Optimal Sizing and Placement of DG in a Radial Distribution Network using Sensitivity based methods

Thesis submitted in partial fulfilment of requirements for the award of degree of

Master of Engineering

in

Power Systems

By

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CERTIFICATE

I, hereby, certify that the thesis entitled **"Optimal Location and Sizing of DG in a Radial Distribution Network using Sensitivity based methods"** submitted in the partial fulfillment of the requirement for the degree of MASTER OF ENGINEERING in POWER SYSTEM, in the Electrical and Instrumentation Engineering Department, Thapar University, Patiala is an authentic work carried out by me under the guidance of **Dr. SMARAJIT GHOSH**, Professor, EIED, Thapar University and refers other researcher's works, which are duly listed in the reference section.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any degree.

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This is certifying that the above statement made by the student is correct and true to the best of my knowledge and belief.

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The paucity of words does not compromise to thank my parents, with whose blessings have brought me this far in life.

(NITIN SINGH)

Dedicated to My Parents

ABSTRACT

In recent years, the power industry has experienced significant changes on the power distribution systems primarily due to the implementation of smart-grid technology and the incremental implementation of distributed generation. Distributed Generation (DG) is simply defined as the decentralization of power plants by placing smaller generating units closer to the point of consumption, traditionally ten mega-watts or smaller. The distribution power system is generally designed for radial power flow, but with the introduction of DG, power flow becomes bidirectional. The presence of DG on the distribution system creates an array of potential problems related to safety, stability, reliability and security of the electrical system. Distributed generation on a power system affects the voltages, power flow, short circuit currents, losses and other results.

Whether the impact of the DG is positive or negative on the system will depend on the location and size of the DG. Therefore this thesis 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 would be equipped with the real time operation of the distribution system and it is seen that execution of the DG placement is quite fast and feasible with the optimization techniques used in this work.

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Z	Impedance Matrix Vector
S	Complex Power Matrix Vector
P_i	Net Active Power
Q_i	Net Reactive Power
V^0	Initial Voltage Vector
I^k	Branch Current of kth Iteration
T	Upper Triangular Matrix
i	Injected Quantity
D_Z	Diagonal Matrix of Vector Z
$r_i(k)$	Per Unit Resistance of Conductor ‘k’ Per Unit Length
$x_i(k)$	Per Unit Reactance of Conductor ‘k’ Per Unit Length
l_i	Length of Segment ‘i’
DG	Distributed Generation

CHAPTER ONE

INTRODUCTION

ELECTRICAL DISTRIBUTION SYSTEM

Until the 1870s electricity was a matter of concern only for engineers and researchers. Several experiments were conducted to study more about electrical phenomena, and batteries were the main source of power. The Belgian researcher Zenobe Gramme invented the generator, which could supply greater electrical currents than the battery. Electricity feeders were then build from small and large power plants to supply light and run electricity machines for primary and secondary industries. The first incandescent lamp came into being around 1880, invented simultaneously by Thomas Alva Edison and the English man Joseph Swan. Electricity had finally reached its consumers providing the demand and rational for electricity power delivery systems.

1.1 Power Distribution Systems

A Distribution network has typical characteristics of its own. Distribution networks design will be introduced though this article. Also the differences between country and urban distribution networks will be clearly defined.

1.2 Global Design of Distribution Networks

The electric utility system is classified into the following three subsystems:

1. Generation
2. Transmission
3. Distribution

A Sub-transmission system is basically a subset of transmission as the voltage levels and protection practices are almost similar, however it is sometimes treated as a Fourth Division. The distribution system is further classified into the following:

- Distribution Substation
- Primary Distribution
- Secondary Distribution

The voltage is reduced at the distribution substation. It is distributed into smaller amounts according to the customer requirements and is supplied through the same distribution substation, thereby making the total number of transmission lines involved in the distribution system more than that in the transmission system. The distribution system is considered as ‘unbalanced’ because of the fact that in a distribution system most of the customers are connected to only one of the three phases available, thus making the power flow in each line different, which makes it unbalanced. The load-flow studies related to distribution networks emphasize on this characteristic.

1.3 Distribution Systems

Distribution system is defined as the part of power system which distributes electric power for local utilization.

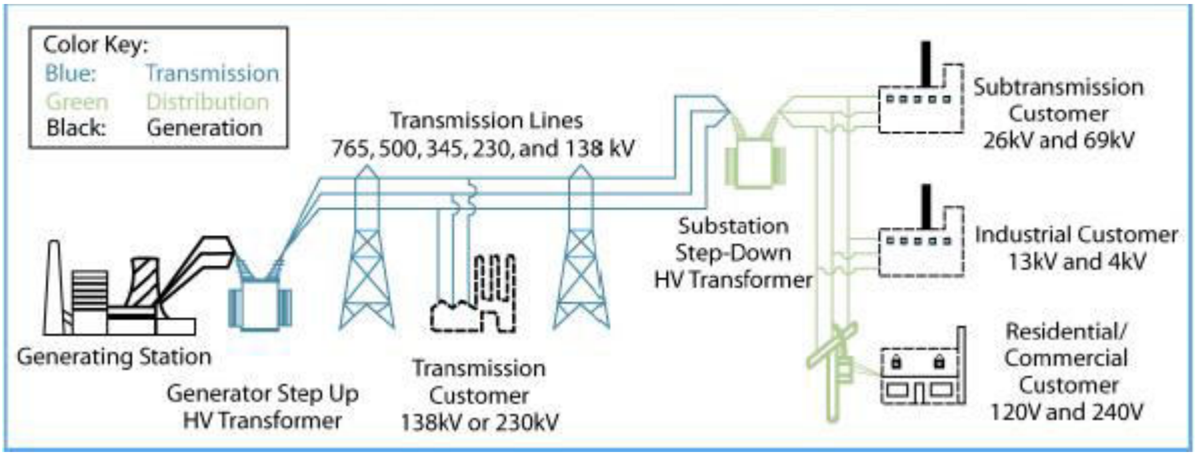

Figure 1.1 Diagram of a distribution system [1]

In other words, the electrical system between the substation fed by the transmission system and the consumer’s meter is known as the distribution system. The basic elements of a distribution system are feeders, distributors and the service mains. Figure 1.1 depicts the single line diagram of a typical low tension distribution system.

(i) Feeders*:* A feeder is essentially a conductor, connecting the localized generating station (or the sub-station) to the desired area where power has to be distributed. In order to keep the current in the feeder same throughout, generally no tapping’s are taken from the feeder. The current carrying capacity is the main point of focus during design of a feeder.

(ii) Distributor*:* A distributor is basically a conductor from which tappings are taken for giving supply to the consumers. In Figure 1.1, AB, BC, CD, and DA represent the distributors. Since the tappings are taken at various places along the length of the distributor; the current through it is not constant. The voltage drop across the length of the distributor is the main point of focus during its design, as the statutory limit of voltage variations is ±10% of rated value at the consumer’s terminal.

(iii) Service mains: The service mains is generally a small cable which connects the distributor to consumer terminals.

1.4 Requirements of a Distribution System

It is mandatory to maintain the supply of electrical power within the requirements of many types of consumers. Following are the necessary requirements of a good distribution system:

1) **Availability of power demand**: Power should be made available to the consumers in large amount as per their requirement. This is very important requirement of a distribution system.

2) **Reliability**: As we can see that present day industry is now totally dependent on electrical power for its operation. So, there is an urgent need of a reliable service. If by chance, there is a power failure, it should be for the minimum possible time at any cost. Improvement in reliability can be made up to a considerable extent by:

a) Reliable automatic control system.
b) Providing additional reserve facilities.

3) **Proper voltage:** Further the requirement of a distribution system is that, the voltage variations at the consumer terminals should be as low as possible. The main cause of changes in voltage variation is variation of load on distribution side which has to be reduced. Thus, a distribution system is said to be only good, if it ensures that the voltage variations are within permissible limits at consumer terminals.

4) **Loading**: The transmission line should never be over loaded and under loaded.

5) **Efficiency**: The efficiency of transmission lines should be maximum say about 90%.

1.5 Classification of Distribution System

A distribution system may be classified on the basis of:-

i) **Nature of current**: According to nature of current, distribution system can be classified as:
a) AC distribution system.
b) DC distribution system.

ii) **Type of construction**: According to type of construction, distribution systems are classified as:
a) Overhead system
b) Underground system

iii) **Scheme of operation**: According to scheme of operation, distribution systems may be classified as:
a) Radial system
b) Ring main system
c) Interconnected system

1.5.1 Radial System

A schematic example of a radial distribution system is shown in Figure 1.2. In this system, primary feeders take power from the distribution substation to the load areas by way of sub feeders and lateral-branch circuits. This is the most commonly system used because it is the simplest and least expensive to build. It is widely used in sparsely populated areas. A radial system has only one power source for a group of customers

Radial feeders are characterized by having only one path for the power to flow from the source (distribution substation) to each customer. If the distributor is connected to the supply system on one end only, that system is called radial distribution system. A typical radial distribution system is shown below.

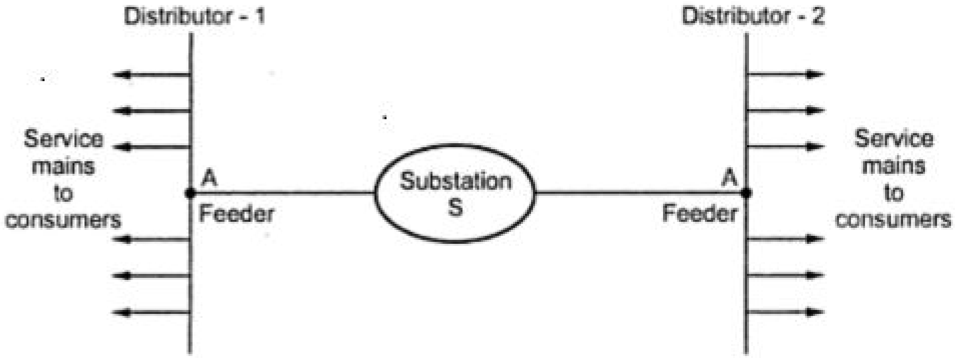

Figure. 1.2 Radial distribution system

This is the simplest distribution circuit and has the lowest initial cost. However it has following drawbacks:

a) The end of the distributor nearest to the feeding point is heavily loaded.

b) The consumers are dependent on a single feeder and single distributor. So, any fault on the feeder or distributor cuts off supply to the consumers who are on the side of the fault away from the substation.

c) The consumers at the distant end of the distributor would be subjected to serious voltage fluctuations when the load on the distributor changes.

1.5.2 Ring main system

The loop (or ring) distribution system is one that starts at a distribution substation, runs through or around an area serving one or more distribution transformers or load centers, and returns to the same substation. The loop system shown in Figure 1.3 is more expensive to build than the radial type, but it is more reliable and may be justified in areas where continuity of service is required—at a medical centre, for example. In the loop system, circuit breakers sectionalize the loop on both sides of each distribution transformer connected to the loop. A fault in the primary loop is cleared by the breakers in the loop nearest the fault, and power is supplied the other way around the loop without interruption to most of the connected loads. If a fault occurs in a section adjacent to the distribution substation, the entire load can be fed from one direction over one side of the loop until repairs are made.

The ring main system has the following advantages:

a) There are very less voltage fluctuations at consumer's terminals.

b) The system is very reliable as each distributor is fed with two feeders. In case, of fault in any section of feeder, the continuity of supply is maintained.

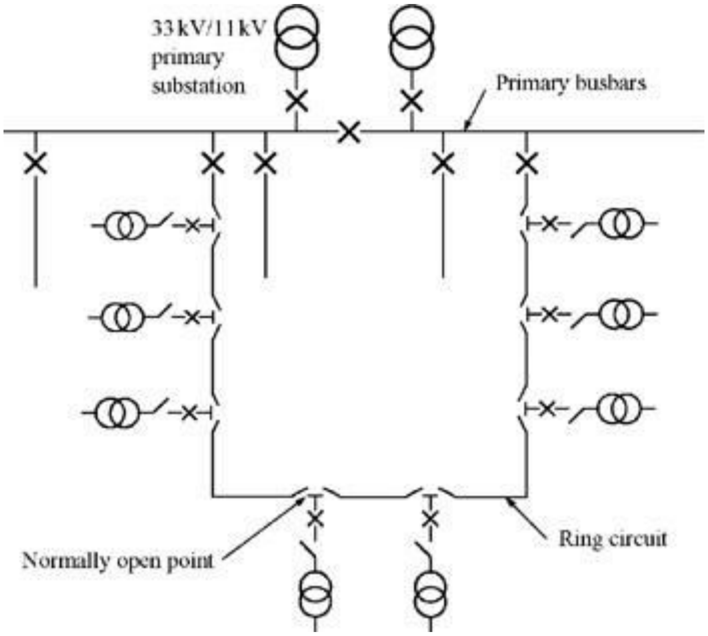

Figure 1.3 Ring main System

1.5.3 Interconnected system

The network system shown in Figure 1.4 is the most flexible type of primary feeder system. It provides the best service reliability to the distribution transformers or load centers, particularly when the system is supplied from two or more distribution substations. Power can flow from any substation to any distribution transformer or load centre in the network system. The network system is more flexible about load growth than the radial or loop system. Service can readily be extended to additional points of usage with relatively small amounts of new construction. The network system, however, requires large quantities of equipment and is, therefore, more expensive than the radial system. For this reason it is usually used only in congested, high load density municipal or downtown areas. When the feeder ring is energized by two or more than two generating stations or sub stations, it is called inter-connected system.

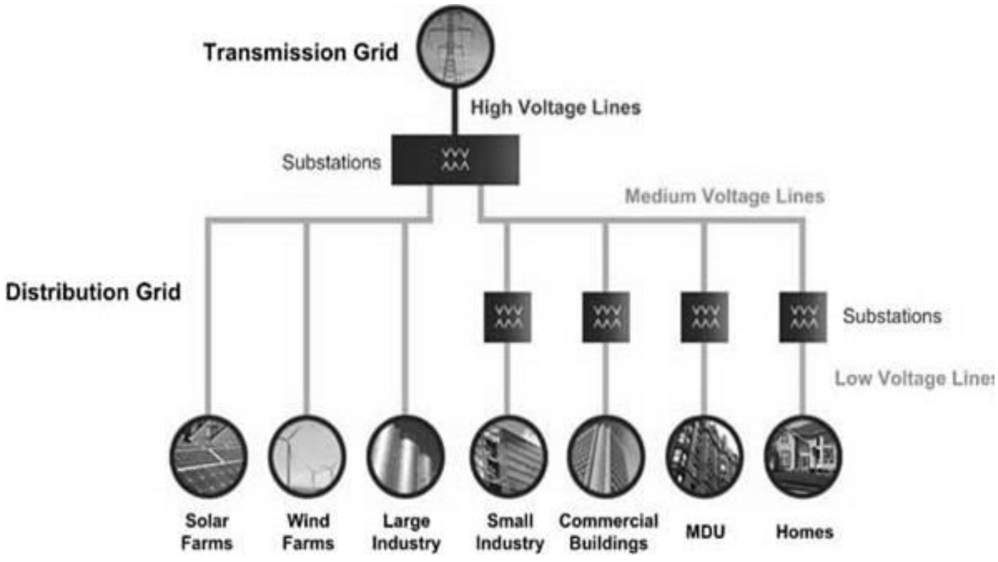

Figure 1.4 Interconnected Systems

1.6 Distributed Generation:

The term Distributed Generation, or DG, refers to the use of small-scale electric power generators dispersed within the distribution network level, whether located on the utility system near customers or at an isolated site not connected to the power grid .The efficiency of DG technologies is high, e.g. 40 to 55% for fuel cells, compared to 28 to 35% for traditional large central power generators.

1.6.1 Distributed Generation: Definition

Distributed generation 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 papers, proposed a general definition for DG, suggesting that the most apt definition would be “an electric power source connected directly to the distribution network or on the customer side of the meter”.

Table 1.1: DG category based on capacity

Categories	Ratings
Micro-distributed generation	~1 W < 5 kW
Small-distributed generation	5 kW < 5 MW
Medium-distributed generation	5 MW < 50 MW
Large-distributed generation	50 MW < 300MW

1.6.2 Distributed Generation Technology

Various DG technologies are involved in power systems. Some of these technologies have been in use for a long time while others are newly emerging. Nonetheless, the features that all DG technologies have in common are to increase efficiency and decrease costs related to installation, running and maintenance. DG technologies are loosely categorized into two types: renewable technologies (e.g., photovoltaic and wind turbine) and non-renewable technologies (e.g., mini and micro-turbines, combustion turbines and fuel cells). DG technologies have a significant impact on the selection of the appropriate size and place of a DG unit to be connected to a grid or customer loads. The following sections provide details on the most popular DG technologies currently in the market:

1.6.3 Fuel Cells

Fuel Cells (FC) are classified as non-traditional generators. They are electrochemical devices that convert chemical energy from a fuel directly into electrical energy by combining oxygen, as an oxidant, and hydrogen, as a fuel, without combustion

1.6.4 Micro-turbines

Micro-turbines (MT) are small electricity generators that burn fuel such as natural gas, propane and fuel oil to create high-speed rotation that is transferred to an electrical generator via a main shaft. MT consists of three basic components: a compressor, a turbine generator, and a recuperator. In present energy markets, MT generators are the most improved and most attractive devices in distributed power generation equipment. Their capacity ranges from 20 kW to 500 kW and their efficiency is more than 80% when the CHP application is used in the system. Also, the NO_X emissions of MT are very low compared to large-scale turbines

1.6.5 Photovoltaic

Photovoltaic (PV) technology converts solar energy directly into electricity using semi-conductor solar cells. These cells are manufactured in small sizes of usually around one square centimeter. When the solar cells are exposed to direct sunlight, each cell generates less than one watt of DC power, with the lowest voltage around 0.5 V. Normally, a panel or module can be formed by electrically connecting twelve solar cell units in series to provide 12 V.. PV systems are divided into three sizes based on the power they produce (the small size is less than 10 kW; the medium size is 10 kW to 100 kW; and the large size is more than 100 kW). The large size is appropriate for the distribution network level.

1.6.6 Wind Turbines

Wind turbines are among the most popular renewable electrical sources in the world. A large number of wind turbine systems have already been installed and connected to the grid, generating globally around 318137 megawatts of electricity in 2013 and many new systems are being planned. Manufacturers offer wind turbines in a capacity range from less than 5 to over 1,000 kW. Wind turbines are usually integrated to the transmission voltage level and combined to make a wind farm. However, wind turbines are sometimes considered distributed generation, because the size and location of some small wind farms make them suitable for connection at the distribution voltage level. Like PV systems, wind turbines require no fuel, no emissions, and produce DC power that needs AC/DC inverters to be connected to the grid. Moreover, small wind turbines can be combined with PV and battery systems to cover loads of 25 to 100 kW. The main drawbacks of wind turbines are their high initial costs and unpredictability of energy production. As well, they are not suited to CHP applications

1.7 DISTRIBUTED GENERATION BENEFITS

Distributed generation promises several potential positive impacts, both economical and technical. The major benefits of the integrations of DG into electric power networks are as follows:

- DG units are usually installed near the load site on the radial distribution networks. Thus, part of the transmission power is replaced by the injected DG power, causing a reduction in transmission and distribution line losses, which minimizes costs related to loss.
- Injecting active and reactive power by DG units improves system voltage profiles and the load factor, which minimizes the number of required voltage regulators, capacitors and their ratings and maintenance costs. However, the amount of improvement depends on the size and location of the DG unit.
- Increases in power demands as a result of load growth can be covered by DG units without

needing to increase existing traditional generation capacity; it also reduces or delays the need for building new T&D lines, upgrades the present power systems and reduces T&D network capacity during the planning phase.

- DGs are flexible devices that can be installed at load centers rather than at substations, where difficulties due geographical constraints or scarcity of land availability may occur. In addition, DG locations are not restricted by the government's choice for potential locations, as is the case when selecting new substation locations.
- DG technology is available in a wide capacity range (i.e., from ten kW up to 15 MW), so it can be installed on medium and/or low voltage distribution networks, giving it flexibility for sizing and location..
- DG plants require a short period of time to install and pose less of an investment risk due to their modular characteristics, which enables them to be easily, assembled anywhere, such as with FC-MT and MT-batteries. Each modular can be operated immediately after its installation, independent of other modules, and is not affected by other modular's operation failure. In addition, the total capacity can be increased or decreased by adding or removing more modules, respectively.
- DGs can help in system service continuity and reliability, as there are many generation spots, not just one large centralized generation site. This is particularly useful in the case of end-user customers with low reliability since, when combined with DGs, there will be new customer classifications :(e.g. those with high need for reliability with high service costs and those with low need for reliability with lower service costs)

On the other hand, integrating DG units may lead to negative impacts on a distribution system, especially for large scale installations if they are not optimally handled. For instance, DG may result in high voltage causing currents that exceed the line's thermal limit, harmonic problems, noticeable voltage flicker and instability of the voltage profile of some electricity customers. In addition, the bi-directional power flows can lead to voltage profile fluctuation and change the short circuit levels sufficiently to cause fuse-breaker miscoordination.

1.8 Optimization for DG Allocation

Solution techniques for DG deployment can be obtained via optimization methods in order to maximize DG benefits. Several optimization techniques have been presented by researchers in determining the optimal location and size of DG. Such optimization methods can be classified into deterministic methods such as analytical and SQP methods and heuristic methods such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), etc., or into single- and multi-objective, based on the number of objectives. The major objective of DG placement techniques used in the literature is to minimize power system losses. However, other objectives, like improving the voltage profile and reliability and maximizing DG capacity and cost minimization.

1.9 Organization of the Thesis

This thesis contains five chapters and one appendix. It is organized as follows:

Chapter 1: Introduction

This chapter presents the introduction of the distribution system, components of the distribution system, primary and secondary distribution system. The discussion about Distribution System in the radial distribution system and aim to do this thesis work is to primarily describe in different sections of the chapter.

Chapter 2: Literature Survey

This chapter presents the contribution of different authors in the field of DG placement as well as the fields used throughout the implementation of problem solution. This chapter basically demonstrates the motivational study to carry out this work.

Chapter 3: Problem Formulation and Proposed methodology

This chapter Presents main body of the thesis i.e. i.e. formulation of the problem in terms of mathematical models and their solutions by using different algorithms proposed.

Chapter 4: Results and Discussions

This chapter analyses the results carried out in our thesis work using proposed and existing methodology and comparison between them to find out the effectiveness.

Chapter 5: Conclusion

Some conclusions are presented in this chapter. The chapter ends naming some of the works that can be done in the future with reference to the work presented in this research.

References section enlists previous papers published by researchers in reconfiguration of radial distribution networks surveyed by the author.

Appendix- A:

It presents data for 33 bus test systems i.e. Line data and load data.

CHAPTER TWO

LITERATURE REVIEW

Distributed Generation (DG) is one of the new trends in power systems used to support the increased energy-demand. There is not a common accepted definition of DG as the concept involves many technologies and applications. Different countries use different notations like “embedded generation”, “dispersed generation “of decentralized generation” Furthermore, there are variations in the definition proposed by different organizations (IEEE, CIGRE…) that may cause confusion. Therefore in this thesis, the following definition is used:

“*Distributed generation is considered as an electrical source connected to the power system, in a point very close to/or at consumer´s site, which is small enough compared with the centralized power plants. Many text resources discussed the complexity and difficulty of DG placement in Radial distribution system using Evolutionary algorithms*”.

Chakravorty and Das [2] proposed a new voltage stability index for identifying most sensitive load on which voltage collapse was possible. New voltage stability index was proposed for identifying the node, which was most sensitive to voltage collapse. Composite load modeling was considered for the purpose of voltage stability analysis.

Eminoglu and Hocaoglu [3] proposed load-flow algorithms based on the forward/backward sweeps. Their convergence ability was quantitatively evaluated for different loading conditions, R/X ratios and sub-station voltage levels. Moreover, the effects of static load modelling on the convergence characteristics of algorithms were also investigated.

Gandomkar *et al.* [4] used the Hereford Ranch Algorithm (HRA) to determine DG location and size that minimized distribution power losses, with the condition that the number of DGs and total capacity of DGs were known. The parent selection algorithm for generating offspring affected the ability of GA in three aspects: finding a correct solution for a variety of problems; preserving diversity to prevent premature convergence; and improving convergence time.

Acharya *et al.* [5] proposed an analytical method to determine the optimal capacity of DG. The optimal sizes corresponding to each network bus were calculated using a direct equation derived from the sensitivity factor equation. In addition, an effective methodology based on an exact loss formula was applied to determine the optimal site of DG that minimizes total power losses. The method carried out the load flow two times, for the base case, without DG, and with DG, and considered installing only a single DG that injects active power.

Borges and Falcao [6] gave a new methodology for optimal distributed generation allocation and sizing in distribution systems, in order to minimize the electrical network losses and to guarantee acceptable reliability level and voltage profile. The optimization process was solved by the combination of genetic algorithms techniques with methods to evaluate DG impacts in system reliability, losses and voltage profile. The losses and voltage profile evaluation were based on a power flow method for radial networks with the representation of dispersed generators.

Kashem *et al.* [7] developed a deterministic methodology based on the SQP algorithm to identify the optimal size and placement of DG in distribution systems. The authors proposed a combined objective function that aimed to reduce power loss at minimal DG cost.

Beromi *et al.* [8] presented a method for optimal allocation of DG for voltage profile improvement and loss reduction. GA was used as the optimization technique. Load flow was applied for decision-making which combined appropriately with GA.

Wu and Zhang [9] suggested theoretical formulation of the forward/backward sweep with compensation power flow method. Subsequently, a novel solution of unbalanced three-phase power systems based on the loop-analysis method was developed. The proposed method had clear theory foundation and took full advantage of the radial (or weakly meshed) structure of distribution systems.

Gozel and Hocauglu [10] formulated a loss sensitivity factor for the distribution systems, based on the equivalent current injection. The calculated sensitivity factor was employed for the determination of the optimum size and location of distributed generation to minimize total power losses by an analytical method without the use of admittance matrix, inverse of admittance matrix or Jacobian matrix. It was shown that, the proposed method was in close agreement with the classical grid search algorithm based on successive load flows.

Mouti and Hawary [11] presented a new optimization approach that employs an artificial bee colony (ABC) algorithm to determine the optimal DG-unit's size, power factor, and location in order to minimize the total system real power loss. The ABC algorithm was a new meta-heuristic, population-based optimization technique inspired by the intelligent foraging behaviour of the honeybee swarm. To reveal the validity of the ABC algorithm, sample radial distribution feeder systems were examined with different test cases. Furthermore, the results obtained by the proposed ABC algorithm were compared with those attained via other methods.

Ghosh *et al.* [12] presented a simple search approach for determining optimal size and optimal placement of DG using N-R method of load flow study. Both optimal DG size and optimal bus location were determined to obtain the best objective. The multi-objective optimization covered optimization of both cost and loss simultaneously. Due to the placement of optimal DG size at its optimal location it was observed that voltages of load buses were improved and the losses were reduced substantially.

Shukla *et al.* [13] minimized active power loss by placing DG in radial distribution system. The problem was formulated as optimization problem and solution was obtained using genetic algorithm. The locations were decided on the basis of loss sensitivity to active power injection at various nodes. The performance of the method was tested on 33-bus test system and comparison of the results with a reported method revealed that the proposed method yielded superior results.

Safari *et al.* [14] showed the results obtained in the analysis of the impact of distributed generation (DG) on distribution losses and presented a new algorithm to the optimal allocation of distributed generation resources in distribution networks. The optimization was based on a Hybrid Genetic Algorithm and Particle Swarm Optimization (HGAPSO) aiming at optimal DG allocation in distribution network. Through this algorithm a significant improvement in the optimization goal was achieved.

Hung *et al.* [15] proposed analytical expressions which were based on an improvement to the method that was limited to DG type, which was capable of delivering real power only. Three other types could also be identified with their optimal size and location using the proposed method. The method had been tested in three test distribution systems with varying size and complexity and validated using exhaustive method. Results showed that the proposed method required less computation, but could lead optimal solution as verified by the exhaustive load flow method.

Abul Wafa [16] successfully analyzed and solved network-topology-based method to the load-flow problem of radial distribution networks. The proposed technique was based on network graphical information and power flow equation formulation which was in matrix form to satisfy the need of distribution automation. In the technique a directed graph of a radial network represented by a nodes-by-nodes sparse matrix (S) allowed detection of the path of power flow from the reference node to the leaf end. The proposed method also allowed dynamic building of the two matrices: BIBC and BCBV matrix which were used to find out the load-flow solution.

Hamouda and Zehar [17] presented an improved method to solve load-flow problem in balanced radial distribution systems with laterals. Their method was based on electric circuit laws with iteration and allowed the evaluation of both, voltage (rms) values and phase-angles. A simple technique of determining nodes beyond each branch was given through load-flow where speed convergence was increased by an appropriate choice of initial voltages. The method required a small number of iterations and less computational time

Amanifar [18] proposed a PSO and sensitivity analysis based approach for optimal DG placement, sizing for loss and THD reduction and voltage profile improvement in distribution systems. Power flow was used to find the global optimal solution. Then, with respect to voltage profile, THD and loss reduction were done by using the sensitivity analysis. PSO was used to calculate the objective function and to verify bus voltage limits.

Mouti and Hawary [19] found the optimal location and size of the DG to minimise the total system power loss for radial distribution feeder systems by solving two independent sub-problems: (i) location and (ii) size. A sufficient sensitivity test for the first problem was suggested determining the optimal DG size was done using a new heuristic curve-fitted technique that reduced the search-space by selecting fewer DG-tests. Four DG sizes, which were carefully selected based on the system's total load demand percentages, were used to determine the optimal solution.

Kansal *et al.* [20] presented the allocation of different types of DGs using PSO technique for active and reactive power compensation to minimize the real power losses in the primary distribution networks. The optimal power factor had also been determined to minimize the power loss. The results obtained by PSO approach, had also been verified using the analytical approach. The proposed PSO approach for optimal placement of multiple types of DGs not only reduced the line losses but also minimized the sizes of DGs with satisfaction of the permissible voltage limits.

Injeti and Kumar [21], proposed a new analytical expression to calculate optimum size and fuzzy logic to identify the optimum location for DG placement were proposed. The DG was considered to be located in the primary distribution system and the objective of the DG placement was to reduce the losses and improve the voltage profile. The cost and other associated benefits had not been considered while solving the location and sizing problem. The proposed methodology was found suitable for allocation of single DG in a given radial distribution network.

Cui and Dai [22] sought the optimal allocation of DG in a smart grid via a multi-objective optimization model. The objectives for the proposed method were to minimize operational costs of DG and network active power loss and to maximize environmental benefits. First, the optimal DG placement was determined by performing a network power loss sensitivity analysis, where a bus with high sensitivity was selected to install a DG unit. To solve the sizing problem, fuzzy theory was proposed. The multi-objective planning was converted into single-objective planning by employing the fuzzy optimization theory.

Naik *et al.* [23] presented a simple method for real power loss reduction, voltage profile improvement, substation capacity which was based on voltage sensitivity index analysis. Power flow analysis was done using the forward-backward sweep method. Study carried out on an IEEE-33- bus test system validated the suitability of this proposed method.

Moradi ***et al.*** **[24]** gave a new combined genetic algorithm (GA) and particle swarm optimization (PSO) for optimal location and sizing of DG on distribution systems. The objective was to minimize network power losses, better voltage regulation and improve the voltage stability within the frame-work of system operation and security constraints in radial distribution systems. A detail performance analysis was carried out on 33 and 69 bus systems.

Moradi ***et al.*** **[25]** proposed a new combined method to solve sitting and sizing problems for DG and capacitor banks simultaneously in distribution system. The ICA algorithm was used to find location and size of the DGs and the capacitors. Then GA was used to generate a new set of colonies and solutions in the all search spaces. Combined method was implemented to minimize the losses, to increase the voltage stability, to improve the voltage regulation index and to balance the loads.

Khatod ***et al*****. [26]** developed an EP based technique for optimal placement of DG units energized by renewable energy resources in a radial distribution system. For tackling uncertainties related with load and renewable resources, probabilistic techniques had been used. To reduce the search space and thereby to minimize the computational burden, a sensitivity analysis technique had been employed. For the approach, an index based scheme had also been developed to generate the population ensuring the feasibility of each individual and thus considerably reducing the computational time.

Garcia and Mena [27] used a new evolutionary method called Teaching–Learning Based Optimization algorithm, which was modified and used in this paper to find the best sites to connect DG systems in a distribution network, choosing among a large number of potential combinations. A comparison between the proposed algorithm and a brute force method was performed. Besides this, it had also been carried out a comparison using several results available in other articles published by others authors. Numerical results for two test distribution systems had been presented in order to show the effectiveness of the proposed approach.

Georgilakis *et al.* [28] aimed at providing the best site and sizes of DGs to optimize radial distribution network operation and planning taking into account DG capacity constraints. Various models and methods had been suggested for the solution of the ODGP problem. This paper presented an overview of the state of the art models and methods applied to the ODGP problem, analyzing and classifying current and future research trends in this area.

Shaaban *et al.* [29] formulated a simple analytical technique to determine the optimal size and optimal siting of distributed generation in distribution network for minimize active power loss and voltage profile enhancement. DG unit sizing and location were calculated using a sensitivity index that combined the exact loss formula and voltage sensitivity coefficients. Test results carried out on the IEEE 13- bus feeder were presented and analyzed.

Kansal *et al.* [30] proposed the application of Particle Swarm Optimization technique to find the optimal size and optimum location for the placement of DG in the radial distribution networks for active power compensation by reduction in real power losses and enhancement in voltage profile. The optimal size of DG was calculated at each bus using the exact loss formula and the optimal location of DG was found by using the loss sensitivity factor. The proposed technique was tested on standard 33-bus test system and the obtained results were compared with the exhaustive load flows

Sajjadi *et al.* [31] considered simultaneous placement of distributed generation (DG) and capacitor in radial distribution network with different load levels. The objectives of the problem were reduction of active and reactive power loss, reduction of energy loss and improvement of voltage profile. Memetic algorithm was used to find optimal solutions. This algorithm was combinatorial form of local search and genetic algorithm. The performance of the proposed method was assessed on a test distribution network.

Mistry and Roy [32] used predetermined annual load growth up to five years with voltage regulation as a constraint. The particle swarm optimization with constriction factor approach was applied to determine the optimum size and location with multiple DGs. In this work, optimal size and location of multiple DGs were found to cater the incremental load on the system and minimization of power loss without violating system constraints.

Shukla ***et al.*** **[33]** used GA based methodology to evaluate the optimal size DG at multiple locations of radial DNs for a minimum loss configuration the loss sensitivity approach was used to decide the appropriate locations for placing DG. The main focus of this article was to find and quantify the technical benefits (loss reduction and voltage regulation), from the customer point-of-view, and overall economic benefits, from the utility point-of-view. The study was performed on two widely used 33bus–32-branch and 69-bus–68-branch test systems.

Legha ***et al.*** **[34]** stated that DG placement and penetration level was an important problem for both the utility and DG owner. The Optimal Power Flow had been widely used for both the operation and planning of a power system. The OPF was also suited for deregulated environment. Four different objective functions were considered in this study: (1) Improvement voltage profile (2) minimization of active and reactive power. The site and size of DG units were assumed as design variables. The results were discussed and compared with those of traditional distribution planning and also with PSO.

Prasanna ***et al.*** **[35]** developed a novel approach for optimal allocation of a distributed generator in a radial distribution feeder for loss minimization and tail end node voltage improvement during peak load. The DG allocation problem was formulated as multi objective function which included two objectives: Power Loss Reduction and Tail End Node Voltage Improvement with associated weights. The proposed methodology used Genetic Algorithm to optimize the multi objective function. This method was tested on standard IEEE 33- bus radial distribution system using MATLAB 8.0. The proposed method yielded significant reduction in line losses and considerable tail end node voltage improvement during peak load.

CHAPTER THREE
PROBLEM FORMULATION

This chapter deals with the problem formulation for optimal sizing and location of DG in the radial distribution network.

3.1 Problem formulation:

This section deals with the development of mathematical model for objective function and different constraints for Radial Distribution system in presence of DG.

3.1.1 Objective function:

The objective of the optimal size and location of DG problem to minimize the total power loss and voltage profile can be expressed as: [36]

$$\text{Minimize } P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} [\alpha_{ij}(P_i P_j + Q_i Q_j) + \beta_{ij}(Q_i P_j - P_i Q_j)] \qquad (3.1)$$

where

$$\alpha_{ij} = \frac{r_{ij}}{V_i V_j} \cos(\delta_i - \delta_j)$$

$$\beta_{ij} = \frac{r_{ij}}{V_i V_j} \sin(\delta_i - \delta_j)$$

$$Z_{ij} = r_{ij} + jx_{ij}$$

where Z_{ij} is the impedance of the line between bus i and bus j;

r_{ij} is the resistance of the line between bus i and bus j;

x_{ij} is the reactance of the line between bus i and bus j

V_i is the voltage magnitude at bus i

V_j is the voltage magnitude at bus j

3.1.2 Constraints:

The objective function in (3.1) is subjected to the following constraints.

(a) Bus voltage limits:

It is well known that a small change in nodal voltage affects the flow of reactive power whereas active power practically does not change. Further, the operating voltage at each node must be in safety range as given below.

$$V_{i_{min}} \leq V_i \leq V_{i_{max}} \qquad i \in \{1,2,3,\ldots\ldots,N_b\} \tag{3.2}$$

where, $V_{i_{min}}, V_{i_{max}}$ = minimum and maximum voltage limits of i th node respectively.

V_i = voltage at i th node.

N_b = number of buses.

(b) Feeder capacity limits:

Power flow in each branch must be less than or equal to its maximum capacity as given below.

$$|I_i| \leq I_{i_{max}} \qquad i \in \{1,2,3,\ldots\ldots,Nbr\} \tag{3.3}$$

where, $I_{i_{max}}$ = maximum current capacity of i th branch.

I_i = current in i th branch

(c) Power flow equations:

Total active power generation must be equal to the sum of total active power losses and total active load. Similarly, total reactive power generation must be equal to the sum of total reactive power losses and total reactive load as given by following equations.

$$\sum P_{i_{Gen}} = P_L + \sum P_{i_{Load}} \tag{3.5}$$

$$\sum Q_{i_{Gen}} = Q_L + \sum Q_{i_{Load}} \tag{3.6}$$

where,

$\sum P_{i_{Gen}}$ = Total active power generation.

$\sum Q_{i_{Gen}}$ = Total reactive power generation.

P_L = Total active power loss.

Q_L = Total reactive power loss.

$\sum P_{i_{Load}}$ = Total active load.

$\sum Q_{i_{Load}}$ = Total reactive load.

(d) ROW:

The right of way buses (The bus which is not appropriate for DG allocation due to some restrictions considerations) are excluded. The detail of the method for load flow is discussed in section 3.2.

3.2 Load Flow of Distribution Network:

Power flow in a radial distribution network can be performed by backward sweep and Forward sweep methods of Load Flow.

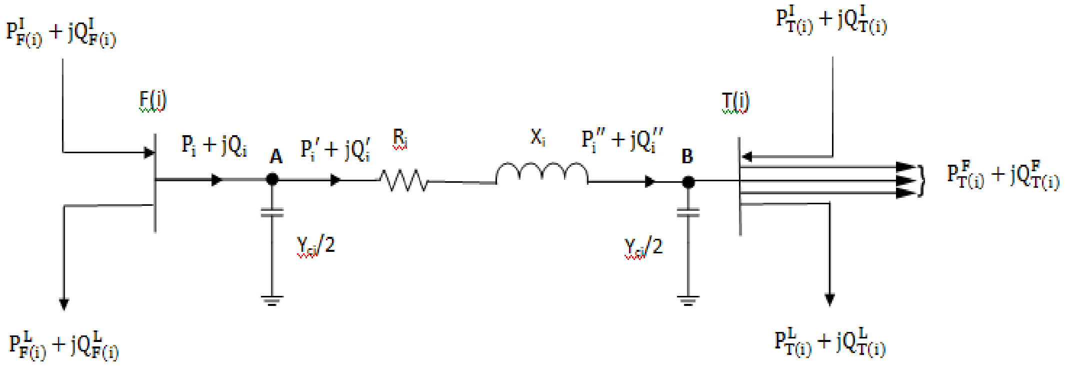

Figure 3.1 ith Branch from bus F(i) to bus T(i) of a distribution network.

Figure 3.1 represents the ith branch of a distribution network which is connected between bus F (i) and bus T(i). Where,

$P^I_{F(i)}$ and $Q^I_{F(i)}$ = Real and reactive injected power at bus F(i) respectively.

$P^L_{F(i)}$ and $Q^L_{F(i)}$ = Real and reactive load power at bus F(i) respectively.

$P^I_{T(i)}$ and $Q^I_{T(i)}$ = Real and reactive injected power at bus T(i) respectively.

$P^L_{T(i)}$ and $Q^L_{T(i)}$ = Real and reactive load power at bus T(i) respectively.

$P^F_{T(i)}$ and $Q^F_{T(i)}$ = Real and reactive power flow from bus T(i) respectively.

R_i and X_i = Series resistance and reactance of the ith branch respectively.

P_i and Q_i = Real and reactive power between bus F(i) and point ‘A’, respectively.

P_i' and Q_i' = Real and reactive power flow just after point ‘A’, respectively.

P_i'' and Q_i'' = Real and reactive power flow just before point 'B', respectively.

$\mathbf{I}_i$ = Current in the i^{th} branch between point 'A' and 'B'.

Y_{ci} = Shunt admittance of the i^{th} branch.

$\mathbf{V}_{F(i)}$ and $\mathbf{V}_{T(i)}$ = Voltage at bus F(i) and bus T(i) respectively.

Therefore we have,

$$I_i^2 = \frac{(P_i'^2 + Q_i'^2)}{V_{F(i)}^2} = \frac{(P_i''^2 + Q_i''^2)}{V_{T(i)}^2} \tag{3.7}$$

$$P_i'' = P_{T(i)}^F + P_{T(i)}^L - P_{T(i)}^I \tag{3.8}$$

$$Q_i'' = Q_{T(i)}^F + Q_{T(i)}^L - Q_{T(i)}^I + V_{T(i)}^2\left(-\frac{Yci}{2}\right) \tag{3.9}$$

$$P_i' = P_i'' + \left\{\frac{(P_i''^2 + Q_i''^2)}{V_{T(i)}^2}\right\} * R_i \tag{3.10}$$

$$Q_i' = Q_i'' + \left\{\frac{(P_i''^2 + Q_i''^2)}{V_{T(i)}^2}\right\} * X_i \tag{3.11}$$

$$P_i = P_i' \tag{3.12}$$

$$Q_i = Q_i' + V_{F(i)}^2\left(-\frac{Yci}{2}\right) \tag{3.13}$$

$$\mathbf{V}_{T(i)} = \mathbf{V}_{F(i)} - \left\{\frac{(P_i' - jQ_i')}{\mathbf{V}_{F(i)}'}\right\} * \{R_i + jX_i\}\,, \quad \text{Or}$$

$$\mathbf{V}_{T(i)} = \mathbf{V}_{F(i)} - \left\{\frac{(P_i'\,Ri + Q_i'\,Xi)}{\mathbf{V}_{F(i)}'}\right\} - j\left\{\frac{(P_i'\,Xi - Q_i'\,Ri)}{\mathbf{V}_{F(i)}'}\right\}$$

Let, $\mathbf{V}_{T(i)} = V_{T(i)} + j\,0$,

Therefore,

$$V_{T(i)}^2 = \left[V_{F(i)} - \left\{\frac{(P_i'\,Ri + Q_i'\,Xi)}{\mathbf{V}_{F(i)}'}\right\}\right]^2 + \left[\frac{(P_i'\,Xi - Q_i'\,Ri)}{\mathbf{V}_{F(i)}'}\right]^2$$

After simplifying, we get,

$$V_{T(i)}^2 = V_{F(i)}^2 - 2(P_i'\,R_i + Q_i'\,X_i) + \frac{(P_i'^2 + Q_i'^2)(R_i^2 + X_i^2)}{V_{F(i)}^2} \tag{3.14}$$

$$\delta_{T(i)} = \delta_{F(i)} - \tan^{-1}\left[\frac{(P_i'\,Xi - Q_i'\,Ri)}{V_{F(i)}^2 - (P_i'\,Ri + Q_i'\,Xi)}\right] \tag{3.15}$$

In Backward sweep and Forward sweep methods of Load Flow, the following steps involved:

(a) Branch numbering:

The process of branch numbering of a network requires the construction of a tree of the network. The tree is constructed in several layers and it starts at the root bus where the source is connected. The swing or slack bus of the network is treated as the root bus. All branches that are connected to the root bus constitute the first layer. The next (second) layer consists of all branches that are connected to the receiving end bus of the branches in the previous (first) layer and so on. All branches of the network should be considered in the tree and they should appear only once. During the tree construction process, if it is found that the receiving end bus of a newly added branch has already been considered in the tree, it should be numbered by adding a prime sign. This implies that the newly added branch makes a loop in the network and it is opened by adding a dummy bus. The branch numbering process starts at the first layer. The numbering of branches in any layer starts only after numbering all the branches in the previous layer. Thus, a forward path is created from the source node to the load node and a backward path is traced from the load node to the source node and hence different layers are formed which are numbered along the forward path as shown in Figure 3.2. The branch node nearer to the source is called as the parent node or root bus and the other node is called as the child node. Initially, the flat voltage start is assumed.

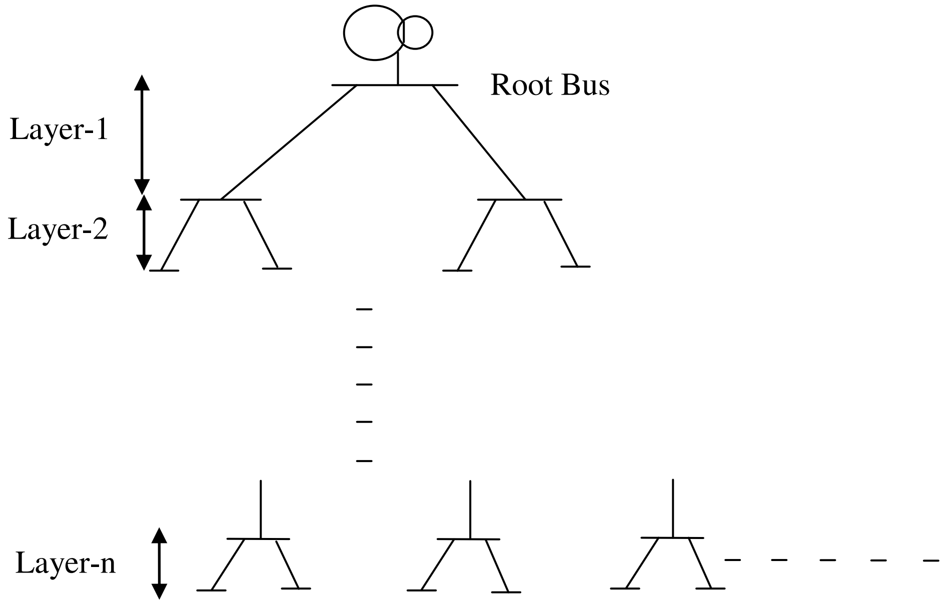

Figure 3.2 Layer formation in Backward/Forward sweep method of load flow

(b) Backward Sweep:

The purpose of the backward sweep is to find the power flow through each branch in the tree in a backward direction by considering the previous iteration voltages at each node. Line flows are calculated using (3.8) to (3.13) starting from last layer to first layer. The backward direction means the equations are first applied to the last branch of the tree and proceed in reverse direction until the first branch is reached. During backward sweep, voltage values are held constant and updated power flows are transmitted backward along the feeder using backward path.

(c) Forward Sweep:

The purpose of the forward sweep is to calculate the voltages at each node starting from the source node. The source node voltage is set as 1.0 per unit and other node voltages are calculated using (3.14) and (3.15). Thus, $V_{T(i)}$ and $\delta_{T(i)}$ are calculated starting from first layer to last layer. The power flow in each branch is held constant at the value obtained in the backward substitution. Thus, using the power flows calculated in the backward substitution, the values of voltages are calculated which are used for calculating the power flows by backward substitution in the next iteration.

The forward and backward substitutions are performed in each iteration of the load flow. The magnitudes of the voltages at each bus in iteration are compared with their values in the previous iteration. If the error is within the tolerance limit, the procedure is stopped. Otherwise, the steps of backward sweep, forward sweep and check for convergence are repeated. As soon as the procedure is stopped, the voltages at each node and the power flows in all the line segments are used to find the power losses in each line segment.

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3.3 Proposed methods:

Numerous techniques are available for sizing and location of DG in radial distribution networks. Out of those several techniques two techniques are very prominent and effective which will be used here and results for those methods will be compared.

3.3.1 Loss Sensitivity Analysis

Sensitivity factor method is based on the principle of linearization of original nonlinear equation around the initial operating point, which helps to reduce number of solution space. Loss sensitivity factor method is mainly used to solve the capacitor allocation problem. Its application in DG location is new in this field and has been reported in [1]. The real power loss in the system is given by "exact loss" formula. The sensitivity factor of real power loss with respect to real power injection is obtained by differentiating exact loss formula with respect to real power injection at bus P_i which is given by:

$$\boldsymbol{\alpha_i = \frac{\partial P_l}{\partial P_i} = 2\sum_{j=1}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j)} \qquad \textbf{(3.16)}$$

Sensitivity factors are evaluated at each bus, firstly by using the values obtained at base case load flows. The buses are ranked in descending order of the values of sensitivity factors to form a priority list. The total power loss against injected power is a parabolic function and at minimum of losses, the rate of change of real power loss with respect to real power injection becomes zero.

$$\boldsymbol{\alpha_i = \frac{\partial P_l}{\partial P_i} = 2\sum_{j=1}^{N}\left(\alpha_{ij}P_j - \beta_{ij}Q_j\right) = 0} \qquad \textbf{(3.17)}$$

which follows that,

$$\boldsymbol{P_i = \frac{1}{\alpha_{ii}}\left[\beta_{ii}Q_i + \sum_{j=1,\ j\neq i}^{N}\left(\alpha_{ij}P_j - \beta_{ij}Q_j\right)\right]} \qquad \textbf{(3.18)}$$

where P_i represents the real power injection at node i, which is the difference between real power generation and real power demand at that node.

$$\mathbf{P_i = P_{DGi} - P_{Di}} \qquad \textbf{(3.19)}$$

where P_{DGi} is the real power injection from DG placed at node i, P_{Di} is the load demand at node i, combining (3.18) &(3.19) we get

$$\boldsymbol{P_{DGi} = P_{Di} + \frac{1}{\alpha_{ii}}\left[\beta_{ii}Q_i - \sum_{j=1,\ j\neq i}^{N}\left(\alpha_{ij}P_j - \beta_{ij}Q_j\right)\right]} \qquad \textbf{(3.20)}$$

The above equation determines the size of the DG at which the losses are minimum. By arranging the list in ascending order, the bus stood in the top is ranked as the first location of DG and further the process is repeated by placing the concerned size of DG at that particular location which generates the next location of DG. The process is said to be terminated when it determines the same location.

3.3.2 Bus Voltage Sensitivity Analysis

Another method for reducing the search space is bus voltage sensitivity analysis. In this case each bus is penetrated at a time, by a DG of 20% size of the maximum feeder loading capacity. After putting DG at each node its voltage sensitivity index can be calculated by Eq. (3.21). When DG is connected at bus I, voltage sensitivity index for bus i is given by:

$$\textbf{BVSI} = \sqrt{\frac{\sum_{k=1}^{N}(1-V_k)^2}{N}} \qquad \textbf{(3.21)}$$

where V_k is the voltage at kth node and N is the number of nodes. The node with the least BVSI will be chosen for DG placement. The algorithm for DG location and sizing can be given as:

Step 1: Run load flow for base case.

Step 2: Find the Bus voltage sensitivity indices at each node using Eq. (3.21) by penetrating the 20 % of DG value at respective node and rank the sensitivities of all nodes in ascending order to form priority list.

Step 3: Select the bus with lowest priority and place DG at that bus.

Step 4: Change the size of DG in small steps and calculate power loss for each by running load flow.

Step 5: Store the size of DG that gives minimum loss.

Step 6: Compare the loss with the previous solution. If loss is less than previous solution, store this new solution and Discard previous solution.

Step 7: Repeat Step 4 to Step 6 for all buses in the priority list.

Step 8: End

3.3 Test System

An IEEE 33- bus radial distribution system has been taken as the test system. The bus connections have been shown below. The line data and bus data for the system is given in appendix –a.

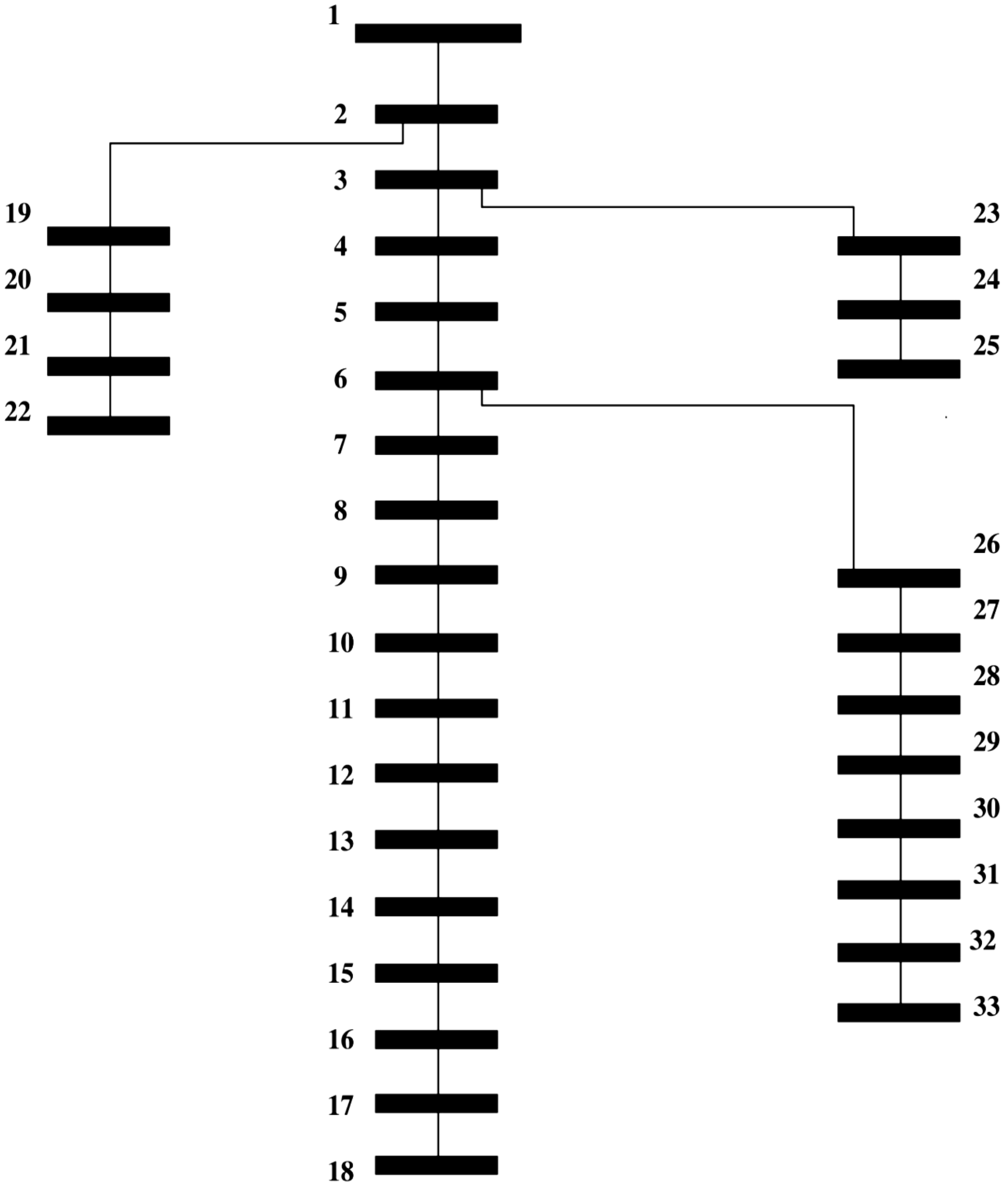

Figure 3.3 33- Bus RDS

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Loss Sensitivity Analysis Method

Sensitivities were calculated at all buses. The bus with least sensitivity was used as optimal location. DG size was tested in the range of 0.5 to 5 MW with the step size of 0.5. Optimal size was obtained as 2.5 MW. A loss reduction of approximately 48% was obtained using this method. The voltage profiles in base case and after DG placement have been shown in the table and figures below.

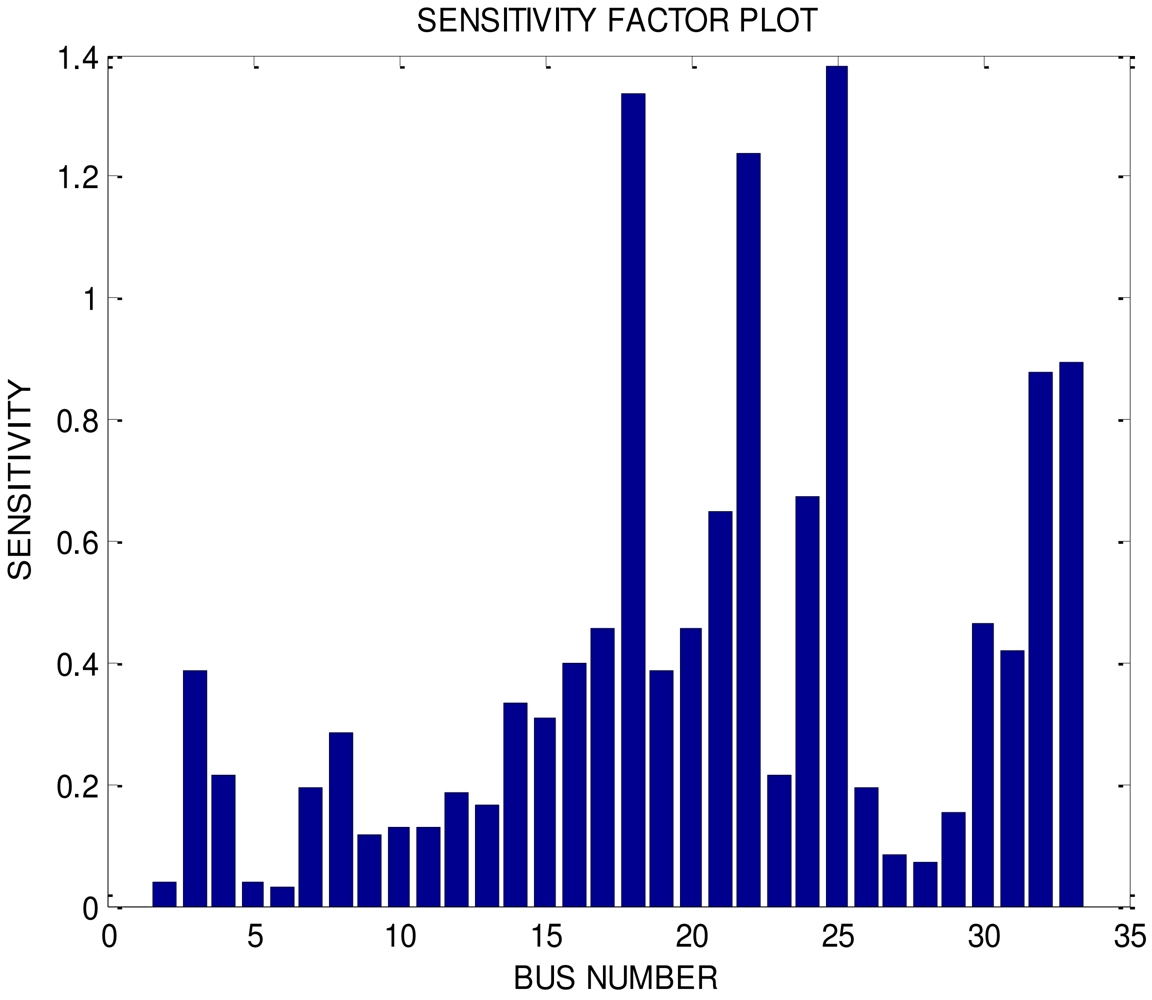

Figure 4.1: Loss Sensitivity at all nodes

Table 4.1: Voltage Profiles with/ without DG

Bus Number	Base Case	With DG
1	1	1
2	0.99702517	0.998539207
3	0.982893027	0.992515487
4	0.975383506	0.991013406
5	0.967957272	0.989852124
6	0.949479405	0.985003553
7	0.945954666	0.981615373
8	0.932298953	0.96848805
9	0.925966382	0.962402799
10	0.920109236	0.956774923
11	0.919242779	0.955942399
12	0.91772794	0.954486991
13	0.91155235	0.948554788
14	0.909262373	0.946355235
15	0.907835562	0.944984872
16	0.906453588	0.943657615
17	0.904405508	0.941690765
18	0.903792196	0.941101768
19	0.996496802	0.998011647
20	0.99291918	0.994439506
21	0.992214672	0.993736077
22	0.991577248	0.99309963
23	0.979307133	0.988965172
24	0.972635663	0.982360002
25	0.969310518	0.979068001
26	0.947549752	0.983147614
27	0.944985492	0.98068153
28	0.933543613	0.969677859
29	0.92532386	0.961773241
30	0.921765723	0.958351742
31	0.917603711	0.954350295
32	0.916688104	0.953470021
33	0.916404403	0.953197271

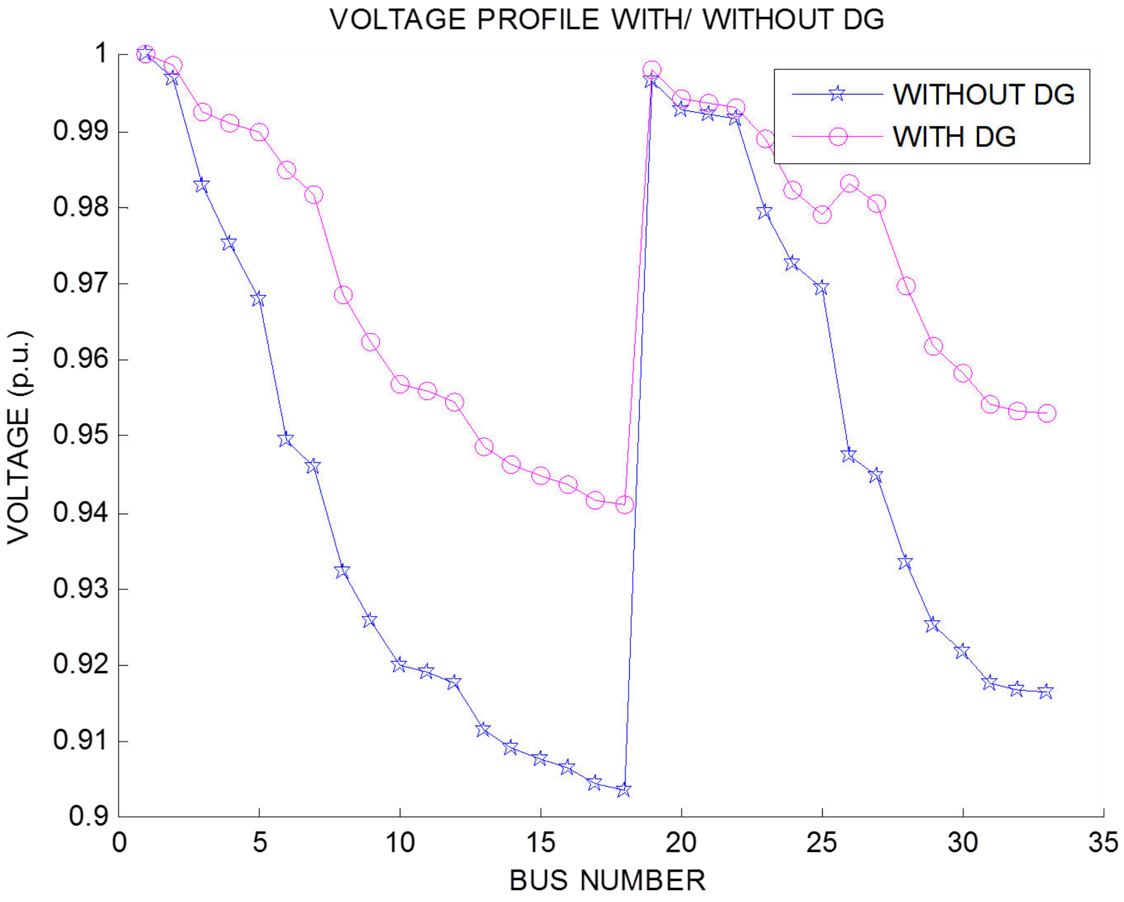

Figure 4.2: Voltage profiles in Loss sensitivity method

4.2 Voltage Sensitivity Index Method

In this method voltage sensitivity index was calculated at all nodes. Bus 18 was found to have the least VSI. Hence DG was placed at this bus. In this case DG sizes were taken in step size of 0.5 MVA starting from 0.5 MVA till 4 MVA at different power factors of 1.0, 0.9, 0.85, 0.8. Voltage Sensitivity Indices of different buses have been shown below.

Table 4.2: DG sizes tested in VSI method

DG SIZE IN MW			
upf	**0.9 lag**	**0.85 lag**	**0.8 lag**
0.5	0.45	0.425	0.4
1	0.9	0.85	0.8

1.5	1.35	1.275	1.2
2	1.8	1.7	1.6
2.5	2.25	2.125	2
3	2.7	2.55	2.4
3.5	3.15	2.975	2.8
4	3.6	3.4	3.2

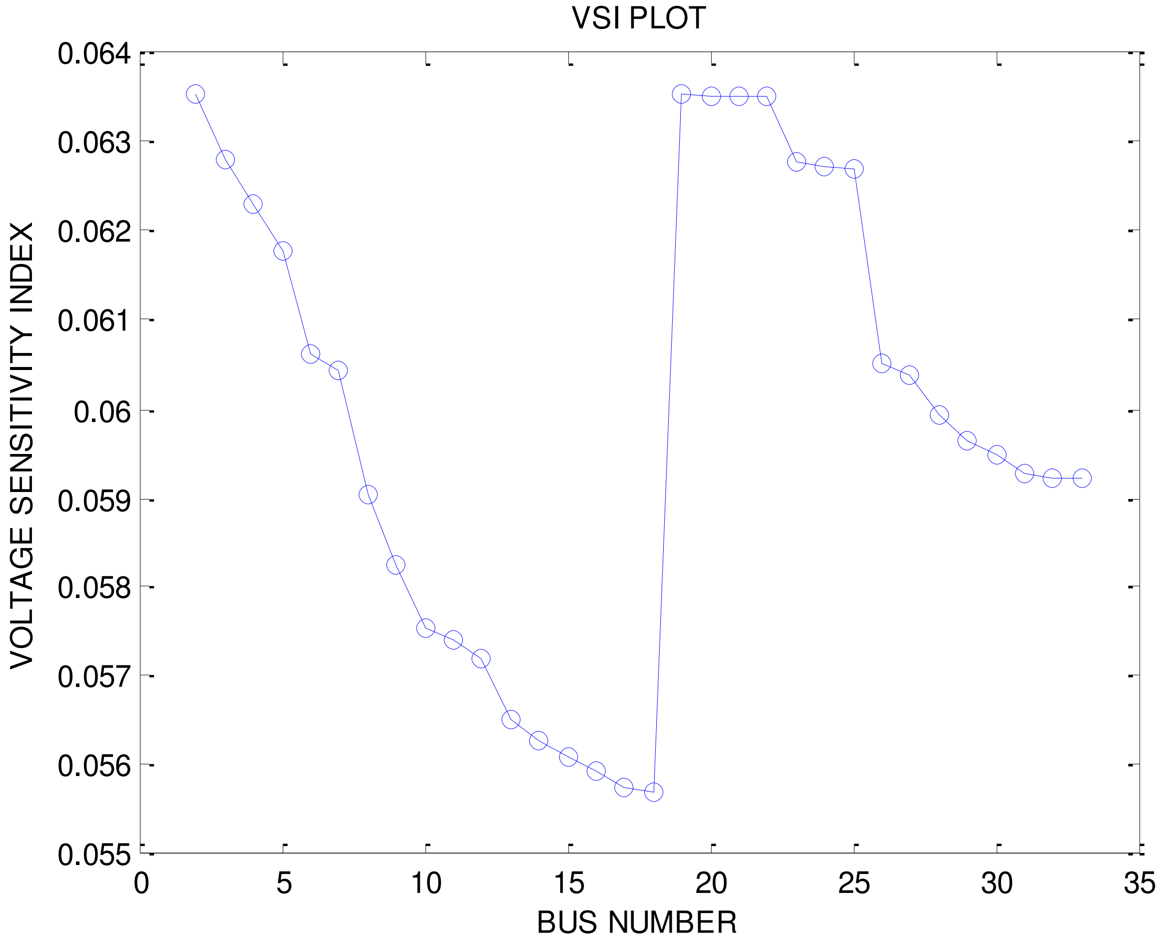

Figure 4.3: VSI at different buses

The sensitivities and DG sizes tested have been shown above. The power loss reduction ranges from 30-35 %. After comparing the two methods it can be concluded that loss reduction in loss sensitivity method is more and it is better in terms of judging the location of DG. For the purpose of sizing the voltage sensitivity analysis index method is a better option. The power loss curves and voltage profiles have been shown in upcoming table and figures.

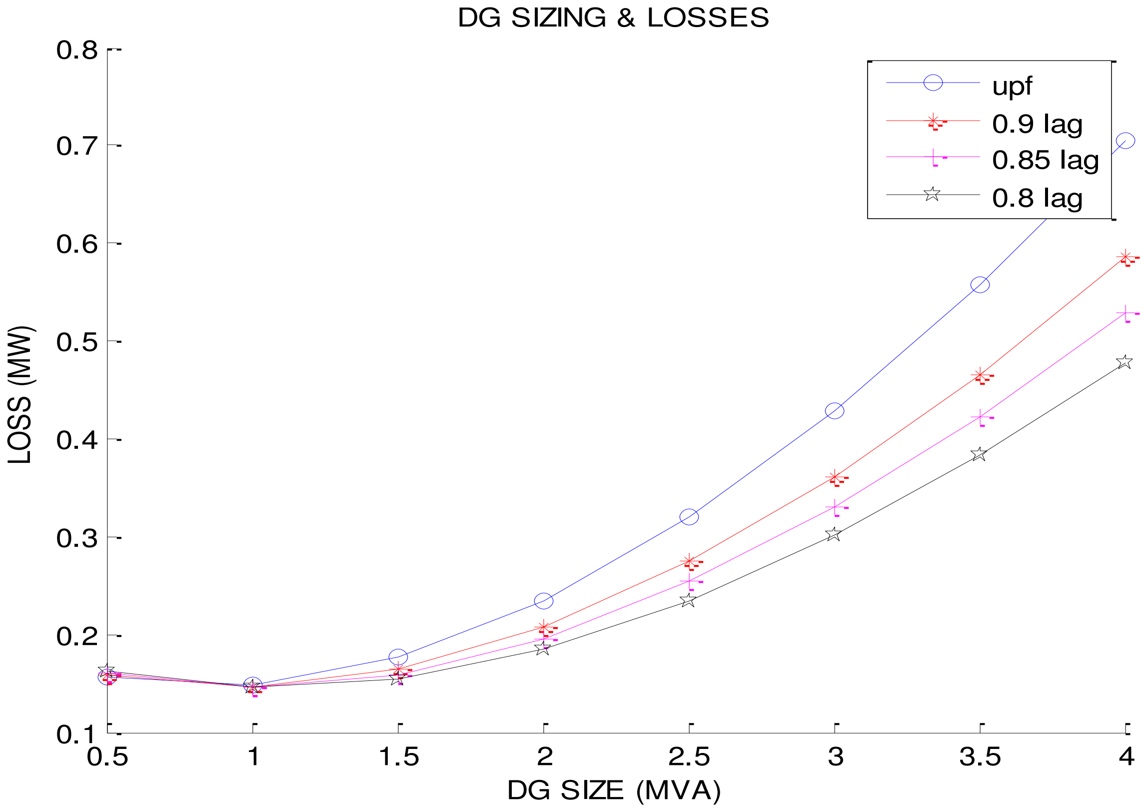

Figure 4.4: Power Loss curves

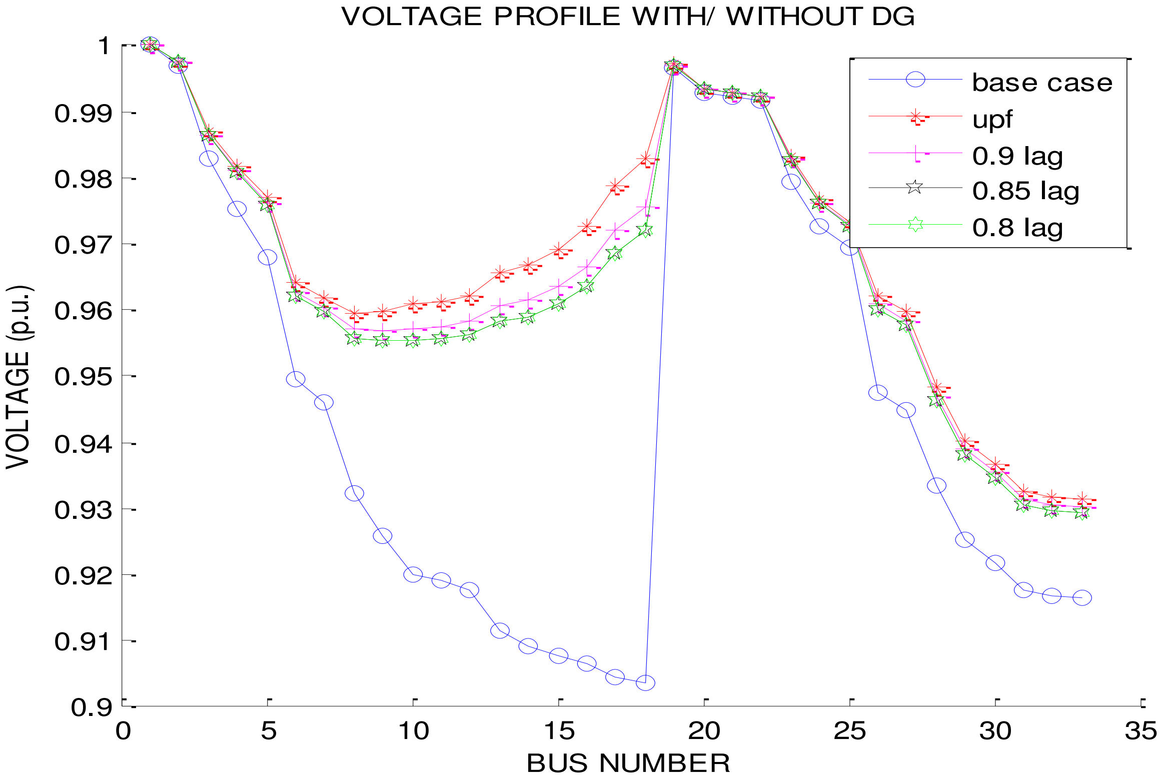

Figure 4.5: Voltage Profiles in VSI method

Table 4.3: Voltage Profiles in VSI method

Bus	Base Case	1MVA @ upf	1MVA @ 0.9	1MVA @ 0.85	1MVA @ 0.8
1	1	1	1	1	1
2	0.99702517	0.99764856	0.997592613	0.997564175	0.997564175
3	0.982893027	0.986852609	0.98649705	0.986316337	0.986316337
4	0.975383506	0.981812219	0.981234695	0.98094119	0.98094119
5	0.967957272	0.976958669	0.976149673	0.975738565	0.975738565
6	0.949479405	0.964072731	0.962769814	0.962107033	0.962107033
7	0.945954666	0.96180722	0.960407336	0.959693988	0.959693988
8	0.932298953	0.959445866	0.957031977	0.955803348	0.955803348
9	0.925966382	0.959871833	0.95684786	0.955309494	0.955309494
10	0.920109236	0.960834004	0.957191945	0.955339993	0.955339993
11	0.919242779	0.961251631	0.957491423	0.955579664	0.955579664
12	0.91772794	0.962184358	0.958198847	0.956173054	0.956173054
13	0.91155235	0.965568946	0.960713533	0.958246687	0.958246687
14	0.909262373	0.966790441	0.961617809	0.958989959	0.958989959
15	0.907835562	0.969164295	0.963643351	0.9608391	0.9608391
16	0.906453588	0.972575004	0.966612249	0.963584444	0.963584444
17	0.904405508	0.978785625	0.972061434	0.968648363	0.968648363
18	0.903792196	0.982862169	0.975700984	0.972067147	0.972067147
19	0.996496802	0.997120525	0.997064548	0.997036095	0.997036095
20	0.99291918	0.993545162	0.993488982	0.993460426	0.993460426
21	0.992214672	0.992841098	0.992784879	0.992756302	0.992756302
22	0.991577248	0.992204077	0.992147822	0.992119227	0.992119227
23	0.979307133	0.983281443	0.982924566	0.982743183	0.982743183
24	0.972635663	0.976637418	0.976278086	0.976095454	0.976095454
25	0.969310518	0.973325993	0.972965434	0.972782178	0.972782178
26	0.947549752	0.962174078	0.960868435	0.960204264	0.960204264
27	0.944985492	0.959651109	0.958341835	0.957675813	0.957675813

28	0.933543613	0.948393534	0.947068055	0.946393771	0.946393771
29	0.92532386	0.940306327	0.938969194	0.938288968	0.938288968
30	0.921765723	0.936805664	0.935463478	0.934780676	0.934780676
31	0.917603711	0.932711201	0.931363076	0.930677246	0.930677246
32	0.916688104	0.931810458	0.930461026	0.92977453	0.92977453
33	0.916404403	0.931531364	0.930181528	0.929494825	0.929494825

CHAPTER FIVE
CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

From the results and discussions in the previous chapter it can be easily concluded that:

1) Better loss reduction was obtained in loss sensitivity method.
2) In loss sensitivity method, bus 6 was chosen for DG placement. Since it was a junction of several branches, voltage profile improvement was better in this case.
3) In VSI method though loss reduction was less, but assessment of DG sizing was better.
4) Since VSI method generally gives minimum sensitivity values at last buses, hence it is a very rigid and improper method for loss reduction and voltage profile improvement.

5.2 Future Scope

After all the discussions, it is very clear that there is a scope for future work in this thesis. It can be discussed through following points:

1) Assessment of impact on power loss, by considering both leading and lagging power factors while sizing of DG.
2) Testing these methods on larger bus systems.
3) Though the power loss reduction was very good in loss sensitivity approach, still a better method can be devised for sizing of DG.

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APPENDIX-A

PARAMETERS FOR 33-BUS DISTRIBUTION SYSTEM

Branch Number	Bus (From)	Bus (To)	R (ohm)	X (ohm)	P-load (kW)	Q-load (kVar)
1	1	2	0.0922	0.047	100	60
2	2	3	0.493	0.2511	90	40
3	3	4	0.366	0.1844	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.819	0.707	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	0.7114	0.2351	200	100
8	8	9	1.03	0.74	60	20
9	9	10	1.044	0.74	60	20
10	10	11	0.1966	0.065	45	30
11	11	12	0.3744	0.1238	60	35
12	12	13	1.468	1.155	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.591	0.526	60	10
15	15	16	0.7463	0.545	60	20
16	16	17	1.289	1.721	60	20
17	17	18	0.732	0.574	90	40
18	2	19	0.164	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	50

23	23	24	0.898	0.7091	420	200
24	24	25	0.896	0.7011	420	200
25	6	26	0.203	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.059	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.963	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.341	0.5302	60	40
33	21	8	0	2		
34	9	15	0	2		
35	12	22	0	2		
36	18	33	0	2		
37	25	19	0	2		

Base kV= 12.66, Base MVA= 0.1

Tie switches = 21-8; 9-15; 12-22; 18-33; 25-19