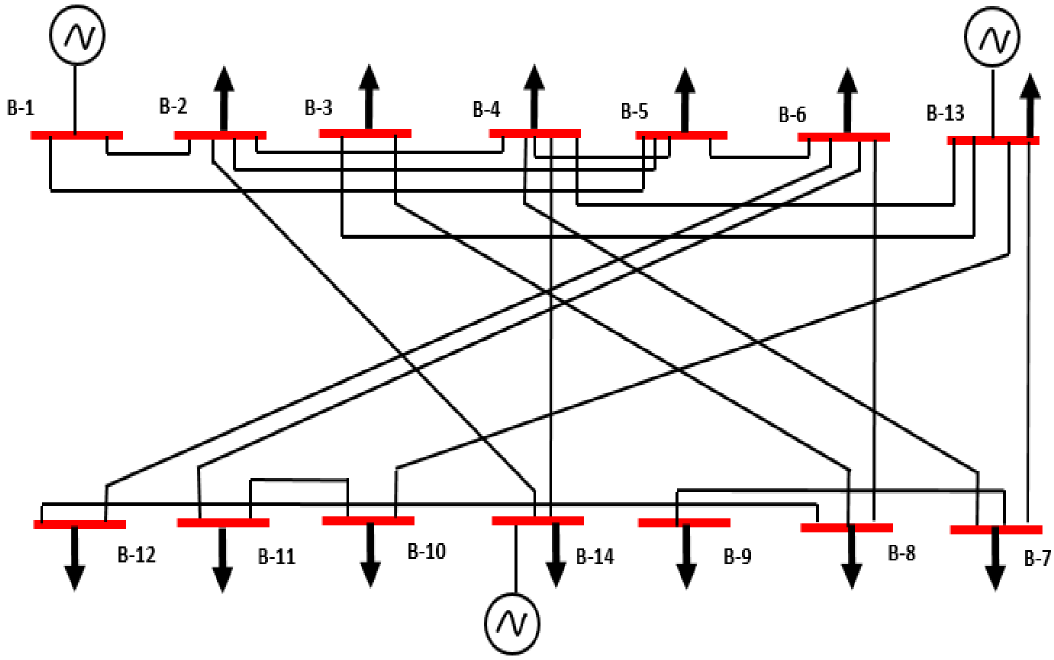

Fig. 4.5: IEEE-14 bus diagram [61]

Table 4.17: IEEE-14 bus system line data [61]

Line (Bus to Bus)		Impedance (pu)		Line Charging (Y/2)
		R ohm	*X* ohm	
1	2	0.01938	0.05917	0.0264
1	5	0.05403	0.22304	0.0219
2	14	0.04699	0.19797	0.0187
2	4	0.05811	0.17632	0.0246
2	5	0.05695	0.17388	0.017
14	4	0.06701	0.17103	0.0173
4	5	0.01335	0.04211	0.0064
4	7	0.0121	0.20912	0.0014
4	13	0.0211	0.55618	0.00241
5	6	0.03217	0.25202	0.0014
6	11	0.09498	0.1989	0.00611
6	12	0.12291	0.25581	0.00121
6	8	0.06615	0.13027	0.0014
7	9	0.04131	0.17615	0.0111
7	13	0.02133	0.11001	0.00131
13	10	0.03181	0.0845	0.0164
13	3	0.12711	0.27038	0.0025
10	11	0.08205	0.19207	0.0114
12	8	0.22092	0.19988	0.0164
8	3	0.17093	0.34802	0.00347

The known bus voltage magnitudes, their angles, operating time & the power generated by generator bus and DG system are given in Table 4.18 and 4.19.

Table 4.18: Bus voltage magnitudes and generated power data

Bus Type	Bus No.	Bus Voltage		Power Generated	
		Magnitude (pu)	Angle (deg)	*P* (MW)	*Q* (MVAR)
Slack	1	1.06	-	40	-
PQ bus	2	-	-	-	-
	3	-	-	-	-
	4	-	-	-	-
	5	-	-	-	-
	6	-	-	-	-
	7	-	-	-	-
	8	-	-	-	-
	9	-	-	-	-
	10	-	-	-	-
	11	-	-	-	-
	12	-	-	-	-
PV bus	13	1.01	-	35	-
	14	1.045	-	25	-
DG	-	1.00	-	3	-

Table 4.19: Generator operating time data

Generator	Max (MW)	Min (MW)	Up Time (Hr)	Down Time (Hr)	Priority Order
Gen-1	40	20	6	3	1
Gen-2	35	10	5	2	2
Gen-3	25	08	4	2	3
DG	3	0.5	2	1	4

The power consumed at each load bus are considered in both time invariant usually maximum load and probabilistic time variant loading conditions in Table 4.20 and Fig. 4.6 respectively. Yearly probabilistic load variation for the above system is assumed as the worst possible case where maximum load data is mark out as the time-invariant load.

Table 4.20: Time invariant loads at all load connected buses

Bus No.	Max Load		Bus No.	Max Load	
	P (MW)	*Q* (MVAR)		*P* (MW)	*Q* (MVAR)
1	0	0	8	8.2	2.2
2	8.2	3.8	9	10.3	3.1
3	8.9	3.2	10	9.4	2.4
4	9.5	2.8	11	10.2	2.7
5	9.3	2.4	12	8.7	2.4
6	9.9	3.1	13	9.3	2.7
7	10.8	2.7	14	10.3	2.6

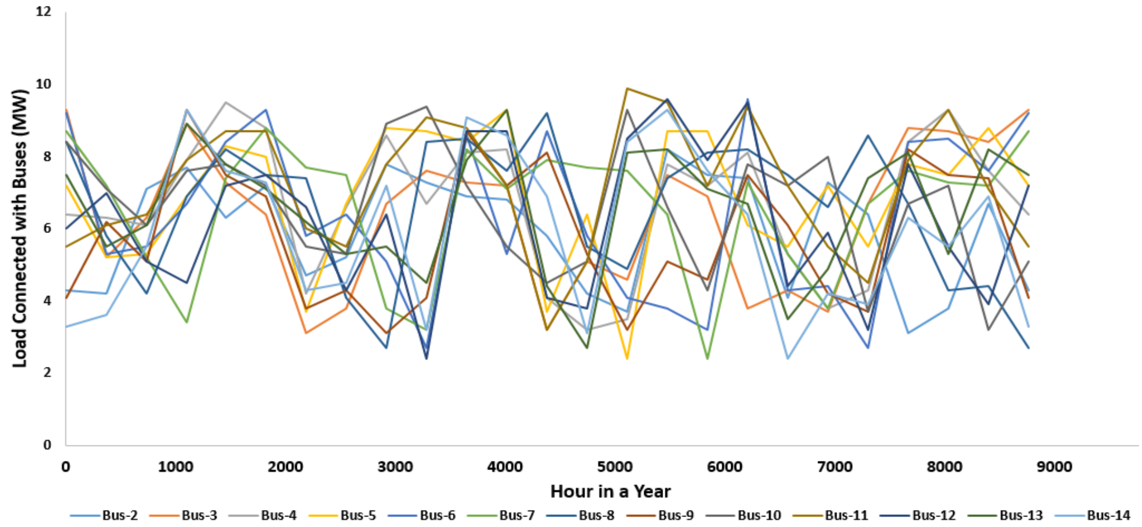

Fig. 4.6(a): Probabilistic time variant loads in buses (Real Power)

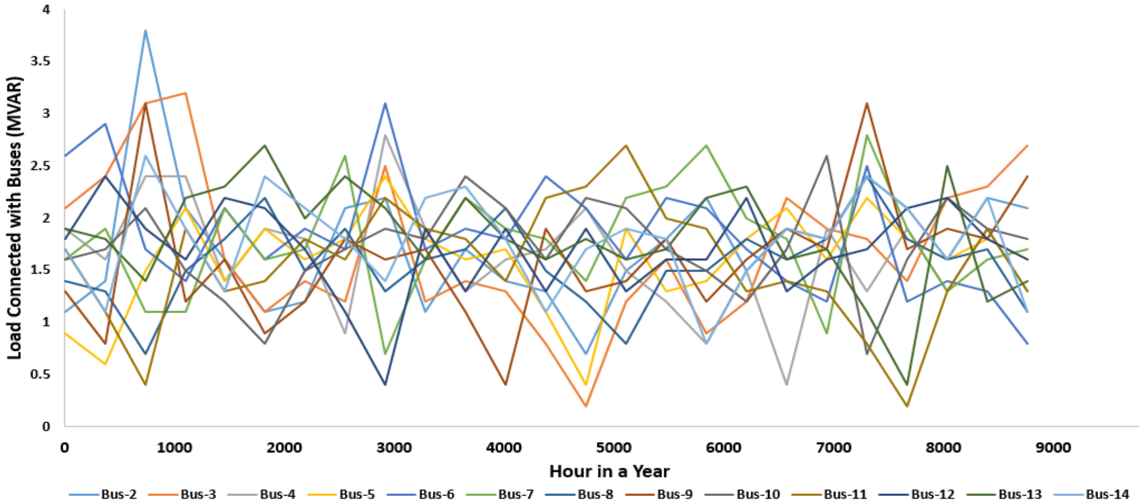

Fig. 4.6(b): Probabilistic time variant loads in buses (Reactive Power)

Considering 3 MW capacity DG need to be connected with the given system which has some possible connection in the system depicted in Fig. 4.6. But to find the optimal position for connection developed algorithm is used.

4.4.1 Load flow analysis

Y bus matrix is formed using the date of Table 4.16. It is to be noted here that the sources and their internal impedances are not considered while forming the *Y* bus matrix for load flow studies which deal only with the bus voltages. The bus voltage magnitudes, their angles, the power generated and consumed at each bus are given in Table 4.17 where, load buses have no voltage values. In the Table 4.21 some of the voltages and their angles are given in boldface letters. This indicates that these are initial data used for starting the load flow program.

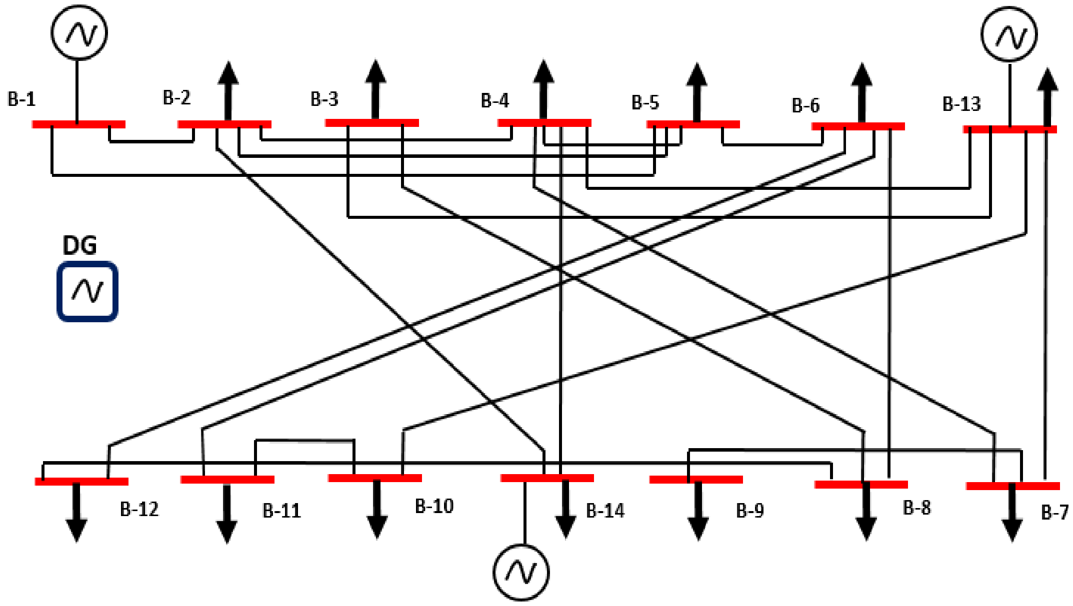

Fig. 4.7: Possible connection for DG in IEEE-14 bus system

The power and reactive power generated at the slack bus and the reactive power generated at the *PV* bus are unknown. Therefore, each of these quantities are indicated by a dash (-). Since, initial estimate is not required of these quantities for load flow calculations. Also note from Fig. 4.5 that the slack bus does not contain any load while the *PV* bus at 13, 14 bus number has a local load and this is indicated in the load column. It is to be noted that the real and reactive powers are given respectively in MW and MVAR. However, they are converted into per unit quantities where a base of 100 MVA is chosen.

Table 4.21: Initial data for buses

Bus Type	Bus No.	Bus Voltage		Power Generated	
		Magnitude (pu)	Angle (deg)	*P* (MW)	*Q* (MVAR)
Slack	1	1.06	0	40	-
PQ	2	**1**	**0**	0	0
	3	**1**	**0**	0	0
	4	**1**	**0**	0	0
	5	**1**	**0**	0	0
	6	**1**	**0**	0	0
	7	**1**	**0**	0	0
	8	**1**	**0**	0	0
	9	**1**	**0**	0	0
	10	**1**	**0**	0	0
	11	**1**	**0**	0	0
	12	**1**	**0**	0	0
PV	13	1.01	**0**	35	-
	14	1.045	**0**	25	-
DG	-	1.00	**0**	3	-

Acceleration factor is used with a value less than 2 for the convergence to occur. It is already seen that the algorithm converges in the least number of iterations when λ is 0.4 and the maximum number of iterations are required when λ is 2. In fact, the algorithm starts to diverge if larger values of acceleration factor are chosen. The system data after the convergence of the algorithm is given at Table 4.22 to Table 4.23 and Fig. 4.8 for all possible connections where, change of bus voltages reduced or improved bus voltage magnitude after inserting DG in each of connection is depicted in details.

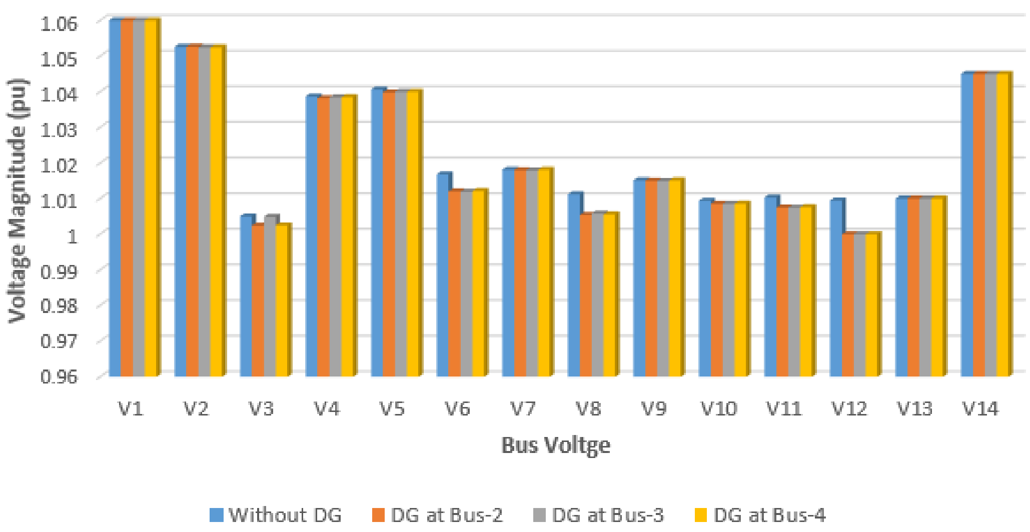

Fig. 4.8(a): Change in voltage profile after DG insertion

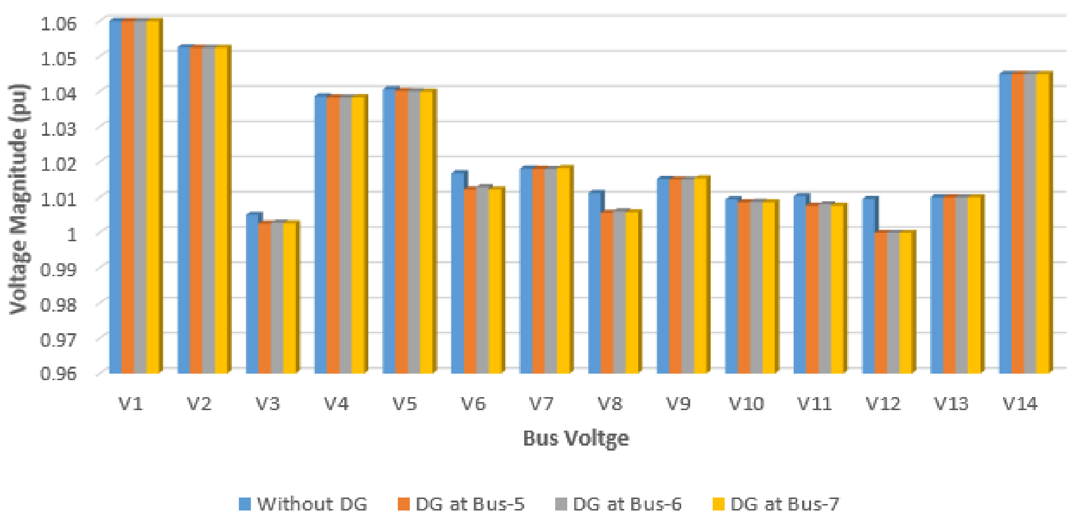

Fig. 4.8(b): Change in voltage profile after DG insertion

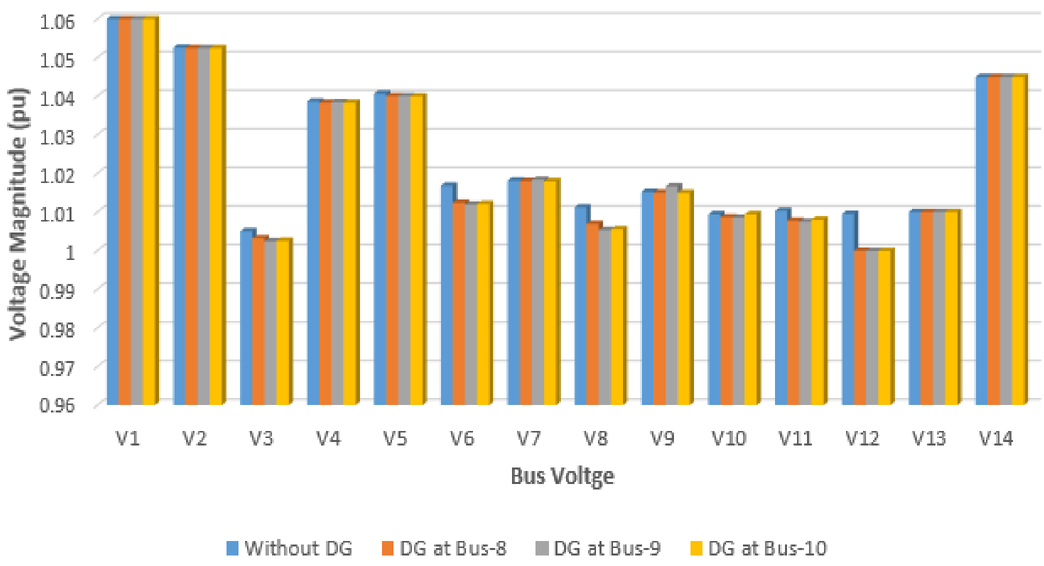

Fig. 4.8(c): Change in voltage profile after DG insertion

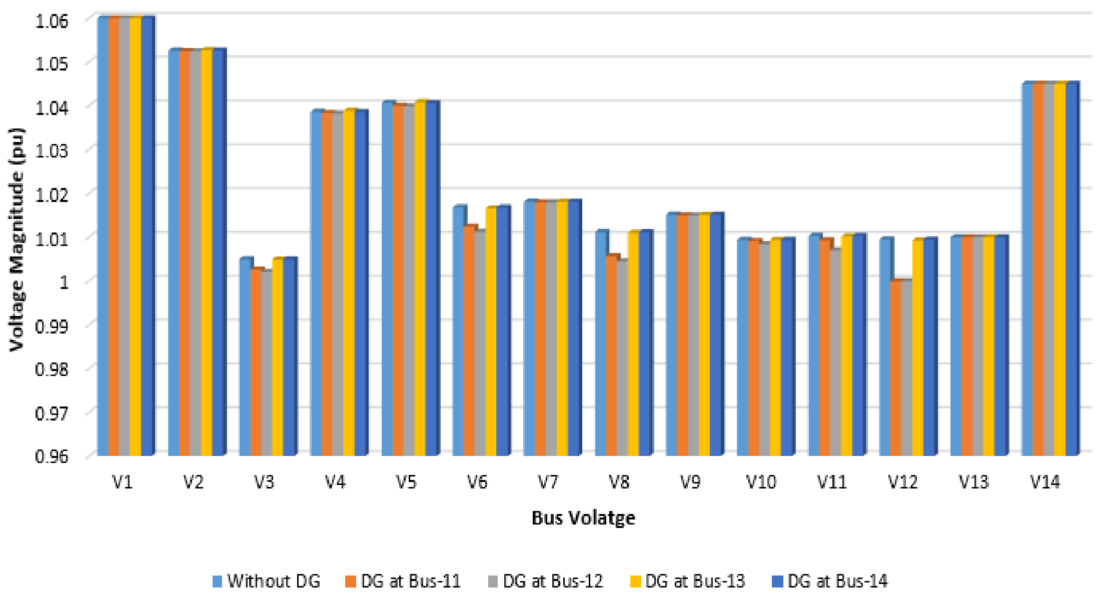

Fig. 4.8(d): Change in voltage profile after DG insertion

Table 4.22: Updated bus voltage after DG insertion (time variant loads)

Voltage pu	Without DG	DG Placement (Bus Number)											
		2	3	4	5	6	7	8	9	10	11	12	13	14
V1	1.060	1.060	1.060	1.060	1.060	1.060	1.060	1.060	1.060	1.060	1.060	1.060	1.060	1.060
V2	1.053	1.053	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.053	1.053
V3	1.005	1.002	1.005	1.002	1.003	1.003	1.003	1.003	1.002	1.002	1.003	1.002	1.005	1.005
V4	1.039	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.039	1.039
V5	1.041	1.040	1.040	1.040	1.040	1.040	1.040	1.040	1.040	1.040	1.040	1.040	1.041	1.041
V6	1.017	1.012	1.012	1.012	1.012	1.013	1.012	1.012	1.012	1.012	1.012	1.011	1.017	1.017
V7	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018
V8	1.011	1.005	1.006	1.005	1.006	1.006	1.006	1.007	1.005	1.006	1.006	1.004	1.011	1.011
V9	1.015	1.015	1.015	1.015	1.015	1.015	1.015	1.015	1.017	1.015	1.015	1.015	1.015	1.015
V10	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.008	1.009	1.009
V11	1.010	1.007	1.007	1.008	1.008	1.008	1.008	1.008	1.007	1.008	1.009	1.007	1.010	1.010
V12	1.009	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.009	1.009
V13	1.010	1.010	1.010	1.010	1.010	1.010	1.010	1.010	1.010	1.010	1.010	1.010	1.010	1.010
V14	1.045	1.045	1.045	1.045	1.045	1.045	1.045	1.045	1.045	1.045	1.045	1.045	1.045	1.045
V_{bus} Index	1.024	1.022	1.0226	1.0224	1.0224	1.0226	1.0225	1.0226	1.0225	1.0225	1.0227	1.022	1.0228	1.0228
f	0.65	0.67	0.69	0.68	0.67	0.63	0.61	0.67	0.68	0.69	0.66	0.68	0.70	0.69

Table 4.23: Line losses after DG insertion (time variant loads)

Ser	Line (Bus to Bus)		Without DG	DG Placement (Bus Number)												
				2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	2	0.052	0.043	0.044	0.047	0.047	0.049	0.049	0.047	0.045	0.047	0.047	0.046	0.044	0.043
2	1	5	0.072	0.071	0.064	0.067	0.066	0.068	0.070	0.066	0.066	0.067	0.067	0.065	0.063	0.066
3	2	4	0.044	0.047	0.040	0.041	0.043	0.043	0.042	0.042	0.040	0.042	0.042	0.041	0.039	0.042
4	2	5	0.045	0.049	0.041	0.043	0.041	0.043	0.045	0.042	0.042	0.043	0.042	0.041	0.040	0.044
5	2	14	0.028	0.027	0.030	0.030	0.029	0.028	0.029	0.029	0.030	0.029	0.029	0.029	0.031	0.039
6	3	8	0.031	0.025	0.037	0.026	0.026	0.023	0.032	0.018	0.027	0.029	0.025	0.017	0.036	0.031
7	3	13	0.096	0.096	0.059	0.099	0.098	0.092	0.107	0.082	0.101	0.103	0.096	0.084	0.104	0.097
8	4	5	0.008	0.007	0.007	0.009	0.006	0.007	0.008	0.007	0.008	0.008	0.007	0.006	0.010	0.010
9	4	7	0.016	0.016	0.015	0.017	0.016	0.016	0.014	0.015	0.014	0.015	0.015	0.015	0.015	0.016
10	4	13	0.006	0.006	0.005	0.006	0.006	0.006	0.006	0.006	0.006	0.005	0.005	0.005	0.006	0.006
11	4	14	0.101	0.103	0.094	0.095	0.098	0.098	0.097	0.096	0.095	0.096	0.096	0.096	0.095	0.124
12	5	6	0.098	0.106	0.092	0.108	0.110	0.094	0.109	0.091	0.101	0.101	0.095	0.090	0.092	0.098
13	6	8	0.019	0.022	0.016	0.023	0.023	0.026	0.023	0.012	0.021	0.022	0.024	0.019	0.018	0.019
14	6	11	0.013	0.008	0.007	0.008	0.008	0.007	0.010	0.007	0.009	0.011	0.013	0.005	0.015	0.013
15	6	12	0.025	0.031	0.027	0.034	0.034	0.040	0.038	0.030	0.030	0.034	0.035	0.020	0.024	0.025
16	7	9	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.004	0.015	0.015	0.015	0.015	0.015
17	7	13	0.025	0.023	0.028	0.023	0.023	0.025	0.021	0.026	0.022	0.027	0.026	0.026	0.030	0.024
18	8	12	0.007	0.009	0.009	0.010	0.010	0.012	0.013	0.015	0.009	0.010	0.010	0.006	0.007	0.007
19	10	11	0.056	0.052	0.052	0.054	0.053	0.048	0.061	0.047	0.057	0.065	0.038	0.045	0.063	0.056
20	10	13	0.070	0.069	0.069	0.070	0.069	0.065	0.074	0.065	0.072	0.052	0.058	0.063	0.075	0.070
Total (MW)			0.826	0.826	0.753	0.822	0.822	0.804	0.861	0.758	0.797	0.823	0.787	0.735	0.819	0.845

4.3.2 Cost analysis

The IEEE-14 system has 3 generator including DG, all the cost coefficient values are given in Table 4.24.

Table 4.24: Data for cost coefficient's value

Generator	*a*	*b*	*c*	*d*
Gen-1 (40 MW)	25.5	12.3	0.2	206
Gen-2 (35 MW)	27.62	15.4	2.2	281
Gen-3 (25 MW)	20.41	11.7	1.7	250
DG (2 MW)	22.21	18.31	15.23	505

Total system cost for time invariant loads can be calculated by using data from Fig. 4.6 and their corresponding line losses. But for time variant loads generator operating hour is calculated from overall loading hour of a year which is shown in Table 4.25 and Table 4.26. Using above coefficient's in cost functions the total system cost is depicted in Table 4.26.

Table 4.25: Calculation of generator operating time in a year

Yearly Hour	Total 14 Bus P (MW)	Total 14 Bus Q (MVR)	Active Gen	Gen-1 (Hr)	Gen-2 (Hr)	Gen-3 (Hr)	DG (Hr)
1 - 425	74.7	21.6	G1+G2	425	425	0	0
426 - 975	74	21	G1+G2	550	550	4	0
976 - 1375	97.9	25.8	G1+G2+G3	400	400	400	2
1376 - 1800	102.4	24.1	G1+G2+G3+DG	425	425	425	425
1801 - 2320	102.6	21.9	G1+G2+G3+DG	520	520	520	520
2321 - 2870	69	21.7	G1+G3+DG	550	2	550	550
2871 - 3590	69.5	21.4	G1+G3+DG	720	5	720	720
3591 - 4120	102.6	22.6	G1+G2+G3+DG	530	530	530	530
4121 - 4570	97.8	24.6	G1+G2+G3	450	450	450	3
4571 - 5100	102.2	22	G1+G2+G3+DG	530	530	530	530
5101 - 5580	102.8	22.9	G1+G2+G3+DG	480	480	480	480
5581 - 6025	57.4	21.2	G2+G3	3	445	445	1
6026 - 6560	59.2	20.3	G2+G3	0	535	535	0
6561 - 7170	57.9	19.3	G2+G3	6	610	610	2
7171 - 7510	102.6	21.7	G1+G2+G3+DG	340	340	340	340
7511 - 8110	92.4	22.5	G1+G2+G3	600	600	600	3
8111 - 8520	102.7	20.8	G1+G2+G3+DG	410	410	410	410
8521 - 8760	73.9	21.6	G1+G2	240	240	2	1
Total				7179	7497	7551	4517

Table 4.26: Total system cost in a year

System	Time-invariant	Time-variant
	Total Annual Cost (BD Tk)	Total Annual Cost (BD Tk)
Without DG	186518.3902	119733.105
With DG At Bus-2	187512.1955	120373.3303
With DG At Bus-3	187365.4067	120261.9845
With DG At Bus-4	187602.765	120366.0432
With DG At Bus-5	187575.247	120366.0432
With DG At Bus-6	187529.9211	120339.8554
With DG At Bus-7	187794.9822	120427.0801
With DG At Bus-8	187231.9035	120268.8932
With DG At Bus-9	187669.225	120328.4409
With DG At Bus-10	187530.3508	120367.4386
With DG At Bus-11	187561.7289	120313.8265
With DG At Bus-12	187257.9474	120233.9478
With DG At Bus-13	187503.3807	120362.3786
With DG At Bus-14	187608.5549	120402.5441

4.3.3 Comparison in loading conditions

Two types of loading condition have different bus voltage profile, line loss and cost values which are depicted in Fig. 4.9 to Fig. 4.11.

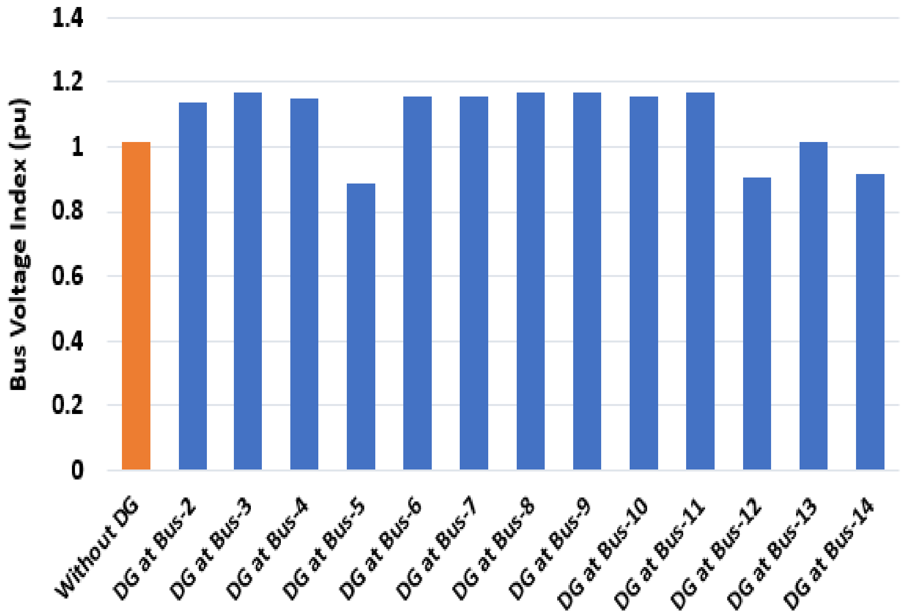

Fig. 4.9(a): Voltage profile variation (time invariant load)

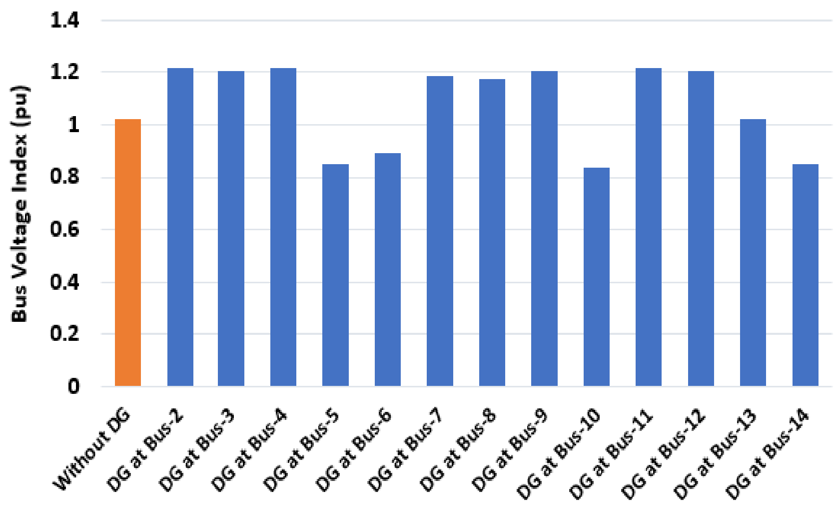

Fig. 4.9(b): Voltage profile variation (time variant load)

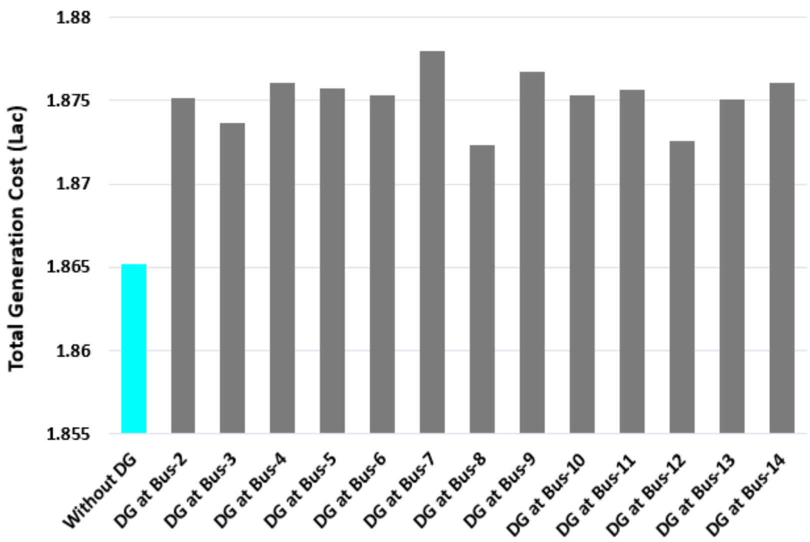

Fig. 4.10(a): Line to line loss variation (time invariant load)

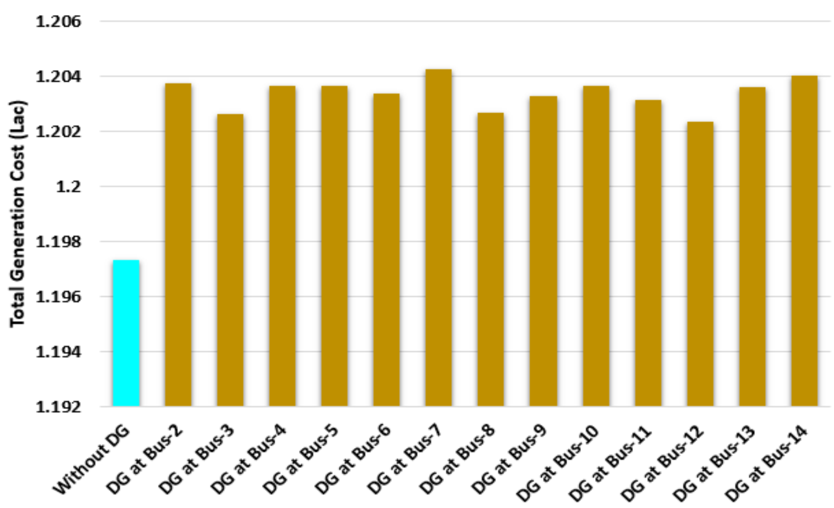

Fig. 4.10(b): Line to line loss variation (time variant load)

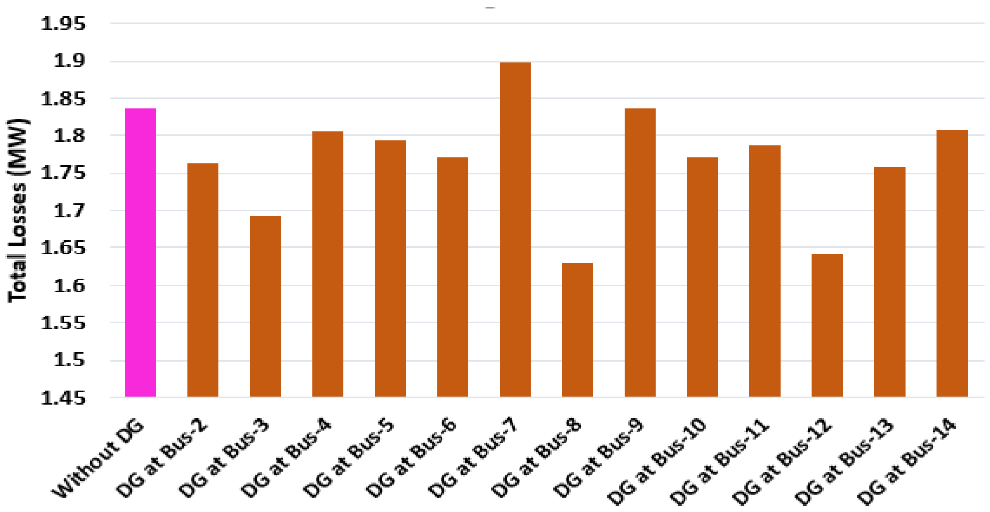

Fig. 4.11(a): Total system cost variation (time invariant load)

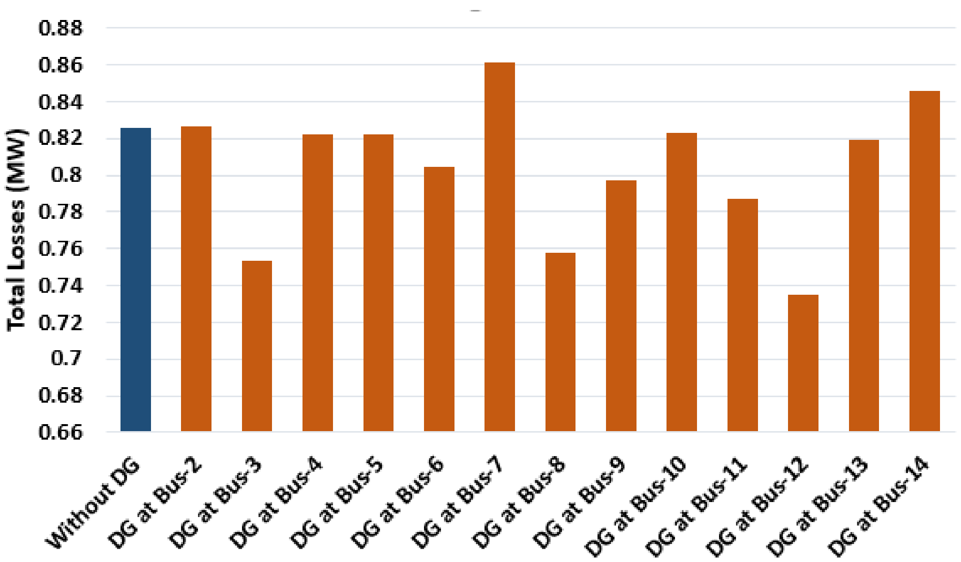

Fig. 4.11(b): Total system cost variation (time variant load)

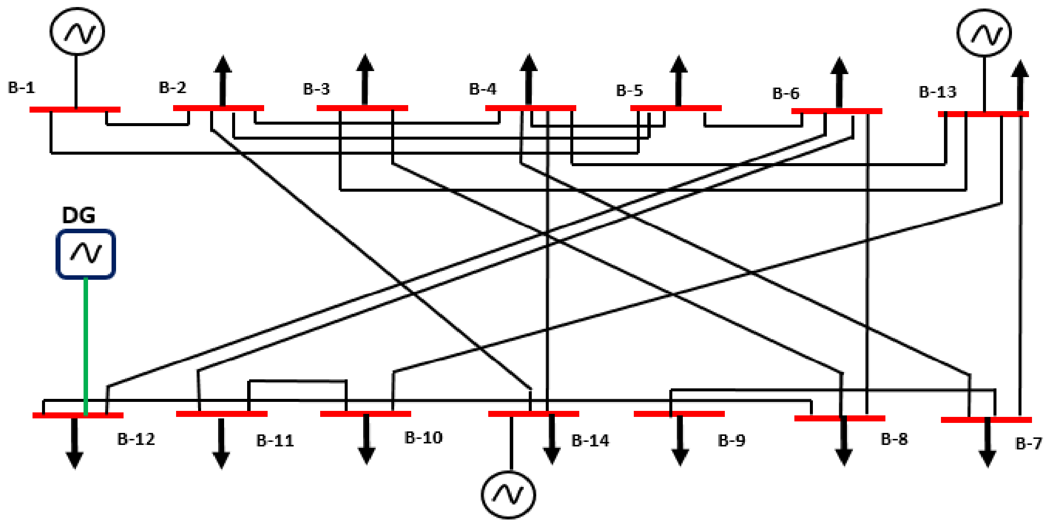

Fig. 4.12: Final optimal DG location (IEEE-14 bus)

4.3.4 Optimal location

From the above discussion it is clear that, with probabilistic time variant loads Bus-12 is found as the optimal place while for invariant loads it is Bus-8 shown in Table 4.27. As power system network is one of the major unpredictable scenario which vary in different time to time. Decision for time invariant system will affect the system during different loading conditions. So final decision for optimal placement will be on basis of time variant systems depicted in Figure 4.12 as it will ensure 2.78% less power loss, 0.03% more qualitative bus voltage enhancement and 0.03% less generation cost.

Table 4.27: Decision for optimal location of DG (IEEE-14 bus)

DG Placement	Time In-variant Loads				Time Variant Loads			
	Total Change in %			Decision	Total Change in %			Decision
	Loss (MW)	Voltage (pu)	Cost (BDT)		Loss (MW)	Voltage (pu)	Cost (BDT)	
Without DG	1.84	1.017	186518.3		0.825	1.024	119733.1	
Bus-2	(-)3.99	(+)0.12	(+)0.53		(+)0.05	(+)0.19	(+)0.53	
Bus-3	(-)7.80	(+)0.15	(+)0.45		(-)8.77	(+)0.18	(+)0.44	
Bus-4	(-)1.64	(+)0.13	(+)0.58		(-)0.52	(+)0.19	(+)0.53	
Bus-5	(-)2.35	(+)0.13	(+)0.57		(-)0.52	(-)0.17	(+)0.53	
Bus-6	(-)3.53	(+)0.14	(+)0.54		(-)2.60	(-)0.13	(+)0.51	
Bus-7	(+)3.33	(+)0.14	(+)0.68		(+)4.30	(+)0.16	(+)0.58	
Bus-8	(-)11.28	(+)0.15	(+)0.38	Selected	(-)8.22	(+)0.15	(+)0.45	
Bus-9	(+)0.08	(+)0.15	(+)0.62		(-)3.50	(+)0.18	(+)0.50	
Bus-10	(-)3.51	(+)0.14	(+)0.54		(-)0.41	(-)0.18	(+)0.53	
Bus-11	(-)2.70	(+)0.15	(+)0.56		(-)4.66	(+)0.19	(+)0.49	
Bus-12	(-)10.60	(+)0.11	(+)0.40		(-)11.0	(+)0.18	(+)0.42	Selected
Bus-13	(-)4.21	(+)0.00	(+)0.53		(-)0.81	0.00	(+)0.53	
Bus-14	(-)1.49	(+)0.00	(+)0.58		(+)2.36	(-)0.17	(+)0.56	

4.4. Case Study

Demand of electricity is increasing rapidly due to enhanced economic activities in the country with sustained gross domestic product growth. At present, growth of demand is about 10% which is expected to be more in coming years [62]. Demand of electricity in the system varies throughout the day and night. The maximum demand is occurred during 5 pm to 11 pm which is termed as 'peak hour' and other part of the time is termed as off-peak hour. The extent of this variation is measured in terms of Load Factor, which is the ratio of average and maximum demand. For economic reasons, it is desirable to have a higher Load Factor, as this would permit better utilization of plant capacity. Moreover, the cost of energy supply during peak hour is higher, because some relatively costlier power plants are required to put in operation during the peak hour. For these reasons, load management is essential throughout the year for better capacity utilization of power plants and minimum generation cost. To ensure proper load management DG placement plays a vital role. The proposed method analyzes the variations in seasonal and daily load patterns as well as hydro generation and the availability of solar and wind energy sources are captured by using data for 2014–15 for Bangladesh where the entire year is divided into 12 seasons to capture seasonal variation. The average hourly load pattern for a day in a month (or season) represents the daily load pattern for that particular season (or month). Thus, an average hourly load of over 24 hours of a day in each month represents the daily load pattern of each month in the model which correspond to a year. We, therefore, have 8760 = 24 x 365 sub-periods for each year. Fig. 4.13 along with Table 4.28 and Table 4.29 presents the organized scaled form of the load curve of the 8760 sub-periods for a year of Bangladesh [63].

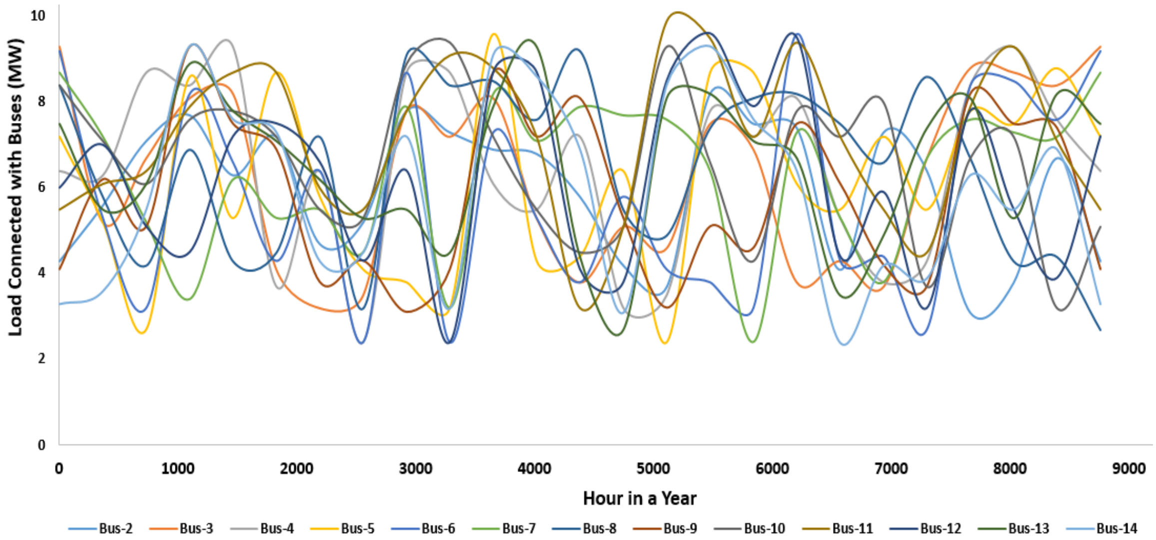

Fig. 4.13(a): Realistic scaled load variation (Real power)

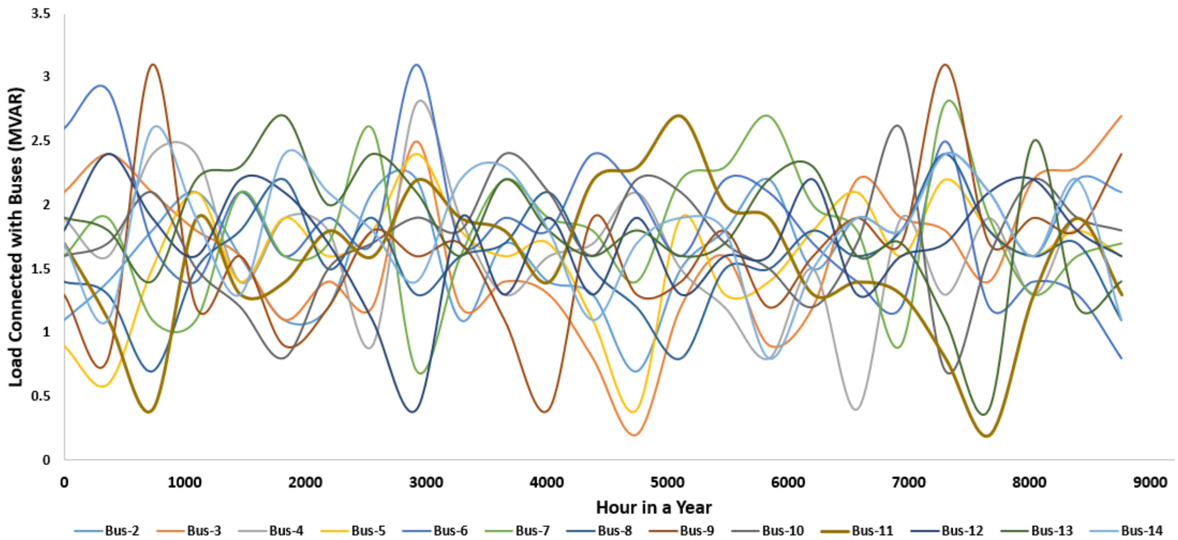

Fig. 4.13(b): Realistic scaled load variation (Reactive power)

Table 4.28: Realistic scaled load variation data (Real power)

Hour	Bus-2	Bus-3	Bus-4	Bus-5	Bus-6	Bus-7	Bus-8	Bus-9	Bus-10	Bus-11	Bus-12	Bus-13	Bus-14
0	4.3	9.3	6.4	7.2	9.2	8.7	8.4	4.1	8.4	5.5	6	7.5	3.3
365	5.6	5.2	6.3	5.2	5.3	7.2	5.8	6.2	7.1	6.1	7	5.5	3.6
730	7.1	6.7	8.7	2.7	3.2	5.2	4.2	5.1	6.1	6.4	5.1	6.1	5.5
1095	7.7	8.1	8.4	8.6	8.2	3.4	6.9	9.3	7.6	7.9	4.5	8.9	9.3
1460	6.3	8.2	9.3	5.3	6.6	6.2	4.3	7.5	7.8	8.7	7.2	7.8	7.6
1825	7.2	4.1	3.7	8.7	4.3	5.3	4.5	6.9	7.2	8.7	7.5	7.1	7.3
2190	4.7	3.2	6.4	5.8	6.4	5.5	7.2	3.8	5.5	6	6.6	6.2	4.3
2555	5.2	3.5	2.4	4.1	2.4	4.5	3.2	4.3	5.3	5.5	4.3	5.3	4.5
2920	7.8	7.8	8.7	3.8	8.7	7.9	9.1	3.1	8.9	7.8	6.4	5.5	7.2
3285	7.3	7.2	8.7	3.2	2.4	3.2	8.4	4.1	9.4	9.1	2.4	4.5	3.2
3650	6.9	8.1	6.1	9.6	7.3	8.2	8.5	8.7	7.2	8.8	8.7	7.9	9.1
4015	6.8	5.3	5.5	4.3	5.3	7.1	7.6	7.2	5.5	7.2	8.7	9.3	8.6
4380	5.8	3.8	7.2	4.4	3.8	7.9	9.2	8.1	4.5	3.2	4.1	4.4	6.9
4745	4.2	5.1	3.2	6.4	5.8	7.7	5.5	5.3	5.1	5.1	3.8	2.7	3.1
5110	3.7	4.6	3.5	2.4	4.1	7.6	4.9	3.2	9.3	9.9	8.5	8.1	8.4
5475	8.2	7.5	7.8	8.7	3.8	6.4	7.4	5.1	6.6	9.5	9.6	8.2	9.3
5840	7.5	6.9	7.2	8.7	3.2	2.4	8.1	4.6	4.3	7.2	7.9	7.1	7.6
6205	7.4	3.8	8.1	6.1	9.6	7.3	8.2	7.5	7.8	9.4	9.5	6.7	6.4
6570	4.1	4.3	5.3	5.5	4.3	5.3	7.5	6.1	7.2	7.2	4.4	3.5	2.4
6935	7.3	3.7	3.8	7.2	4.4	3.8	6.6	4.2	8	5.5	5.9	4.9	4.2
7300	6.4	6.7	4.3	5.5	2.7	6.7	8.6	3.7	3.7	4.5	3.2	7.4	3.9
7665	3.1	8.8	8.4	7.8	8.4	7.6	6.7	8.2	6.7	7.9	7.8	8.1	6.3
8030	3.8	8.7	9.3	7.5	8.5	7.3	4.3	7.5	7.2	9.3	5.5	5.3	5.5
8395	6.7	8.4	7.6	8.8	7.6	7.2	4.4	7.4	3.2	7.1	3.9	8.2	6.9
8760	4.3	9.3	6.4	7.2	9.2	8.7	2.7	4.1	5.1	5.5	7.2	7.5	3.3

Table 4.29: Realistic scaled load variation data (Reactive power)

Hour	Bus-2	Bus-3	Bus-4	Bus-5	Bus-6	Bus-7	Bus-8	Bus-9	Bus-10	Bus-11	Bus-12	Bus-13	Bus-14
0	2.1	1.2	1.3	1.6	0.8	1.7	1.1	2.4	1.8	1.3	1.6	1.4	1.1
365	1.4	2.4	1.6	0.6	1.2	1.9	1.3	0.8	1.7	1.1	2.4	1.8	1.1
730	1.8	2.1	2.4	1.5	1.7	1.1	0.7	2.1	2.1	0.4	1.9	1.4	2.6
1095	2.1	1.8	2.4	2.1	1.4	1.1	1.5	1.2	1.5	1.9	1.6	2.2	1.9
1460	1.6	1.6	1.4	1.4	2.1	2.1	1.8	1.6	1.2	1.3	2.2	2.3	1.3
1825	1.1	1.1	1.9	1.9	1.6	1.6	2.2	0.9	0.8	1.4	2.1	2.7	2.4
2190	1.2	1.4	1.8	1.6	1.9	1.7	1.5	1.2	1.5	1.8	1.7	2	2.1
2555	2.1	1.2	0.9	1.8	1.7	2.6	1.9	1.8	1.7	1.6	1.1	2.4	1.8
2920	2.2	2.5	2.8	2.4	1.6	0.7	1.3	1.6	1.9	2.2	0.4	2.1	1.4
3285	1.1	1.2	1.9	1.8	1.7	1.6	1.6	1.7	1.8	1.9	1.9	1.6	2.2
3650	1.7	1.4	1.3	1.6	1.9	2.2	1.7	1.1	2.4	1.8	1.3	2.2	2.3
4015	1.4	1.3	1.6	1.7	1.8	1.9	2.1	0.4	2.1	1.4	1.9	1.8	1.8
4380	1.3	0.8	1.7	1.1	2.4	1.8	1.5	1.9	1.6	2.2	1.3	1.6	1.1
4745	0.7	0.2	2.1	0.4	2.1	1.4	1.2	1.3	2.2	2.3	1.9	1.8	1.7
5110	1.5	1.2	1.5	1.9	1.6	2.2	0.8	1.4	2.1	2.7	1.3	1.6	1.9
5475	1.8	1.6	1.2	1.3	2.2	2.3	1.5	1.8	1.7	2	1.6	1.7	1.8
5840	2.2	0.9	0.8	1.4	2.1	2.7	1.5	1.2	1.5	1.9	1.6	2.2	0.8
6205	1.5	1.2	1.5	1.8	1.7	2	1.8	1.6	1.2	1.3	2.2	2.3	1.5
6570	1.9	2.2	0.4	2.1	1.4	1.8	1.6	1.9	1.7	1.4	1.3	1.6	1.9
6935	1.8	1.9	1.9	1.6	1.2	0.9	1.8	1.7	2.6	1.3	1.6	1.7	1.8
7300	2.4	1.8	1.3	2.2	2.5	2.8	2.4	3.1	0.7	0.8	1.7	1.1	2.4
7665	2.1	1.4	1.9	1.8	1.2	1.9	1.8	1.7	1.6	0.2	2.1	0.4	2.1
8030	1.6	2.2	1.3	1.6	1.4	1.3	1.6	1.9	2.2	1.3	2.2	2.5	1.6
8395	2.2	2.3	1.9	1.8	1.3	1.6	1.7	1.8	1.9	1.9	1.8	1.2	2.2
8760	2.1	2.7	1.3	1.6	0.8	1.7	1.1	2.4	1.8	1.3	1.6	1.4	1.1

Table 4.30: Updated bus voltage after DG insertion (proposed technique)

Voltage pu	Without DG	DG Placement (Bus Number)												
		2	3	4	5	6	7	8	9	10	11	12	13	14
V1	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
V2	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.052
V3	1.007	1.002	1.004	1.002	1.002	1.003	1.002	1.003	1.002	1.002	1.002	1.002	1.006	1.007
V4	1.038	1.037	1.037	1.037	1.037	1.037	1.037	1.037	1.037	1.037	1.037	1.037	1.038	1.038
V5	1.04	1.039	1.039	1.039	1.039	1.039	1.039	1.039	1.039	1.039	1.039	1.039	1.04	1.04
V6	1.018	1.011	1.011	1.012	1.011	1.012	1.011	1.012	1.011	1.011	1.012	1.011	1.018	1.018
V7	1.017	1.017	1.017	1.017	1.017	1.017	1.017	1.017	1.017	1.017	1.017	1.017	1.017	1.017
V8	1.012	1.004	1.004	1.004	1.004	1.004	1.004	1.005	1.004	1.004	1.004	1.004	1.011	1.012
V9	1.013	1.013	1.013	1.013	1.013	1.013	1.013	1.013	1.014	1.013	1.013	1.013	1.013	1.013
V10	1.009	1.008	1.008	1.008	1.008	1.008	1.008	1.008	1.008	1.008	1.008	1.008	1.009	1.009
V11	1.01	1.007	1.007	1.007	1.007	1.007	1.007	1.007	1.007	1.007	1.008	1.006	1.01	1.01
V12	1.012	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	1.012	1.012
V13	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009
V14	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044
V_{bus} Index	1.024	1.022	1.022	1.022	1.022	1.025	1.022	1.022	1.022	1.023	1.022	1.026	1.024	1.024
f	0.409	0.411	0.409	0.41	0.411	0.410	0.411	0.407	0.409	0.409	0.406	0.412	0.336	0.334

Table 4.31: Line to line losses after DG insertion (proposed technique)

Ser	Line (Bus to Bus)		Without DG	DG Placement (Bus Number)												
				2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	2	0.056	0.056	0.049	0.061	0.055	0.05	0.059	0.061	0.06	0.057	0.061	0.053	0.05	0.05
2	1	5	0.073	0.081	0.067	0.081	0.073	0.067	0.078	0.08	0.079	0.076	0.08	0.07	0.067	0.069
3	2	4	0.046	0.053	0.043	0.049	0.047	0.044	0.048	0.05	0.048	0.047	0.049	0.045	0.043	0.045
4	2	5	0.044	0.052	0.041	0.049	0.044	0.041	0.048	0.048	0.048	0.046	0.048	0.043	0.041	0.043
5	2	14	0.031	0.029	0.033	0.03	0.031	0.033	0.03	0.03	0.03	0.031	0.03	0.032	0.033	0.039
6	3	8	0.016	0.014	0.015	0.016	0.013	0.009	0.016	0.012	0.016	0.015	0.015	0.009	0.018	0.016
7	3	13	0.092	0.096	0.06	0.102	0.09	0.075	0.102	0.089	0.103	0.098	0.099	0.076	0.098	0.092
8	4	5	0.006	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.007	0.007
9	4	7	0.018	0.019	0.017	0.02	0.019	0.017	0.017	0.018	0.017	0.017	0.018	0.017	0.017	0.018
10	4	13	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
11	4	14	0.122	0.127	0.115	0.123	0.12	0.116	0.122	0.124	0.122	0.121	0.123	0.117	0.117	0.138
12	5	6	0.085	0.105	0.082	0.11	0.10	0.079	0.104	0.099	0.105	0.098	0.101	0.085	0.081	0.085
13	6	8	0.019	0.024	0.016	0.026	0.023	0.021	0.024	0.019	0.024	0.023	0.026	0.018	0.018	0.019
14	6	11	0.01	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.004	0.004	0.01	0.01
15	6	12	0.017	0.036	0.024	0.041	0.032	0.027	0.037	0.038	0.038	0.035	0.041	0.023	0.017	0.017
16	7	9	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.013	0.024	0.024	0.024	0.024	0.024
17	7	13	0.024	0.021	0.026	0.021	0.022	0.025	0.02	0.022	0.02	0.024	0.023	0.025	0.027	0.024
18	8	12	0.001	0.004	0.003	0.005	0.003	0.003	0.004	0.007	0.005	0.004	0.005	0.002	0.001	0.001
19	10	11	0.049	0.049	0.042	0.051	0.046	0.038	0.052	0.047	0.052	0.055	0.04	0.041	0.053	0.049
20	10	13	0.067	0.068	0.063	0.07	0.066	0.06	0.071	0.067	0.071	0.055	0.061	0.062	0.07	0.067
Total (MW)			0.805	0.872	0.734	0.893	0.821	0.744	0.870	0.849	0.865	0.84	0.858	0.755	0.797	0.818

Table 4.32: Updated bus voltage after DG insertion (average load value)

Voltage pu	Without DG	DG Placement (Bus Number)											
		2	3	4	5	6	7	8	9	10	11	12	13	14
V1	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
V2	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.052	1.052
V3	1.005	1.001	1.002	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.004	1.005
V4	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.038	1.039	1.038
V5	1.04	1.039	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.041	1.04
V6	1.017	1.011	1.011	1.011	1.011	1.012	1.011	1.011	1.011	1.011	1.011	1.011	1.017	1.017
V7	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018	1.018
V8	1.011	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.01	1.011
V9	1.015	1.014	1.014	1.014	1.014	1.014	1.015	1.014	1.015	1.014	1.014	1.014	1.015	1.015
V10	1.009	1.008	1.008	1.008	1.008	1.008	1.008	1.008	1.008	1.009	1.008	1.008	1.009	1.009
V11	1.01	1.007	1.007	1.007	1.007	1.007	1.007	1.007	1.007	1.007	1.008	1.007	1.01	1.01
V12	1.011	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	1.01	1.011
V13	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009
V14	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044
V_{bus} Index	1.024	1.021	1.025	1.022	1.025	1.022	1.023	1.025	1.022	1.023	1.022	1.022	1.024	1.024
f	0.417	0.419	0.414	0.418	0.419	0.418	0.419	0.415	0.418	0.417	0.414	0.418	0.349	0.346

Table 4.33: Line to line losses after DG insertion (average load value)

Ser	Line (Bus to Bus)		Without DG	DG Placement (Bus Number)												
				2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	2	0.043	0.038	0.04	0.041	0.04	0.039	0.04	0.041	0.04	0.041	0.043	0.041	0.039	0.038
2	1	5	0.062	0.062	0.059	0.061	0.058	0.057	0.06	0.06	0.059	0.06	0.062	0.059	0.057	0.058
3	2	4	0.04	0.042	0.038	0.038	0.039	0.038	0.038	0.039	0.038	0.039	0.04	0.039	0.037	0.039
4	2	5	0.039	0.043	0.038	0.039	0.037	0.037	0.039	0.038	0.038	0.039	0.04	0.038	0.036	0.039
5	2	14	0.03	0.03	0.031	0.031	0.031	0.032	0.031	0.031	0.032	0.031	0.03	0.031	0.032	0.038
6	3	8	0.015	0.01	0.014	0.01	0.01	0.008	0.011	0.008	0.01	0.011	0.011	0.008	0.016	0.015
7	3	13	0.124	0.118	0.094	0.121	0.118	0.108	0.123	0.106	0.121	0.124	0.123	0.107	0.131	0.124
8	4	5	0.008	0.006	0.007	0.008	0.006	0.006	0.007	0.006	0.007	0.007	0.007	0.006	0.009	0.009
9	4	7	0.015	0.015	0.014	0.015	0.015	0.014	0.013	0.014	0.013	0.014	0.014	0.014	0.014	0.015
10	4	13	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
11	4	14	0.098	0.098	0.093	0.093	0.094	0.093	0.093	0.094	0.092	0.094	0.095	0.094	0.093	0.112
12	5	6	0.087	0.094	0.088	0.096	0.096	0.082	0.093	0.086	0.091	0.091	0.092	0.086	0.082	0.086
13	6	8	0.017	0.019	0.016	0.019	0.019	0.02	0.019	0.014	0.018	0.019	0.021	0.017	0.016	0.017
14	6	11	0.011	0.005	0.005	0.005	0.005	0.004	0.005	0.004	0.005	0.006	0.007	0.004	0.012	0.011
15	6	12	0.02	0.029	0.028	0.031	0.029	0.029	0.029	0.028	0.028	0.03	0.034	0.023	0.02	0.02
16	7	9	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.006	0.013	0.013	0.013	0.013	0.013
17	7	13	0.022	0.021	0.023	0.021	0.022	0.023	0.02	0.023	0.02	0.024	0.022	0.023	0.025	0.022
18	8	12	0.002	0.003	0.004	0.004	0.003	0.003	0.003	0.005	0.003	0.004	0.004	0.002	0.002	0.002
19	10	11	0.053	0.049	0.049	0.05	0.049	0.043	0.052	0.046	0.051	0.057	0.041	0.045	0.057	0.053
20	10	13	0.066	0.064	0.064	0.065	0.064	0.06	0.066	0.062	0.066	0.053	0.058	0.062	0.069	0.066
Total (MW)			0.770	0.764	0.773	0.766	0.778	0.714	0.760	0.793	0.743	0.762	0.762	0.787	0.765	0.782

Table 4.34: Updated bus voltage after DG insertion (maxmium load value)

Voltage pu	Without DG	DG Placement (Bus Number)											
		2	3	4	5	6	7	8	9	10	11	12	13	14
V1	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
V2	1.049	1.05	1.049	1.049	1.049	1.049	1.049	1.049	1.049	1.049	1.049	1.049	1.049	1.049
V3	0.994	0.995	0.996	0.995	0.995	0.995	0.995	0.996	0.995	0.995	0.995	0.995	0.994	0.994
V4	1.032	1.032	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.033	1.032	1.032	1.032
V5	1.034	1.034	1.034	1.034	1.034	1.034	1.034	1.034	1.034	1.034	1.034	1.034	1.034	1.034
V6	1.005	1.007	1.007	1.007	1.007	1.008	1.007	1.007	1.007	1.007	1.008	1.007	1.005	1.005
V7	1.014	1.014	1.014	1.014	1.014	1.014	1.014	1.014	1.014	1.014	1.014	1.014	1.014	1.014
V8	0.997	0.999	1.000	0.999	0.999	1.000	0.999	1.000	0.999	0.999	0.999	0.999	0.997	0.997
V9	1.006	1.006	1.006	1.007	1.006	1.006	1.007	1.006	1.008	1.006	1.006	1.006	1.006	1.006
V10	1.005	1.005	1.005	1.005	1.005	1.005	1.005	1.005	1.005	1.006	1.005	1.005	1.005	1.005
V11	1.000	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.002	1.001	1.000	1.000
V12	0.995	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.999	0.995	0.995
V13	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009	1.009
V14	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044	1.044
V_{bus} Index	1.017	1.018	1.016	1.016	1.018	1.018	1.017	1.018	1.018	1.018	1.016	1.018	1.017	1.017
f	0.454	0.455	0.449	0.454	0.454	0.451	0.455	0.45	0.453	0.453	0.449	0.454	0.487	0.485

Table 4.35: Line to line losses after DG insertion (maxmium load value)

Ser	Line (Bus to Bus)		Without DG	DG Placement (Bus Number)												
				2	3	4	5	6	7	8	9	10	11	12	13	14
1	1	2	0.278	0.243	0.257	0.257	0.261	0.26	0.252	0.256	0.257	0.258	0.262	0.26	0.26	0.258
2	1	5	0.274	0.254	0.254	0.256	0.255	0.256	0.25	0.253	0.255	0.256	0.259	0.256	0.259	0.263
3	2	4	0.144	0.139	0.133	0.132	0.136	0.135	0.13	0.133	0.132	0.133	0.136	0.135	0.135	0.14
4	2	5	0.135	0.132	0.126	0.127	0.126	0.126	0.125	0.125	0.127	0.127	0.128	0.127	0.129	0.134
5	2	14	0.002	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.002	0.003
6	3	8	0.009	0.009	0.014	0.01	0.01	0.009	0.01	0.008	0.011	0.011	0.01	0.008	0.01	0.009
7	3	13	0.198	0.188	0.163	0.196	0.197	0.188	0.197	0.177	0.201	0.201	0.197	0.183	0.207	0.199
8	4	5	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001
9	4	7	0.04	0.039	0.038	0.04	0.04	0.039	0.035	0.038	0.035	0.037	0.038	0.039	0.037	0.041
10	4	13	0.01	0.009	0.009	0.01	0.01	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.01
11	4	14	0.152	0.149	0.145	0.145	0.147	0.147	0.143	0.145	0.145	0.146	0.147	0.147	0.146	0.169
12	5	6	0.244	0.228	0.224	0.238	0.243	0.221	0.227	0.219	0.233	0.229	0.229	0.222	0.236	0.244
13	6	8	0.046	0.042	0.038	0.044	0.046	0.048	0.042	0.035	0.044	0.044	0.047	0.04	0.044	0.046
14	6	11	0.005	0.008	0.008	0.007	0.007	0.008	0.007	0.008	0.007	0.007	0.006	0.008	0.005	0.005
15	6	12	0.055	0.043	0.048	0.051	0.053	0.055	0.046	0.046	0.05	0.051	0.056	0.039	0.054	0.055
16	7	9	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.023	0.036	0.036	0.036	0.036	0.036
17	7	13	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.003
18	8	12	0.004	0.003	0.005	0.004	0.005	0.004	0.003	0.005	0.004	0.005	0.005	0.002	0.005	0.004
19	10	11	0.06	0.056	0.059	0.059	0.059	0.054	0.06	0.055	0.062	0.067	0.048	0.055	0.064	0.06
20	10	13	0.101	0.099	0.1	0.101	0.101	0.097	0.102	0.097	0.103	0.085	0.091	0.097	0.105	0.102
Total (MW)			1.797	1.686	1.666	1.822	1.741	1.801	1.683	1.654	1.707	1.811	1.713	1.672	1.848	1.782

Table 4.36: Total system generation cost in a year

System	Proposed Total Annual Cost (BD Tk)	Average Load Total Annual Cost (BD Tk)	Maximum Load Total Annual Cost (BD Tk)
Without DG	119776.584	119723.121	121325.0011
With DG At Bus-2	120340.6663	120287.208	121889.0835
With DG At Bus-3	120443.2226	120278.0517	121712.613
With DG At Bus-4	120232.3052	120215.5461	121680.9029
With DG At Bus-5	120475.4271	120281.1035	121769.7575
With DG At Bus-6	120365.1309	120261.2712	121799.9516
With DG At Bus-7	120247.5476	120201.8410	121736.4128
With DG At Bus-8	120440.157	120271.9488	121707.8548
With DG At Bus-9	120407.9838	120215.5461	121661.8896
With DG At Bus-10	120432.4941	120246.023	121745.9369
With DG At Bus-11	120394.2041	120275.0001	121752.2876
With DG At Bus-12	120421.7688	120275.0001	121755.4634
With DG At Bus-13	120264.3216	120206.4081	121690.4132
With DG At Bus-14	120328.4403	120279.5776	121811.0818

4.4.1 Optimal bus location

For a realistic load data variation, change of bus voltages, line to line loss and generation cost are tabulated in Table 4.30 to 4.36. All the results have been compared with available average load and maximum load of the system as realistic power system network shows many unpredictable scenarios which vary in different time to time. It is clear that with proposed technique Bus-3 is found as the optimal place while for average loads it is Bus-6 and Bus-8 for maximum load value

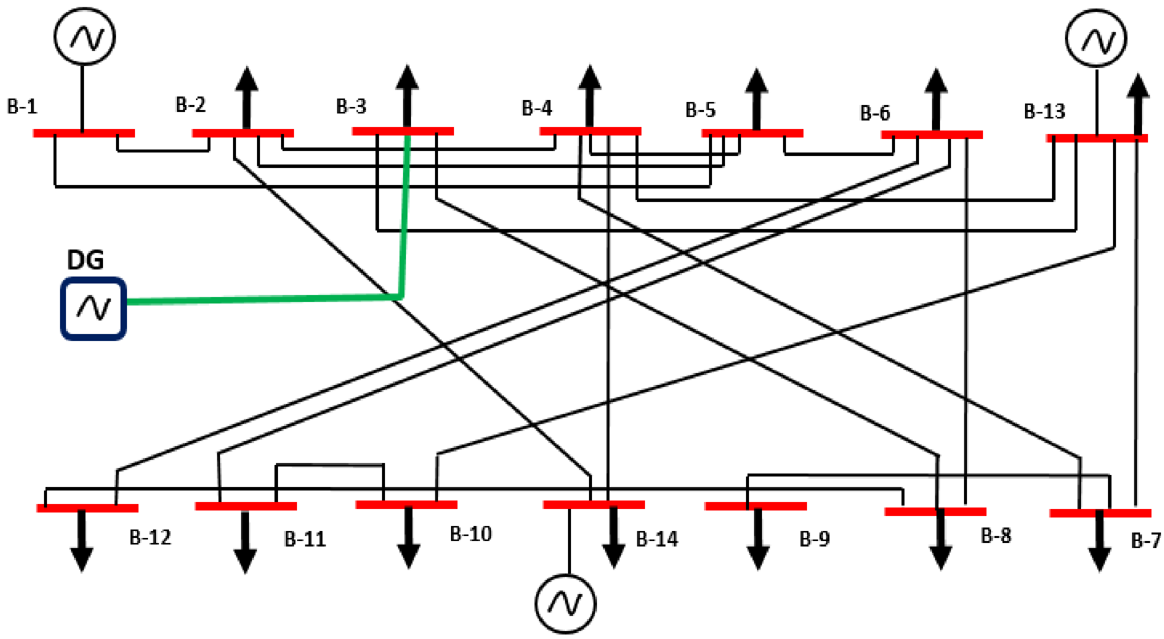

Fig. 4.14: Final optimal DG location for realistic load data

Table 4.39: Decision for optimal location of DG in a realistic load

DG Placement	Proposed Technique				Average Load				Maximum Load			
	Total Change in %			Decision	Total Change in %			Decision	Total Change in %			Decision
	Loss (MW)	Voltage (pu)	Cost (BDT)	Voltage (pu)	Loss (MW)	Voltage (pu)	Cost (BDT)		Loss (MW)	Voltage (pu)	Cost (BDT)	
Without DG	0.805	1.023	119776		0.77	1.024	119723		1.797	1.1017	121325	
Bus-2	(+)8.32	(-)0.17	(+)0.56		(-)0.78	(-)0.14	(+)0.46		(-)6.18	(+)0.18	(+)0.40	
Bus-3	(-)8.82	(+)0.13	(+)0.38	Selected	(-)6.10	(+)0.13	(+)0.38		(-)7.29	(-)0.06	(+)0.39	
Bus-4	(+)10.9	(-)0.12	(+)0.58		(-)0.52	(-)0.14	(+)0.47		(+)4.17	(-)0.08	(+)0.40	
Bus-5	(+)1.99	(-)0.13	(+)0.49		(+)2.21	(+)0.14	(+)0.45		(-)3.12	(+)0.18	(+)0.43	
Bus-6	(-)7.58	(+)0.14	(+)0.39		(-)7.27	(+)0.15	(+)0.37	Selected	(+)5.34	(+)0.09	(+)0.41	
Bus-7	(-)8.07	(-)0.11	(+)0.39		(-)1.30	(-)0.13	(+)0.46		(-)6.34	(-)0.08	(+)0.39	
Bus-8	(-)5.47	(-)0.15	(+)0.53		(-)6.10	(+)0.14	(+)0.41		(-)7.96	(+)0.18	(+)0.39	Selected
Bus-9	(+)7.45	(-)0.16	(+)0.55		(-)3.51	(-)0.13	(+)0.44		(-)5.01	(+)0.19	(+)0.42	
Bus-10	(+)4.35	(+)0.14	(+)0.52		(+)1.04	(-)0.13	(+)0.46		(+)4.79	(+)0.18	(+)0.42	
Bus-11	(+)6.58	(-)0.16	(+)0.54		(-)1.04	(-)0.13	(+)0.46		(-)4.67	(-)0.09	(+)0.43	
Bus-12	(-)6.21	(+)0.13	(+)0.41		(-)6.88	(+)0.14	(+)0.40		(-)6.96	(-)0.07	(+)0.40	
Bus-13	(-)0.99	(+)0.01	(+)0.46		(-)0.65	(-)0.01	(+)0.46		(-)2.73	(+)0.00	(+)0.46	
Bus-14	(+)1.61	(+)0.00	(+)0.49		(+)1.56	(+)0.00	(+)0.49		(-)0.83	(+)0.00	(+)0.49	

from the comparative resulted data analysis at Table 4.39. Though average load value ensures the maximum 0.02% voltage improvement, 0.01% less cost than the proposed technique, but it will cause 1.55% ($\approx$ 0.015 MW) more line to line loss if the DG is connected on basis of this load value. As during DG placement, line to line loss has more prominent impact than improvement of voltage and other factors results the desired final optimal location at Bus-3 of Fig. 14.

4.5. Conclusion

In this chapter, a deterministic method to find optimal DG placement in a distribution network is proposed, where the total real power losses, qualitative bus voltage profile and generation cost of the network are employed as the objective to be optimized. The proposed method is formulated as a constrained nonlinear programming problem and applied to two different distribution systems topologies such as IEEE-6 and IEEE-14 test bus meshed distribution networks along with a realistic case study is also analyzed to show its applicability. Additionally, probabilistic time invariant and variant loading cases were performed for each test system and compared to the case without DG. The results demonstrated that DG placement have a significant influence in minimizing power losses as well as enhancing qualitative voltage profiles at minimum generation cost for time variant loading conditions. Next chapter covers the conclusions made from the results obtained, the beneficiaries of this research work and the recommendations for furthering this research work.

CHAPTER 5

CONCLUSION

5.1 Conclusion

Inclusion of DG units in the system for loss reduction is a very important way to save energy. DG installation is one of the better methods to improve service reliability. It improves system efficiency by enhancing the system voltage profile, reducing the power losses and by decreasing the loading on electrical equipment. In this research, an algorithm is developed for determining the optimal location of DG units with multiple number of objective function in a N-bus network where N is a positive integer value like 10, 58, 178 etc. The proposed algorithm results that reduction of active power loss in distribution system is possible and all node voltages variation can be minimized after ameliorating maximum bus voltage at a least generation cost after inserting DG at an optimal location of a power system network. Due to uncertain loading conditions of today's existing power system network, proposed technique analyzed time variant probabilistic load and distinguishes the divergent of DG location with satisfactory outcomes. It is crucially important to determine the optimal location of DG to be placed for ensuring cost effective network. This developed method is one of the better available for finding out the optimal sizes of multiple DG units in distribution system as it is easy to implement, fast and accurate. For two different test systems, the results of the total power losses, voltage profile change and cost with or without DG for both the systems, are tabulated. From the results obtained, it is found that for large systems, DG placement depends highly on the load variation criterion in the network. Hence to mitigate this problem DGs need to be placed optimally in the system. This results in placement of any number of DGs in the system which results in reduction in power loss and improvement in voltage profile in a cost effective manner.

5.2 Research Findings

The installation of DG units in power distribution networks is becoming more prominent. Consequently, utility companies have started to change their electric infrastructure to adapt to DGs due to the benefits of DG installation on their distribution systems. These benefits include reducing power losses, improving voltage profiles, reducing emission impacts and improving power quality. Additional benefits are avoiding upgrading the present power systems and preventing a reduction of transmission & distribution network capacity during the planning phase. Nevertheless, achieving these benefits depends highly on the capacity of the DG units and their installation placement in the distribution systems. In this research, an innovative approach for management of DG power is represented. The proposed method deals with optimal selection of nodes for the placement of the DG by using MATLAB code. The load flow problem has been solved by gauss-seidal iteration methodology. The rating and location has been optimized using heuristics algorithm. In developed algorithm, coding is developed to carry out the allocation problem, which is identification of location by one dimensional array. The effectiveness of the approach is demonstrated on the IEEE-6 and 14 bus reliability test system. If DGs are connected to the system, the simulation results conclude that reduction of active power loss in distribution system is possible and all node voltages variation can be achieved within the required limit. Multi-objective optimization gives the better optimal result then the single-objective optimization. Induction DGs are connected into the systems power loss and voltage profile is better from when the capacitor bank is connected into the systems, though the induction DGs are consuming reactive power from the system where extra amount of power loss is occurred due to reactive power flow through the line. The proposed adaptive algorithm gives the most satisfactory and acceptable result among all the approach is considered in the literature study. The proposed algorithm gives the better result in all part of optimization (i.e. in case for minimum voltage and power loss with cost) for not only time invariant but also time variant loads. The convergence criteria of the proposed algorithm are well acceptable. In modern load growth scenario probabilistic load and generation model shows that the system, reduction of power loss in distribution system is possible and all node voltages variation can be achieved within the required limit without violating the thermal limit of the system. From the analysis of load and generation uncertainty, the system has different bus location during static and dynamic loading conditions. So, decision for optimal placement must be taken on dynamic loading conditions due to the large variations in load characteristics. From the study the following conclusions are drawn.

- The optimal placement is yielding leading to increase in qualitative voltage profile magnitudes and reduction in losses in a cost effective manner.
- The developed algorithm is effective in interpreting the allocation of distributed generator for different number of candidate nodes and generators.

- The study has been carried out on unbalanced distribution networks with worst possible loading characteristics.
- Developed algorithm has better performance over basic DG allocation techniques.

5.3 Future Work

The completion of research project opens the avenues for work in many other related areas. The following areas are identified for future work:

- Optimization process has been carried out on basic optimization process. The improved version of other algorithm like different types of genetic, artificial intelligence algorithm is available and can be applied in this networks for better optimization.
- The boundary conditions (DGs rating, total DGs power injection etc.) can be modified and applied into the networks.
- The DGs allocation problem can be extended for DGs reactive power optimization.

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LIST OF PUBLICATIONS

[1] **S. M. Hossain** and A. H. Chowdhury "Optimal Placement of Distributed Generation to Enhance Bus Voltage Qualitative Index", *International Journal of Engineering and Technology (IJET),* Vol-10, No-6, Jan 2019, pp: 1778-1786.

[2] **S. M. Hossain** and A. H. Chowdhury "Multi-objective optimal placement of distributed generations for dynamic loads", accepted on '*International Journal of Electrical and Computer Engineering'*.

APPENDIX-A

MATLAB CODE

***Y*-BUS:**

```
function Y = ybus(I)

global N;

Y = zeros(N);
Y_ch = zeros(N);

size_I = size(I);
for k = 1:size_I(1)
    Y(I(k,1),I(k,2)) = -1/((I(k,3)+i*I(k,4)));
    Y(I(k,2),I(k,1)) = -1/((I(k,3)+i*I(k,4)));
    Y_ch(I(k,1),I(k,2)) = i*I(k,5);
    Y_ch(I(k,2),I(k,1)) = i*I(k,5);
end
for k = 1:N
    Y(k,k) = -sum(Y(k,:))+sum(Y_ch(k,:));
end

end
```

BUS VOLTAGE & LOSS CALCULATION:

```
function [V, L, V_sum, loss] = gausseidel(P, Q, Y,
in)

global V_initial;
global N;

V = V_initial;
tolerance = 1000;
accelaration = 0.4;
while tolerance > 1e-8

    V_temp = V;
    for k = 2:in
        V(k) = ((P(k)-i*Q(k))/conj(V(k))-
Y(k,:)*V)/Y(k,k)+V(k);
    end
    Q(in+1:N) = -
imag((Y(in+1:N,:)*V).*conj(V(in+1:N)));
    for k=in+1:N
        V(k) = ((P(k)-i*Q(k))/conj(V(k))-
Y(k,:)*V)/Y(k,k)+V(k);
        V(k) = abs(V_temp(k))*V(k)/abs(V(k));
```

```
    end
    tolerance = max(abs((V-V_temp)./V_temp));
    V = V_temp+accelaration*(V-V_temp);

end

P_Q = conj(conj(V).*(Y*V));

% V=[abs(V) 180*angle(V)/pi]

I_loss = conj((diag(V)*Y)')-diag(V)*Y;

V_loss = diag(V)*ones(N)-conj((diag(V)*ones(N))');

L = real(I_loss.*conj(V_loss));
L = 100*L;

loss = sum(sum(L))/2;

V_sum = sum(abs(V));
V=[abs(V) 180*angle(V)/pi];

end
```

OPTIMIZATION PROCESS:

```
clc;
clear all;
close all;

I = xlsread('impedance14bus.xlsx');
A = xlsread('ieee_infomax.xlsx');

% I = xlsread('impedance.xlsx');
% A = xlsread('info.xlsx');

global V_initial;
global N;

size_A = size(A);
N = size_A(1);

Y = ybus(I);

%% Calculating the Bus Voltage

B_type = [1 zeros(1,N-1)];
Check = isnan(A(:,4:5));
```

```
for k = 2:N
    if Check(k,1)||Check(k,2)
        B_type(k) = 3;
    else
        B_type(k) = 2;
    end
end

for k = 2:N
    if B_type(k)==3
        in = k-1;
        break;
    end
end

[V_r, V_i] = pol2cart(A(:,3)*pi/180,A(:,2));
V_initial = V_r+i*V_i;
P = (A(:,4)-A(:,6))/100;
Q = (A(:,5)-A(:,7))/100;

%% Optimization

lambda = 1;

P_dg = 2.5/100;

[V_ix, L_ix, V_sumx, loss_x] = gausseidel(P, Q, Y,
in);

for j=2:in
    I_temp = I;
    A_temp = A;
    for k = 1:N
        if I_temp(k,1) == j
            I_temp(k,1) = in;
        end
        if I_temp(k,1) == in
            I_temp(k,1) = j;
        end
        if I_temp(k,2) == j
            I_temp(k,2) = in;
        end
        if I_temp(k,2) == in
            I_temp(k,2) = j;
        end
    end
    A_temp(j,3:end) = A(in,3:end);
    A_temp(in,3:end) = A(j,3:end);
    P_temp = (A_temp(:,4)-A_temp(:,6))/100;
    Q_temp = (A_temp(:,5)-A_temp(:,7))/100;
    Y_temp = ybus(I_temp);
```

```
    P_temp(j) = P(j)+P_dg;
    [V_idg{j}, L_idg{j}, V_sum(j), loss(j)] =
gausseidel(P_temp, Q, Y, in-1);
    V_norm(j) = (V_sum(j)-V_sumx)/V_sumx;
    V_var(j) = var(V_idg{j}(:,1));
    L_norm(j) = (loss_x-loss(j))/loss_x;
    J(j) = lambda*V_norm(j)+(1-lambda)*L_norm(j);

end

for j = in+1:N
    P_temp = P;
    P_temp(j) = P(j)+P_dg;
    [V_idg{j}, L_idg{j}, V_sum(j), loss(j)] =
gausseidel(P_temp, Q, Y, in);
    V_norm(j) = (V_sum(j)-V_sumx)/V_sumx;
    V_var(j) = var(V_idg{j}(:,1));
    L_norm(j) = (loss_x-loss(j))/loss_x;
    J(j) = lambda*V_norm(j)+(1-lambda)*L_norm(j);
end

[Jmax, index] = sort(J, 'descend');
for j = 1:N
    if Jmax(j)~=Jmax(1)
        break
    end
end

[~, b] = min(V_var(index(1:j-1)));
index(b)
J
```