ELECTRICAL POWER DISTRIBUTION SYSTEM MANAGEMENT UNDER DEREGULATION REGIME

Thesis

Submitted in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

by

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DECLARATION

by the Ph.D. Research Scholar

I hereby ***declare*** that the Research Thesis entitled **"ELECTRICAL POWER DISTRIUBUTION SYSTEM MANAGEMENT UNDER DEREGULATION REGIME"** which is being submitted to the ***National Institute of Technology Karnataka, Surathkal*** in partial fulfilment of the requirements for the award of the Degree of ***Doctor of Philosophy*** in **Power & Energy Systems, Department of Electrical and Electronics Engineering** is a ***bonafide report of the research work carried out by me.*** The material contained in this Research Thesis has not been submitted to any University or Institution for the award of any degree.

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CERTIFICATE

This is to *certify* that that the Research Thesis entitled ***"*ELECTRICAL POWER DISTRIBUTION SYSTEM MANAGEMENT UNDER DEREGULATION REGIME*"*** submitted by **Mr. K. Manjunatha Sharma (Register Number: 03221015A)** as the record of the research work carried out by him, is accepted as the *Research Thesis submission* in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy.**

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ABSTRACT

The distribution system in the electrical power network is the most vital section being nearest to the consumers. The effectiveness of the power delivery to the loads is governed by the design, operation and maintenance of the distribution network. Over the years, the researchers are attempting to achieve improvements in the distribution system performance by adopting newer topologies, strategies for network design and control. In this context, globally the need for distribution system improvement is acknowledged by all countries and since past decade distribution sector reforms are being executed by initiating newer government policies which led to de-regulation regime worldwide.

This thesis addresses the issues of DG insertion to distribution system in deregulation regime. The analysis carried out evaluates the feasibility of an Industrial captive power plant to operate as a DG Source, complex issues associated with multiple DG sources insertion to distribution system and impact of DG sources in network reconfiguration.

A tool which facilitates decision on power export by an industrial captive power plant to grid has been developed. This tool accounts existing load pattern and generation scenario of the industrial unit. The proposed analytical approach gives with emphasis on choice of improving any specific parameter from either technical or economical perspective. The strategic technique developed proposes a comprehensive index termed as Network Performance Enhancement Index (NPEI). This index is a combination of indices related to loss reduction, voltage profile improvement, voltage regulation, voltage stability. Adapting this index provides enough alternatives to the designer so that he can decide on the most feasible solution. The technique designed for service restoration enumerates the situations of islanding of DGs due to fault in any part of network and guides the operator for supply of local loads in such a situation. This work proposes most feasible schemes for DG insertion to overcome the difficulties in implementation of the conventional fixed solutions schemes. The software tools adopted are SKM Power Tools and MATLAB and all evaluations are done using standard bus structures reported in literature and nearby captive plant data of an industry.

Keywords *– Captive Power Plant, Distributed Generation Source, Genetic Algorithm, Performance Indices, Power Loss Reduction, Service Restoration, Techno-Economic Perspective, Voltage Profile Improvement.*

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NOMENCLATURE / ABBREVIATIONS / ACRONYMS

I	Current
IL_P	Real Power Loss Index
IL_Q	Reactive Power Loss Index
IVD	Voltage Regulation Index
IVR	Voltage Regulation Index
M	Sensitivity Matrix
NPEI	Network Performance Enhancement Index
P	Real Power
Q	Reactive Power
P_{Loss}	Real Power Loss
Q_{Loss}	Reactive Power Loss
PTW	Power Tools for Windows developed by SKM Inc.
R	Resistance
S	Apparent Power
V	Voltage
VAR	Volt Ampere Reactive
VSI	Voltage Stability Index
W	Watts
Whr	Watt-hour
X	Reactance
Y	Admittance
Z	Impedance

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CHAPTER 1

INTRODUCTION

The Power distribution system in the form of dc systems came into operation at the end of 19th Century. Since then distribution systems have evolved into more complex structure. In the past, the distribution sector did not receive enough attention globally under regulated environment. The crucial aspects of distribution system management like planning, design, operation and control were totally ignored which led to inefficient network with poor performance. The losses in the distribution network were in the range of 20% to 40%. The voltage profile was very poor, which was severely affecting remote customers [1].

There are constraints on generation like availability of resource and also limitations on of power transmission network for power transfer exists. The conventional distribution systems are operating at the tail end of the electrical power system. The generation has to be transported through long transmission lines to the distribution network. The load at the distribution end is increasing drastically and eventually there exists a large gap between the supply and demand. This aspect has gained much significance during past decade and new policies have been framed in all countries to execute distribution sector reforms.

The reforms are aimed at the following domains:

(i) New technologies and materials for distribution system

(ii) Incorporation of distributed generation sources

(iii) Efficient analysis and computational tools

With the help of distribution sector reforms, the real time monitoring, control and protection of distribution system has been implemented. The network losses have been reduced. The gap between generation and supply has been bridged considerably.

Keeping the pace with international countries, India has implemented in distribution sector reforms effectively. The changes have been brought in by way of making new polices, enhancement of infrastructure, encouragement for independent power producers in deregulation regime. The Figure 1.1 shows the typical distribution system existing in India.

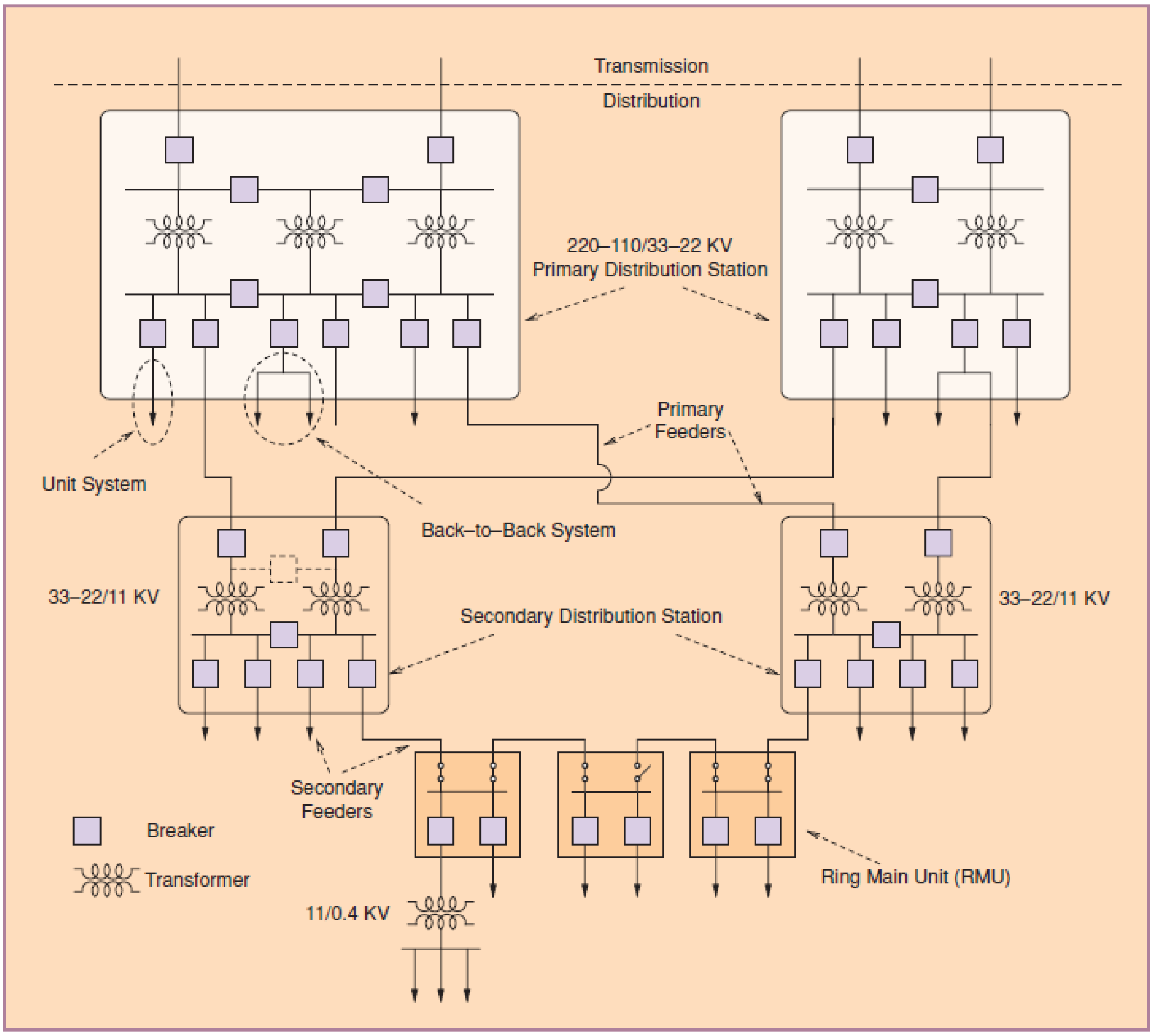

Figure 1.1 Scheme of Distribution Network in India [2]

The participation of independent power producers in the improvement of distribution network is very crucial. The Indian electricity system suffers from huge gap in electricity supply and demand, higher transmission and distribution losses and poor voltage profile. In this regard, incorporation of distributed generation sources operated by private players helps to improve the prevailing power distribution scenario.

The advantages of the Distributed Generation (DG) [7] are :

- Voltage Profile Improvement
- Reduction in System Losses
- Sharing the burden of Transmission and Distribution Lines
- Enhancement of system reliability
- Realisation of efficient Systems
- Higher safety and security measures

The disadvantages are :

- Possibility of Reverse Power Flow situations
- Increased Complications in system stability
- Impact of fault in the network in operation and protection of the system

This thesis reports development of strategies for Distributed Generation Source Allocation in a distribution system with focus on overall performance improvement in operating conditions. The investigations are carried out by considering technical aspects such as loss reduction, voltage profile improvement, voltage stability improvement and economical aspects such as operational costs. The investigations conducted cover the following areas:

- ***Analysis of Integrated operation of Industrial System with Captive Plant and utility Grid.***
    a. Different Operating Scenarios in Industrial System.
    b. Power Import and Export Situations from Industry
    c. Estimation of System Losses during the process

- ***Impact of Single Distributed Generation Source on operation of network***
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1.1. Research Motivation and Contribution of the Thesis

The development of strategies for efficient operation and control of distribution network is always a challenge. The insertion of distributed generation sources to the distribution network creates more complexities in management of network. Since the modern distribution network essentially comprises of DG sources to bridge the gap between power supply and demand, the issues associated with integrated operation of utility and DG sources needs to be addressed with utmost care.

The major contribution of the work is to suggest strategies for planning and operation of distributed generation sources for distribution networks. The deregulation regime has brought many independent power producers to the power generation domain. The exchange of power between the power producers and utility has taken a new dimension of power trade. In this context the strategies to be adopted in planning and management of the distribution network should address both technical and economic considerations. The development of such strategies is a challenge for research in the area of distribution system. This thesis presents the analysis carried out on distribution systems with DG sources and recommends strategies for incorporation of DG sources for efficient operation both from technical and economical perspectives. The subsequent paragraphs highlight the major contribution of the thesis.

The distribution systems are characterized by long distance, more resistive networks. The poor operation of the distribution systems is due to improper planning, inefficient operation and control strategies. The power flow solutions for the distribution systems are difficult to formulate due to characteristics of the network. The power flow solution for the industrial plant is much tougher owing to its complexity. The different components used are generators, bus bars, transformers, circuit breakers, cables, motor loads and other types of loads. Each component has its own specific setting and needs to be incorporated in the analysis. This requirement makes the solution much more difficult. The graphical simulation packages help to model the large industrial systems so that the different types of analysis can be carried out with variation in the network parameters.

With reference to the above, the research work presented as *first module* in this thesis deals with analysis of an industrial captive power plant serving as distributed generation source. A tool has been developed to assist the system operator in decision making process during combined operation of utility and industrial captive power plant.

There are many software tools for simulation of industrial systems. “SKM power tools” is one such software package with built in models for industrial components[3]. The various capabilities of the package include Load flow analysis, short circuit analysis, Transient motor starting analysis, reliability analysis. The package is user friendly with graphical user interface and menu driven system. The parameters of all the devices can be set by appropriate selection before running the simulation studies. This package is employed in the analysis of industrial power plant as distributed generation source in the first module of this thesis.

In the study carried out, the industrial plant is operated as distributed generation source and operating with utility in integrated manner. Since industrial unit is exporting power, the load conditions and generation scenario within the plant are extremely important to arrive at quantum of power export. In the literature, attempts have been made to suggest suitable methodologies to address this issue. Hugo Morais, Marilo Cardoso proposed a visual tool for decision making process which presents the actual scenario to the operator. This visual tool incorporates modeling of the industrial system guide on the appropriate solutions based on load and generation scenarios [4] [24]-[33].

In this research work, the analysis of a practical industrial captive power plant functioning as distributed generation source has been carried out. To help the decision making process regarding power export to the utility based on generation and load pattern a tool has been developed by way of simulating the actual operating conditions. The field data from a petrochemical industry, Mangalore Refinery and Petrochemicals Limited (MRPL) has been considered for this purpose. The developed tool facilitates decision on power export based on existing load and generation scenario of the industrial unit and also considering utility requirement of energy.

The allocation of distributed generation source in a large distribution network is very crucial for system operation. The improper location and capacity of DG may lead to deteriorated performance in terms of increased power losses and poor voltage profile. The capacity of the DG source at any particular location influences the power losses of the system. As the capacity of DG increases, system losses will be reduced, however if the capacity of DG is increased beyond certain value, the system losses will increase when compared with initial case of without DG. Hence it is very much necessary to consider this aspect while planning the network. This aspect demands the judicious choice of optimum DG allocation techniques considering power loss minimization [5] [34]-[36].

The presence of DGs in the distribution network should aid improvement of system voltage stability. The static voltage stability is evaluated based on the load flow computations and impact of DGs on the network can be accessed. It is necessary to devise appropriate model reflecting the generation technology employed. The DG location can be arrived at so that system voltage stability can be improved [6] [38].

The voltage profile improvement is a key objective in system improvement. The impact of selected DG location and size on the voltage profile is very much crucial so that all nodes in the network operate within the prescribed limits. This parameter along with the loss reduction needs to be considered at the planning stage in order to arrive at feasible solutions [7] [8] [39]-[45].

The insertion of DG source brings in many advantages for network operation. The quantification of technical benefits will help to carry out feasibility studies in order to decide upon most feasible solution. Since different systems have been designed and operated to achieve improvement in a particular parameter of interest, depending on this parameter of interest, the approach for quantification of technical benefit will differ and decision of DG allocation also varies accordingly [9] [42]. Keeping up with these objectives, research work is undertaken to analyse the impact of insertion of a single distributed generation source to the distribution network, and proposed technique is presented in the *second module* of the research work.

As discussed earlier, the second module of the work describes the analysis of distribution system performance in presence of a single distributed generation source. An analytical technique for single distributed generation source allocation for a large distribution network has been developed and implemented in MATLAB. The proposed approach gives with emphasis on improvement on any specific parameter like power loss reduction, voltage profile improvement, voltage stability based on choice of system designer from network planning and operation perspective.

The allocation of multiple DG sources to distribution system is very complex phenomenon. The *third module* describes the strategies to be adopted in selecting the locations and operation of multiple DG sources. The developed approach encompasses both technical and economical parameters in arriving at recommendation. The reported literature in the allocation of multiple DG sources is discussed below.

The distribution sector reform under deregulation regime encourages independent power producers to install and supply energy at distribution system level. This energy exchange assumes the power trade philosophy and analysis of the system from both technical and economic angles becomes essential. A restructured power trading model for Indian scenario within the boundary of legal framework had been developed in literature by taking into consideration the major issues faced by the power traders in Indian electricity market [10] [46]-[62].

The optimal locations and size of DG’s in a distribution system were determined by adopting ant colony optimization. In this technique, a cost based model decides the optimal size and location of the distributed generation sources in a power distribution system. The objective is defined as minimization of DG investment cost and total operation cost of the system. The model considered time varying load for a period of a year, as well as the optimal operation strategy of DG sources in the system providing minimization of DG investment and operating cost of the system [11] [48][56].

The placement of DGs has to be done so that voltage collapse is prevented at most sensitive buses. The algorithm comprises of installing certain capacity of DGs at these buses and determination of voltage collapse point or maximum loading. An iterative procedure was developed to investigate the impact of DGs on static voltage stability and arriving at suitable solutions [12][46][62].

As insertion of DGs improve many system parameters, the determination of the extent of improvement in each parameter is vital in decision making process The multi objective function defined comprises of the objectives as (a) minimize real power, reactive power loss (b) voltage deviation index. Evolutionary programming was adopted for solving the objective function. The approach incorporated load models for analysis [13] [63]-[81].

With the deregulation of energy market and the appeal for environment protection, more and more distributed generation with clean technologies is embedded in the distribution network. However the capacity of DG inserted at any location depends on potential of energy generation at the location and also the economic aspects. The distribution network operators always wish to play safe by avoiding the negative effects of high level penetration. The technical and economical impacts must be assessed before deciding the allocation of DG sources. To facilitate this objective, computation of indices related to system improvement will be very much essential. By this approach the effective distribution system management can be realised [14] [82]-[90].

Since process of multiple DG source allocation is quite cumbersome, artificial intelligence techniques had been attempted to arrive at suitable solution. The focus for the approach was to obtain solution achieving reduction in power losses and improvement in voltage profile. The model aimed at allocation of multiple DGs from overall management perspective including control and protection was proposed by Qudaih and Syafaruddin Hiyama [15]. The approach for optimal allocation of DG Units using PSO Algorithm has been suggested by K. Varesi [107].

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Based on the work reported in the literature as discussed above, the *third module* of this research encapsulates the development of a strategic approach for multiple distributed generation source allocation for large distribution network. A comprehensive index termed as Network Performance Enhancement Index (NPEI) is proposed which is a combination of indices related to loss reduction, voltage profile improvement, voltage regulation, voltage stability. The selection based on NPEI ensures overall improvement on all these parameters. The methodology developed provides enough alternatives from both technical and economical perspectives to the designer to enable him to decide on most feasible solution.

The network reconfiguration at the power distribution systems with distributed generation results in reduced system losses. The conventional power distribution systems have a radial network and unidirectional power flows. The distribution system with DG sources has a locally looped network and bidirectional power flow. Therefore, DG into the power distribution system can cause operational problems and impact on existing operational schemes. In this context, Joon –Ho Choi and Jae-Chul Kim have reported the importance and necessity of selection of appropriate operational scheme from many alternatives is essential in safeguarding system security [16].

The integrated operation of DG sources with utility grid can be successful only when distribution automation is achieved. Since real time monitoring can be carried out and suitable control actions can be taken in automated schemes, network performance will significantly improve. Joon –Ho Choi and Jae-Chul Kim have proposed operational strategies for network reconfiguration with DGs in automated distribution systems [17][94][98][101].

The cost of transmission and distribution losses needs to be accounted by means of allocating the losses to consumers. The allocation of power losses to consumers connected to radial distribution networks before and after network reconfiguration in a deregulated environment is to be done in reasonable manner. The approach to allocate losses allocation with identification of the real and imaginary parts of current in each branch and network reconfiguration based on the fuzzy multi objective optimization had been developed by J.S. Savier and D. Das [18].

The network reconfiguration will alter the power flow amongst different branches of the system. The algorithm employed to decide on network re-configuration involves aspects of loss minimization and voltage profile improvement during network reconfiguration process had been analysed and effective solutions have been computed [19].

The artificial intelligence techniques have been very much useful in analysis of distribution system with distributed generation sources. The adoption of genetic algorithm helps in getting solutions which optimises desired objective function [20]. The approach developed using Ant Colony Algorithm has objective of minimising power loss and accounts for load balance [21].

The occurrence of a fault in a radial distribution system leads to service discontinuity for certain locations after fault isolation. If tie- switches are present in the system, service restoration can be attempted with reconfiguration by providing alternate path. However it may not be possible to restore entire area due to network constraints. In this scenario, presence of DG sources will be advantageous for service restoration process through alternate routes ensuring continuity of power supply. The technique to decide upon service restoration process has been developed for establishment of continuity of supply in a network in presence of DG sources [22] [91]-[105].

In the *fourth module* of this thesis, the schemes for network reconfigurations have been developed. The reconfiguration has been recommended for both cases of without DG and with DG for optimal operation. The fault scenario has been considered and recommendations for reconfiguration to achieve service continuity and efficient operations have been made. The critical situation of multiple faults occurring on the network which results in Islanding operation of DGs is included in the analysis and suitable strategies have been recommended for operation of the network.

Though many approaches suggest the scheme for DG allocation, it is not in possible to achieve all objectives of network operation. In this regard, a comprehensive tool to bring out the most feasible solution addressing the technical, economic and geographical constraints is very much needed. This aspect is the motivation for the work presented in the thesis. The approach developed in the present work addresses both technical parameters as well as economic factor. As the location of insertion of DG puts constraint on its capacity due to potential of generation as well as land use requirements, developed strategy caters to different capacity of DGs injection and solution for overall network performance improvement has been arrived at. Also the best solution may not be feasible for implementation for various reasons. Hence priority list of different alternatives has been proposed. The most feasible option can be selected from the priority list for successful insertion of DGs and also ensuring better performance of the system in presence of DGs. The scope of service restoration enhances with DGs. The schemes for service restoration after occurrence of fault in the network have been developed considering different possibilities including scenario of islanding operation of DGs .

In all, an effort is made and reported in this thesis, dedicated to the domain of power distribution systems, in the view of improving the performance of the present day network integrated with distributed generation resources.

1.2 Organization of the Thesis:

The investigations conducted based on above objectives are presented sequentially in the thesis. A brief skeletal structure of the thesis along with the summary of the individual chapters therewith, is detailed in this section. This is as follows:

Chapter 1 : Introduction

This chapter gives the insight about the research area and aimed at familiarisation of issues associated with the topic. The literature survey brings out the existing concepts and techniques for addressing the problem and highlights the motivating factors for the present work. The chapter contains the distribution system operation and control aspects, global reforms in distribution sector, relevance of reforms in Indian context, De-regulation policy adopted by India, factors associated with insertion of distributed generation sources and the scope of present work. The issues addressed in the research work related to insertion of DG sources to distribution system are listed.

Chapter 2 : Analysis of Industrial Captive Power Plant as DG Source

In De-regulation regime, as per the policy of Government of India, any company having its own power plant is entitled to sell the energy to the utility with appropriate integration with the grid. This provision will be effective only when there exists a visual tool for arriving at decision about quantum of power export after due analysis of the load and generation scenario of plant and requirement of the utility.

To cater to this need, the electrical power distribution system of and industry Mangalore Refinery and Petrochemicals Limited (MRPL) is simulated using SKM power tools. The system comprises of the generators, transformers, switchgears, cables, motor loads. The plant layout has been categorised as Phase – I, Phase – II. These Phase – I and II can operate independently and also in integrated manner. The industry can either import power from the utility or export power to it. Considering these probabilities the case studies have been formulated as below.

- Case Study 1 : Only Phase – I Generators and Load Exists
- Case Study 2 : Only Phase – II Generators and Load Exists
- Case Study 3 : Both Phase – I and Phase – II Generators and Load Exists, Integrated Operation of Phase – I and Phase – II.
- Case Study 4 : Integrated Operation of Phase – I and Phase – II with Power Import from the Utility Grid
- Case Study 5 : Integrated Operation of Phase – I and Phase – II with Power Export to the Utility Grid

In each of the above cases, the parameters of the plant are tuned to meet the power flow constraints. The simulation results obtained are matching with the field results for the industrial operation. The system losses are computed for each of the cases and observed voltage profile is found conforming to the standards.

Chapter 3: Impact of Single DG Source on Distribution System Performance

Since the distribution system comprises of many buses spread over large geographical area, the selection of location and capacity of DG source for optimal operation has to be done carefully. Any wrong placement can deteriorate the system performance. In addition the system designer and operator aim at improvement of any specific parameter depending on the policies and requirement of the utility. To resolve such selection procedure, the impact of existence of single DG source for systems comprising of different number of buses has been analysed and various indices based on loss reduction, voltage profile improvement, voltage stability improvement have been computed. In addition the location which gives maximum possible loss reduction with lowest capacity of DG has been arrived. This aspect helps to take decision of DG location and capacity wherein economical constraints exist and Investment costs have to be reduced. Also this factor is useful in the geographical areas with limited generation potential demanding for lower DG capacity. While assessing the impact it has been observed that the system designer has to select proper location and size of the DG to improve the parameter of his interest. Hence a comprehensive guidance table has been worked out for catering to the needs of distribution system design. The approach is applied to 33 bus, 69 bus and 90 bus test systems.

Chapter 4: Criteria for Multiple DG Source Insertion to Distribution System

The insertion of multiple DG sources is of more complex nature than single DG case. The numerous combinations possible throw challenge to the designer to design efficient system. As reported in the literature Genetic Algorithms are employed to arrive at the best combination of the locations. In order to facilitate the selection of DG location different performance indices based on real and reactive power loss reduction, voltage profile improvement, voltage regulation and voltage stability are computed. The objective function used for arriving at the solution is the Network Performance Enhancement Index (NPEI) which is newly proposed index in the present research work. The combinations of locations which give highest NPEI will be the most suitable location for insertion of DG sources. The NPEI will guide the designer to fix the appropriate location of DG sources with optimal capacity so that all parameters of network operation like network losses, voltage profile, voltage stability improve after DG insertion. The approach developed was tested on 33 bus, 69 bus and 90 bus System. The economics of DG insertion is evaluated on the basis of total operating cost of the utility and DGs, and net savings possible. The final selection of the best combination can be made as tradeoff between the most economical choice and best NPEI as per requirement. The proposed methodology is demonstrated for 33 bus, 69 bus and 90 bus test systems.

Chapter 5: Role of DG sources in Post Fault Network Reconfiguration

The role of DG is much crucial when distribution system is subjected to fault. The process of isolation of fault will lead to disconnection of certain portion of the network from supply. By means of switching alternate paths, the power supply in those disconnected areas can be restored. However this will change the network topology and system operating conditions. The DG sources placed at some previously selected locations play a role in deciding the best route for reconfiguration. During fault isolation, it may so happen that some DGs are forced to go out of service due to separation from utility. The various cases of faults occurrence at different branch locations show that the reconfiguration must be attempted to bring back all DGs to service It has been shown that in case of simultaneous faults on a distribution system the islanding results and there is no way DGs can be operated in conjunction with utility. This results in power failure in few parts of the system, unless the disconnected DG is operated in stand-alone mode. The typical cases have been considered which result in islanding situations and the network operator can obtain islanding information and analysis of stand-alone operation of DG which will help the decision making process while reconfiguration.

Chapter 6: Conclusions and Future scope

This chapter lists the broad conclusions arrived from the results of the analysis carried out in the research work. The discussion about future scope of research as an extension of present work is incorporated.

Appendix A: Features of SKM Power Tools and MRPL Plant Data

Appendix B: Voltage Stability Index Computation

Appendix C: Data for 33 Bus, 69 Bus and 90 Bus Systems

CHAPTER 2

ANALYSIS OF INDUSTRIAL CAPTIVE POWER PLANT AS DG SOURCE

2.1 Introduction

Distribution networks have recently acquired a growing importance in the automated systems management. Because of the complexity of the network, their simulation study is always a challenging field of research. The technological developments have brought higher quality of service to consumers. Since past decade, Distribution Automation has made great impact in improving reliability and efficiency in the operation of distribution systems. Many applications, such as network optimisation, reactive-power planning, feeder reconfiguration, state estimation, short-circuit analysis etc. are included in distribution automation systems. This chapter describes the analysis of a practical industrial captive power plant operating as DG source integrated with utility grid. The simulation is done in SKM Power Tools and verified with field results.

For carrying out simulation based analysis, selection of a proper distribution model is necessary to get comparable results with the field values. The analysis mainly focuses on the power generated by the generators and the power consumed by the load and losses occurring in the system. The scenario considered includes the field data and various possibilities of operation and control is analysed. For the purpose of planning and design the steady state analysis has been carried out. The power flow solution is the key factor in decision making process. Hence a brief review of distribution system load flow studies is presented below.

2.2 Distribution Load Flow Problem

The load flow computation for electrical distribution networks is an important aspect in system design. With the help of good knowledge on the state of the system, efficient operation and management can be exercised.

Load flow study is one of the elementary calculations of power systems. Its accuracy is crucial to power system security and stable operation. The errors are mainly caused by the two factors mentioned below:

1. The mathematical model of each component is not reflecting the actual behaviour of that component
2. The parameters chosen for modelling differ from the real life values and the level of assumptions made play very important role in accuracy of results.

Generators and loads represent the boundary conditions of the solution. Mathematically the load flow requires a solution of a system of simultaneous nonlinear equation [26]-[30].

2.3 Load Flow Analysis

Power flow studies, more commonly known as load flow studies, are extremely important in evaluating the operation of power systems, controlling them, and planning for future expansions. A power flow study is helpful in knowing the real and reactive power and phasor voltage at each bus on the system. The required numerical computations are performed systematically by means of an iterative procedure with the help of digital computer.

Two of the more commonly used iterative numerical procedures are the Gauss-Seidel method and the Newton Raphson method.

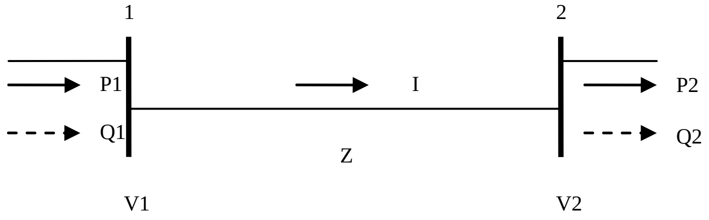


Figure. 2.1 Schematic of a Two Bus System

Figure 2.1 shows a two bus system with the real power represented by solid arrows and the reactive power by dashed arrows. The governing equations for the system are given by [27]

$$S_2 = V_2 I^* \tag{2.1}$$

$$V_1 = V_2 + Z_l I \tag{2.2}$$

Solving for V_2 and eliminating I from these equations we obtain

$$V_2 = V_1 - Z_l I = V_1 - Z_l (S_2^* / V_2^*) \tag{2.3}$$

To solve equation 2.3 iteratively an initial value for $V_2^{(0)}$ is assumed. By substitution of this $V_2^{(0)}$ in the right hand side of equation 2.3 and solving for V_2, an updated value of V_2 is obtained at the end of first iteration. This process is repeated until convergence to the desired precision is achieved. The iterative process in a general form is given as

$$V_2^{(k)} = V_1 - Z_l I = V_1 - (Z_l S_2^{*)} / V_2^{(k-1)\,*}) \tag{2.4}$$

Gauss-Seidel method uses iterative procedure for solving the simultaneous nonlinear equations. The Newton Raphson method is based on finding Jacobian matrices for the new estimation. One of the disadvantages of the Gauss Seidel method lies in the fact that each bus is treated independently. Each correction to one bus requires subsequent correction to all the buses to which it is connected. The Newton Raphson method is based on the idea of calculating the corrections while taking account of all the interactions [28].

Many important contributions have been made on this field of power flow analysis in the past [27]-[31]. The Newton- Raphson formulation for the solution of the power flow problem, comprising of ‘2n’ current injection equations written in rectangular coordinates is discussed in [29]. The results of current injection technique shows substantially faster power flow solution, when compared to the conventional Newton- Raphson formulation, expressed in terms of power mismatches and written in polar co-ordinates. A comprehensive method for carrying out the load flow is discussed in [32].

2.4 Load Flow Analysis based on SKM Power Tools

The load flow analysis carried out on SKM Power Tools package computes overall apparent real and reactive power distribution throughout a power system, including associated losses in the network components. In addition, the study gives voltage drop through each branch impedance component, and then arrives at the voltages at each bus or node in the electrical system. The following section discusses state load flow equations used in the power flow analysis by SKM Power Tools for Windows (herein termed as PTW) with the help of DAPPER package. The powerful algorithm designed is capable of solving complex networks [33]. The flow chart for load flow analysis is shown in Figure 2.2.

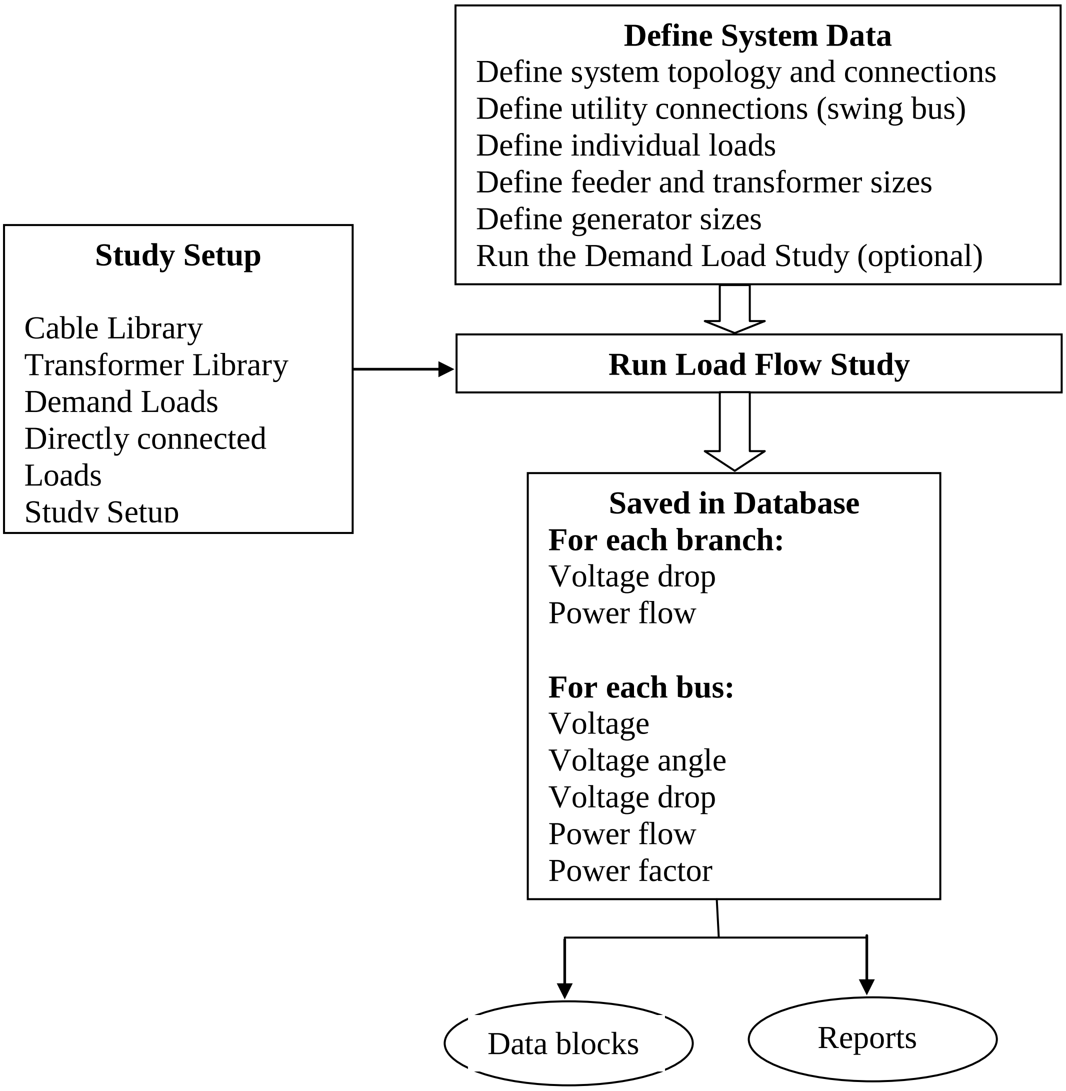


Figure 2.2 Load Flow Analysis Process of SKM Power Tools

A Load Flow Study is conducted on a power system to evaluate the adequacy of continuous and emergency overload ratings of cables, transformers, and protective devices. The study is also useful to determine anticipated low, or high, voltage levels on various sections of the power system under various loading conditions. This information can then be used to determine the associated impact of abnormal voltage on electrical apparatus. The analysis can be instrumental in evaluating the impact of motor starting, and can help to recommend economical sizes of local generation equipment and power factor correction equipment.

2.4.1 Formulation of Power Flow Equations

The steady-state load flow solution to a power system network involves Ohm's Law:

$[I] = [Y]\ [V]$ ---(2.5)

Where [I] is the column vector of total positive sequence currents flowing into each node or bus in the system.

[Y] is the network admittance matrix (1/Z);

[V] is the column vector of positive sequence voltage at each bus.

This equation is a linear algebraic equation with complex real and imaginary coefficients. The matrix may be reduced and the solution for either voltage or current reached using matrix algebra. The current flowing into any node of the system may be defined as below:

$I_i = [(P_i + jQ_i)^* / V_i^*]$---(2.6)

Where $P_i + jQ_i$ is the complex apparent power flowing into the ith node

V_i^* is the complex conjugate of the voltage of the ith node.

Combining Equation 2.5 and Equation 2.6 yields:

$[P - jQ]/ V^* = [Y]\ [V]$ --(2.7)

Equation 2-7 is non-linear, and has to be solved in iterative manner. Hence the numerical analysis solution technique employed must guess each branch power flow, and evaluate the algebraic equations. Then power balance is checked so that sending end power is equal to sum of receiving end power and losses in the branch. This iterative-type numerical analysis solution method continues until convergence is reached. A convergence criteria is established, based on an acceptable level of precision.

The practical field data from nearby petrochemical industry Mangalore Refinery and Petrochemicals Industry (MRPL) is considered for simulation studies using SKM Power Tools package. The components are modelled as per the guidelines of the package with the help of in built libraries. The different components modelled in this analysis are, generators, transformers, feeder cables, loads existing in the industrial plant. The features of SKM Power tools package and field data taken from MRPL is given in Appendix A. The following sections describes the power distribution system at MRPL and presents the results of analysis.

2.5 Power Distribution System at MRPL

The SKM Power Tools are used to model the practical industrial system from an industry 'Mangalore Refinery Petrochemical Limited (MRPL)' which is considered as distributed generation source operating in conjunction with utility. MRPL has two Captive Power plants (located at north end of the Refinery complex) of total generation capacity 124.5 MW with 5 numbers of steam turbine Generators. The capacities of individual generators and their physical location are as below:

22.5 MW – 2 numbers in Phase-1
26.5 MW – 3 Numbers in Phase-2.

The daily average power consumption id around 1695 MWhr, which varies depending on refinery throughputs.

The power generated at 11 kV level in Phase-1 is distributed at 11 kV switchgear in Sub-station-1 while the power generated is at 11 kV in Phase-2 distributed at 33 kV switch gear located in Sub-station-21. Phase-2 Generators are provided with Generator transformers of capacity 33 MVA, 11 kV/ 33 kV.

Phase-1 and Phase-2 power plants are hooked up through a Hook-up transformer of capacity 33 MVA, 33 kV/11 kV.

The other source of power is from Karnataka state grid (Karnataka Power Transmission Corporation Limited-KPTCL). Power to MRPL site is coming a substation located around 20 km away, through 110 kV over-head lines to 110 kV yard sub-station. The power consumption from the grid is for the start-up of the captive plant / in case of emergency due to the non-availability of required number of generators. There are 2 Numbers of transformers – 20/26.5 MVA, 110 kV/11 kV for Phase-1 and 33MVA, 110 kV/33 kV for Phase-2 power plant.

2.5.1 MRPL Co-Generation Plant Phase 1

MRPL Phase # 1 Co-Generation power plant is equipped with two Steam driven turbo generators of General Electric-USA make rated to 26.5 MW. Power generation and primary distribution is at 11 kV. Main distribution is at Sub-Station 1, which is a single bus system with two-bus coupler. From this Sub Station Power is distributed to the refinery process units and utilities through four main distributing substations located at various places in the refinery premises in the downstream of Sub-Station # 1.

2.5.2 Primary Power Distribution of Phase 1

Substation 1 is the heart of Power distribution in the phase # 1 refinery. Schematic power distribution diagram at Sub-Station 1 is shown the figure 2.3. Two Separate auxiliary transformers of 6.3 MVA, 11/ 6.6 kV supply power to HT drives like boiler forced draft fan and boiler feed water pumps. Two 2 MVA, 11/0.415 kV Transformers meant to meet the power plant auxiliary loads, supplying power to boilers, blowers and other associated equipments. Substation is also equipped with emergency diesel generator which provides power supply to very critical loads / drives in case of total power failure. The following 11 kV- primary distributing feeders supply power to process units from their respective substations:

Table 2.1 Primary Distribution Feeders of Phase 1

Substation No.	Unit Name
1	Power Plant Auxiliary
2	Hydro cracker Unit
	Power plant Utility
3	Crude Distillation Unit
	Visbreaker Unit / Merox
4	Oil Movement Storage

2.5.3 MRPL Co-Generation Plant Phase 2

MRPL Phase # 2 Co-Generation plant is equipped with three Steam driven turbo generators of 26.5 MW capacities each. Steam turbines of SKODA make are supplied by Czech- republic, while the Generators are supplied by Jeumont Industries- France. Power generation is at 11 kV and distribution is at 33 kV. Generator Transformer steps up 11KV to 33 kV. Main distributing Sub-Station # 21 is a single bus system with two-bus couplers. From this substation power is distributed to the refinery process units and utilities through six distributing substations in the downstream of Sub-Station # 21 located at various places in the refinery premises. Start-up or Emergency power is drawn from state grid supply, for which 26 MVA capacity transformer is installed with a voltage rating of 110 kV/ 33 kV.

2.5.4 Primary Power Distribution of Phase 2

This substation is heart of Power distribution in the phase # 2 refinery. Schematic power distribution diagram at Sub-Station # 21 is shown the figure 2.4. Two Separate auxiliary transformers of 8.5 MVA, 33/6.9 KV supply power to HT drives like boiler forced draft fan and boiler feed water pumps. Two 2 MVA, 33/0.433 KV transformers meant to meet the power plant auxiliary loads, supplying power to boilers, blowers and other associated equipments. Substation is also equipped with

Emergency Diesel Generator which provides power supply to very critical loads / drives in case of total power failure.

Table 2.2 Primary Distribution Feeders of Phase 2

Substation No.	Unit Name
21	Power Plant Auxiliary
22	Hydro cracker Unit
	Process Cooling Tower
23	Crude Distillation Unit
	Visbreaker Unit / Merox
24	Oil Movement Storage
26	Continues catalytic reactor
	GOHDS
28	Sulfur recovery unit
	Power plant Utility

2.5.5 Hook Up Transformer

Phase # 1 & Phase # 2 electrical systems are interconnected through Hook up transformer of rating 33 kV /11 kV, 33 MVA at the bus sections of both the system are at different voltages. Hook Up transformer will be in charged condition to share the electrical load of both the Phases depending on the loading on either side of the system. The maximum loading of the Hook Up Transformer is 26.4 MW at a power factor of 0.8.

2.5.6 Load Shedding Scheme

For handling the power and steam load distribution of the refinery during the emergencies, in case of tripping of any turbine or boiler, MRPL had incorporated load shedding in its system. During emergency the Load shedding scheme will act automatically, depending on the selection made, to bring down the power and steam load within the operating limits of the running equipment in order to avoid the complete black out of the system.

2.5.7 Grid Transformers

MRPL power plant is equipped with two grid Transformers, one for each phase, to draw power form the state Grid during the start up and emergency. As per operation philosophy of the power plant, one transformer will be always charged and the other will be in isolated condition in order to reduce the transformer losses.

The schematic of power distribution systems of phase 1, phase 2, integrated power distribution system is shown in figure 2.3, 2.4 and 2.5 respectively.

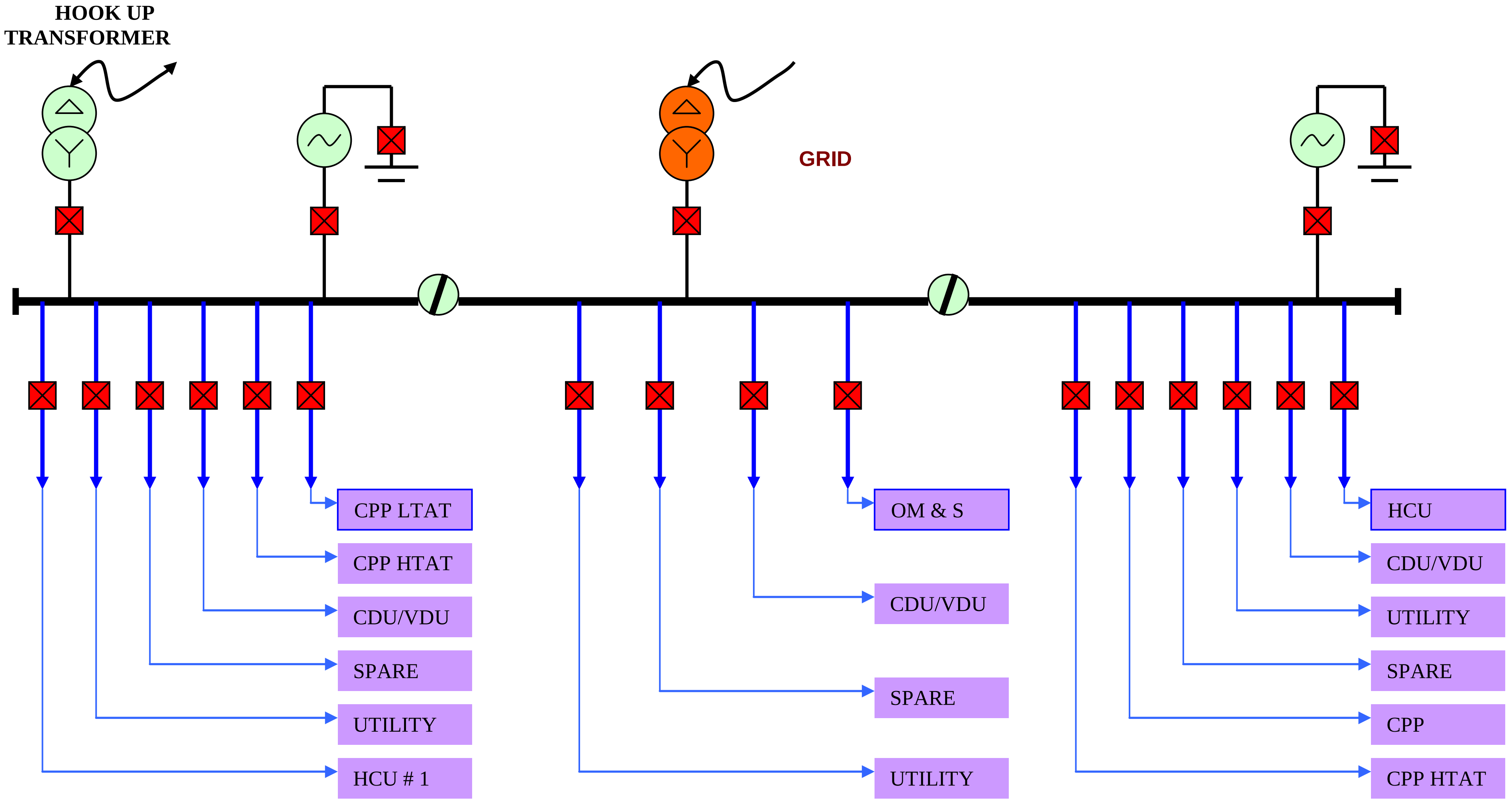


Figure 2.3 Captive Power Plant # 1 Power Distribution System

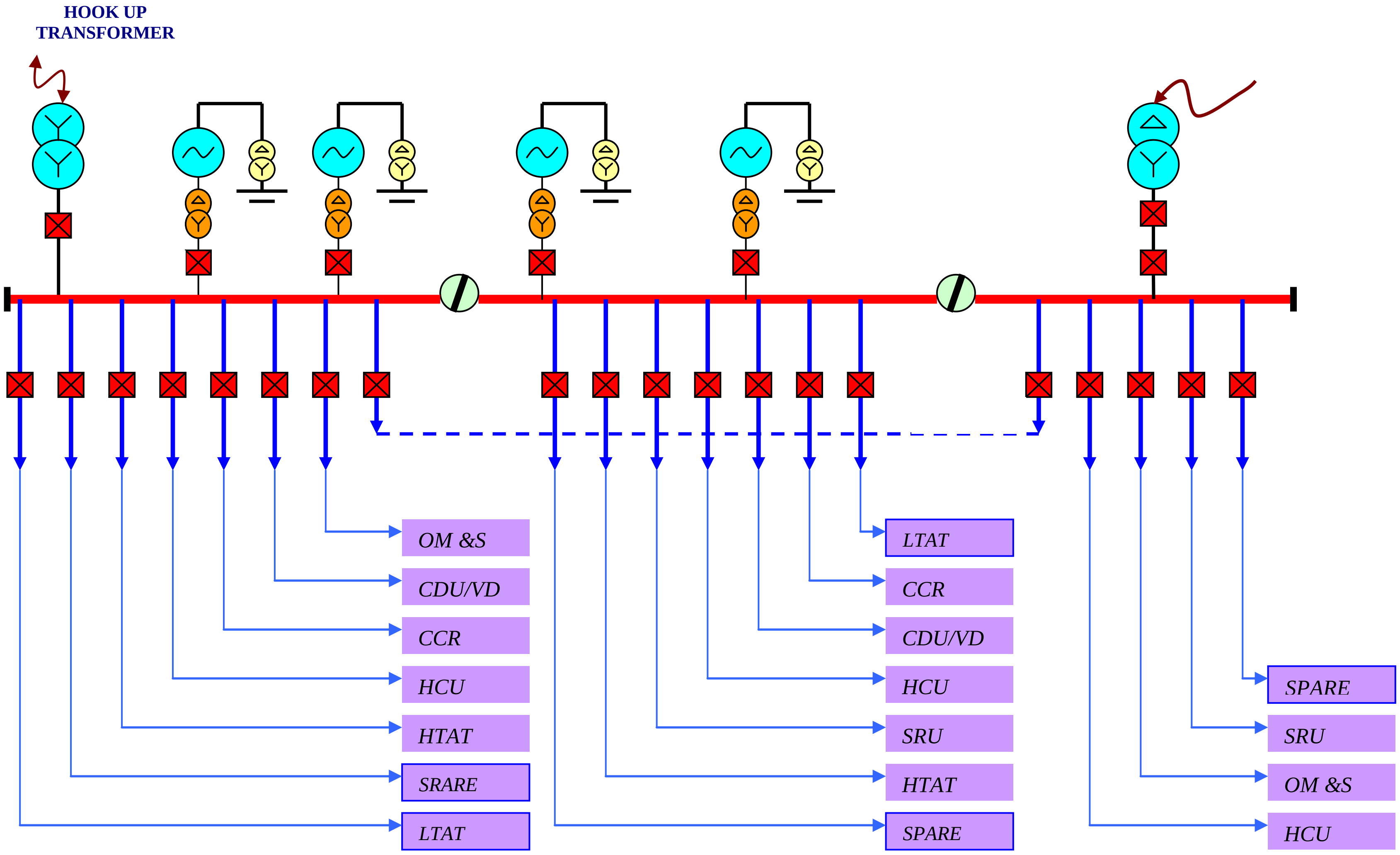


Figure 2.4 Captive Power Plant # 2 Power Distribution System

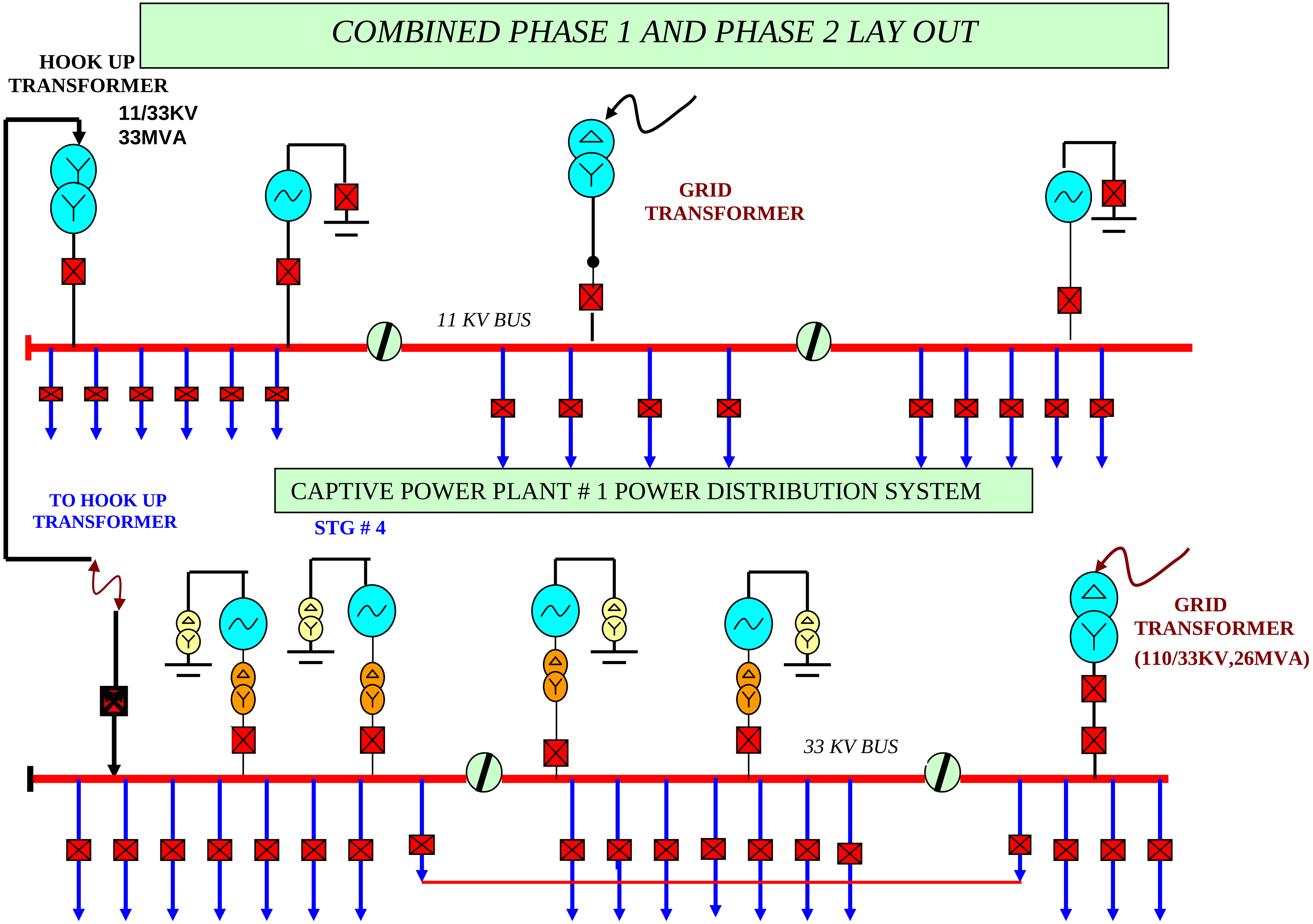


Figure 2.5 Integrated Power Distribution System

2.6 Power Consumption at MRPL

The maximum total connected load of Phase # 1 & Phase # 2 Refinery as per Design is 88405 kW as the connected load. However, the total actual power requirement for the Refinery during full load operation will be always less than the designed value. Looking from the data available for the month of July 2006 as per actual operation of the Phase # 1 refinery, the peak loading of the Phase # 1 Refinery the peak load was 30905 kW against the designed connected load of 41491 kW than the designed connected load. Similarly for Phase # 2 Refinery load was 37411 kW against design load of 46914 kW.

The study conducted here was based on the actual data available for the month of July 2006. The system is modelled in SKM Power Tools and data obtained from field under a particular loading scenario are used for modelling purpose as given in the tables of this section. Table 2.3 and 2.4 gives design power projection and average actual power consumed by the various units as in the month of June 2006 as obtained from field data. Table 2.5 and 2.6 gives power balance. The Unaccounted power consumption is in the range of 3 to 7% is attributed to the metering errors and line losses of the distributing feeders. The data of generators, transformers, loads are given in Appendix A.

The recordings given in Table 2.3 to Table 2.6 are used in simulation analysis. The models for all components such as generators, transformers, loads are selected from library of SKM Power Tools package to conform to the readings from the field. The data used to build model of all network components are given in Appendix A.
The simulation studies have been carried out to compute the power consumption and power balance data for phase 1 and phase 2 of industry. It has been observed that simulation results are matching with the measured reading. This process of verification of the simulation results with the actual reading has been carried out to validate the model built in SKM power tools for its correctness to real time scenario. Hence this model can be used for further studies on industrial captive power plant acting as DG source exporting power to the grid.

Table 2.3 Power Consumption of Phase 1

Sl. No.	Units and their Power requirement in kW	Design (kW)	Measured Peak Load (kW)
1	Crude and vacuum distillation unit/FO System	4436	4325
2	CCR/Naphtha HDT	3427	3031
3	Hydrogen Plant	872	609
4	Hydro cracker unit	10395	10076
8	Visbreaker unit /LPG & kerosene merox unit	1096	1066
10	Bitumen unit	350	40
11	Amine unit	190	103
12	Sour water unit	262	154
13	Sulfur recovery unit	517	357
14	Raw water Plant	813	637
15	Cooling Tower	2317	2220
16	De-mineralization water Plant	264	75
17	Process de-aerator	235	0
18	Air compressor unit	465	426
20	Flare	9	0
21	Utility distribution	13	0
22	Tank farm – upper plateau	1121	443
23	Fire fighting – upper plateau	31	24
24	Tank farm & Air Compressor lower plateau	4036	2511
26	Fire fighting – lower plateau	31	25
27	Effluent treatment	1020	221
28	Air conditioning/Tech Bldg/Lab	2550	1236
29	Lighting	3001	1126
30	Power plant	4040	2200
	Others	0	0
	Total consumption	41491	30905

Table 2.4 Power Consumption of Phase 2

Sl. No.	Units and their Power requirement in kW	Design (kW)	Measured Peak Load (kW)
1	Crude and vacuum distillation unit	8350	8168
2	Hydrogen Plant	750	726
3	Hydro cracker unit	10395	9486
5	Continuous catalytic reformer	4317	3774
7	Visbreaker unit	122	103
8	Bitumen unit	1017	40
11	Sulfur recovery unit/ATU/SWS	1250	1100
12	Gas oil hydro de-sulfuring unit	517	421
13	Raw water Plant	2488	1427
14	Cooling Tower	813	741
15	De-mineralization water Plant	3476	1080
17	Air compressor unit	353	284
19	Flare	0	0
20	Process cooling tower	1250	994
20	Utility distribution	120	0
21	Tank farm – upper plateau	9	0
22	Fire fighting – upper plateau	19	0
23	Tank farm – lower plateau	1760	1348
24	Air compressor – lower plateau	31	0
25	Fire fighting – lower plateau	20	0
26	Effluent treatment	31	15
27	Air conditioning	1530	1250
28	Lighting	1275	1100
29	Power plant	3001	2854
30	Others	4848	2500
	Total Consumption	46914	37411

Table 2.5 Power Balance Validation of Phase 1

CPP – I POWER BALANCE					**June – 2006**
POWER GENERATION IN MW		POWER DISTRIBUTION IN MW			
DCS DATA			DCS DATA		
		SS1			
		6.6 KV HT	HTAT 1	HTAT 2	2.24
		Power Plant HT Auxililary	1.13	1.11	
STG # 1	15.900	415 V LT Aux	LTAT 1	LTAT 2	0.4690
		Power Plant HT Auxililary	0.19	0.275	
STG # 2	15.400	SS2			
		SWGR 213	TR41	TR42	4.2100
		DM Plant	2.267	1.943	
Total power generation	31.300	Cooling water			
		Air compressor (U/P)			
Import From Ph 2	0.670	Fire water (U/P)			
		SWGR 223	TR31	TR32	8.1780
		Hydrogen Plant	5.26	2.92	
		Hydrocraker plant			
		CCR/Naphta HDT			
		SRU			
		ATU			
		SWS			
		BFW/Condensate/Deaerator			
		SS3	TR 51	TR 52	10.3640
		SWGR 233	4.534	5.830	
		CDU / VDU/NSU/ Tank farm (U/P)			
		Visbreaker / merox / MCC 11			
		BBU			
		SS 4 AND SS 5	Feeder 1	Feeder 2	4.5340
		SWGR 242	2.429	2.105	
		Raw water treatment			
		Fire water (L/P)			
		SS5			
		SWGR 245			
		OM & S / Comp. air (L/P)			
		OM & S (U/P Tank farm area)			
		Bitumen drum filling plant			
		WWTP			
		Flare / Utility distribution			
		Admn. Bldg./ Workshop / Lighting / Colony drinking water (SS-9)			
		Tech. bldg. / Lab/ Pump House 2 (MCC 11)			
		Power to BASF			
		Housing Colony			
		SS6	TR 37		0.000
		SWGR 371	0.000		
		FO system in CDU			
TOTAL	31.970	TOTAL			29.9950
UN-ACCOUNTED POWER CONSUMPTION DUE TO MEETERING ERROR			**1.975**		
PERCENTAGE UN ACCOUNTED POWER CONSUMPTION			6.17		

Table 2.6 Power Balance Validation of Phase 2

		CPP – II POWER BALANCE		**June – 2006**	
POWER GENERATION IN MW		POWER DISTRIBUTION IN MW			
DCS DATA			DCS DATA		
STG # 3	20.000	SS21	HT AT 1	HTAT 2	2.740
STG # 4	0.000	Power plant	1.370	1.37	
STG # 5	20.000		LTAT 1	LTAT 2	0.4900
			0.16	0.33	
		SS22			
Total power generation	40.000	SWGR 2213	TR231	TR232	10.5600
		Hydrogen Plant	6.500	4.06	
		Hydrocraker plant			
Import From Ph 1	0.00	Process Cooling Tower			
		HCU Lighting	TR 239		0.0900
			0.090		
		SS23	TR 252	TR 251	7.2600
		SWGR 2233	3.030	4.23	
		CDU / VDU/NSU/ Tank farm (U/P) / FO system in CDU			
		SS26			
		SWGR 2243	TR 262	TR 261	7.4200
		Visbreaker	2.11	5.31	
		Merox			
		CCR/Naptha HDT			
		GO HDS			
		SS28	TR 242	TR 241	6.2200
		UTILITIES / Cooling Tower	3.080	3.14	
		D.M. Plant			
		Air Compressor			
		SRU			
		ATU/SWS/DEAERATOR			
		SS24			
		SWGR 2251	Feeder 1	Feeder 2	2.1100
		OMS	1.030	1.08	
		WWTP			
		Raw water treatment			
		Flare / Utility distribution			
		Lighting power			
		Hindustan Gas			
					0.0000
TOTAL	40.000	TOTAL			36.8900
UNACCOUNTED POWER CONSUMPTION DUE TO MEETERING ERROR/LINE LOSS			**3.110**		
PERCENTAGE UN ACCOUNTED POWER CONSUMPTION			7.775		

2.7 Integrated Operation of MRPL as DG Source and Utility Grid

As described in the previous section, the electrical power distribution system of MRPL is simulated using SKM power tools and validated with the field records. Extending this study the MRPL working as Independent Power Producer is analysed in this section. To account for various possibilities of plant operation, the plant layout has been categorised as Phase – I , Phase – II. These Phase – I and II sections can operate independently and also in integrated manner. The situations of industry importing power from utility and exporting power to utility have been investigated. Summarising these possibilities, the case studies have been formulated as below.

- Case Study 1 : Only Phase – I Generators and Load Exists
- Case Study 2 : Only Phase – II Generators and Load Exists
- Case Study 3 : Both Phase – I and Phase – II Generators and Load Exists, Integrated Operation of Phase – I and Phase – II.
- Case Study 4 : Integrated Operation of Phase – I and Phase – II with Power Import from the Utility Grid
- Case Study 5 : Integrated Operation of Phase – I and Phase – II with Power Export to the Utility Grid

In each of the above cases, the parameters of the plant are tuned to meet the power flow constraints. The simulation results obtained are matching with the field results for the normal configuration considered as case study 3. The voltage profile is found conforming to the industrial standards. The power balance is achieved in all the cases considering the appropriate expression.

For Case Study 1 to Case Study 3 :

Power Generation = Power Demand + Power Losses in all the components of the lay out.

For Case Study 4 :

Power Generation + Power Import from the Utility = Power Demand + Power Losses in all the components of the lay out.

For Case Study 5 :

Power Generation - Power Export to the Utility = Power Demand + Power Losses in all the components of the lay out.

The simulation results of the above cases considering the loading and generation conditions of the MRPL plant for different cases is given below.

Table 2.7 Integrated Operation of MRPL and Utility

CASE STUDY NO.	SOURCE OF POWER	POWER CONTRIBUTION (MW)	CONSUMPTION PARAMETER	POWER CONSUMPTION (MW)
1	STG1	7.69	LOAD DEMAND	20.577
	STG2	13.00		
	STG3	0		
	STG4	0	SYSTEM LOSSES	0.113
	STG5	0		
	UTILITY IMPORT	0		
	TOTAL	20.69	TOTAL	20.69

CASE STUDY NO.	SOURCE OF POWER	POWER CONTRIBUTION (MW)	CONSUMPTION PARAMETER	POWER CONSUMPTION (MW)
2	STG1	0	LOAD DEMAND	16.892
	STG2	0		
	STG3	6.726		
	STG4	5.20	SYSTEM LOSSES	0.238
	STG5	5.20		
	UTILITY IMPORT	0		
	TOTAL	17.13	TOTAL	17.13

Table 2.7 Integrated Operation of MRPL and Utility (Continued)

CASE STUDY NO.	**SOURCE OF POWER**	**POWER CONTRIBUTION (MW)**	**CONSUMPTION PARAMETER**	**POWER CONSUMPTION (MW)**
3	STG1	14.00	LOAD DEMAND	49.267
	STG2	12.68		
	STG3	9.01		
	STG4	0	SYSTEM LOSSES	0.423
	STG5	14.0		
	UTILITY IMPORT	0		
	TOTAL	49.69	TOTAL	49.69

CASE STUDY NO.	**SOURCE OF POWER**	**POWER CONTRIBUTION (MW)**	**CONSUMPTION PARAMETER**	**POWER CONSUMPTION (MW)**
4	STG1	15.57	LOAD DEMAND	49.27
	STG2	0		
	STG3	9.01		
	STG4	0	SYSTEM LOSSES	0.60
	STG5	14.0		
	UTILITY IMPORT	11.30		
	TOTAL	49.88	TOTAL	49.87

Table 2.7 Integrated Operation of MRPL and Utility (Continued)

CASE STUDY NO.	SOURCE OF POWER	POWER CONTRIBUTION (MW)	CONSUMPTION PARAMETER	POWER CONSUMPTION (MW)
5	STG1	24.16	LOAD DEMAND	49.27
	STG2	0		
	STG3	13		
	STG4	0	SYSTEM LOSSES	0.60
	STG5	15.0		
	UTILITY IMPORT	-2.28 *		
	TOTAL	49.88	TOTAL	49.87

In the case 5, the neighbouring load was considered with load demand of 3 MW. The MRPL, plant is exporting 2.28 MW to 110 kV Utility Grid. Remaining 0.72 MW demand of neighbouring load is transferred from the utility to the neighbouring industry.

As seen from the table pertaining to case study 5, Industrial power plant is acting as distributed generation source exporting power to utility grid. In the scenario considered, according to the generation schedule one generator each from phase 1 and phase 2 is not generating any power. Even in such a situation, from the analysis it is found that the loading on the plant permits export of 2.28 MW to the utility. If both these generators are generating to its capacities, power export to utility can be enhanced to higher level. Hence with the help of the simulation tool developed in this work, the decision of the quantum of power export to the utility can be arrived out by the industry by accounting all power needs of the petrochemical plant. In case of different loading pattern and generation schedule, the approach developed assists in taking decision regarding whether power import or export as well as quantum of power. This study has demonstrated the benefit of the simulation tool to perceive industrial captive power plant as distributed generation source. The generation done at captive power plant will be catering to the needs of the local loads of the industry as well exporting power to utility concurrently.

2.8 Conclusive Remarks

- The Practical System of Mangalore Refinery and Petrochemical Limited has been Modelled in SKM Power Tools, accounting all components with their characteristics.

- The simulation studies have been performed with practical field data and simulation results have been validated with actual data recordings from field.

- The simulation technique developed will serve as decision making tool for power plant operation and management for any generation and load scenario.

- The studies on integrated operation of MRPL plant as DG source and utility grid serve as a scheduler for power import/export from grid depending on loading conditions of the plant and neighbouring area served by utility.

- It can be further noted that the quantum of power export depends on the generation and load scenario at any interval. The necessary agreement of power export with the utility has to be made judiciously considering the energy needs of the industry including future expansion. The failure for exporting the agreed quantum of power will lead to technical, financial as well as administrative problems. In this context, the industrial unit must be extremely careful in entering to pact as DG source. To overcome this difficulty, in the following chapters, DG sources operated by independent power producers are considered for analysis. These DG sources can be located at optimal locations of large distribution system, and the power export can be controlled effectively.

CHAPTER 3

IMPACT OF SINGLE DG SOURCE ON DISTRIBUTION SYSTEM PERFORMANCE

3.1 Introduction

Based on the unique characteristics found in medium voltage radial distribution networks, various distribution power flow methods have been investigated over the past years. These include the forward/backward updating and the bus-impedance matrix forms of the power flow calculations using linear network equations. These methods typically assume a radial or weakly meshed topology and a single power source.

3.1.1 Forward and Backward Sweep Method

There are so many variants of this method and all are based on ladder network theory. These methods model the distribution network as a tree with the slack bus being the root and the branch sections being ordered by layers away from the root node. Weakly meshed systems are converted into radial networks by breaking loops and adding current injection compensation [34]. The backward sweep primarily sums either the line currents or power flows from the extremities to the root. The forward sweep is a voltage drop calculation, providing updates to the voltage profile based on the current estimates of the flows.

3.1.2 Bus Impedance Methods

These methods use the bus impedance matrix and equivalent current injections to solve the network equations. The principle of superposition is applied to the bus voltages throughout the network. Two different contributions make up the voltage of each bus. They are the specified slack bus voltage and the incremental potentials due to current injections flowing into the network. Loads and generator are modelled as equivalent current injections. The method may utilize the sparse bus admittance matrix instead of constructing the bus impedance matrix. The difference in computational effort is minor as the admittance matrix is decomposed at the beginning and stored for using in iterations. Solving the matrix equation is substituted for matrix multiplication. This method is often referred to as the Implicit Bus Impedance method [35]. This load flow technique is adopted in this work for obtaining load flow results for radial distribution systems.

3.2 Distributed Generation Allocation in Distribution Systems

Distributed Generation (DG) allocation studies are relatively new when compared to capacitor allocation in distribution systems. In the past DG allocation has been considered as optimum active power compensation in similar lines with capacitor allocation for reactive power compensation. A second order algorithm was proposed to identify the optimal location for DG from selected nodes of a six bus test system. The selection of DG is based on two objectives, reduction of line losses and reduction in line loads [39]. The computational requirements (memory and speed) for a realistic system are very high for this method. A method to optimally locate distributed generation in a meshed network for maximizing the potential benefits is proposed using improved Hereford Ranch Algorithm was developed [40]. In this the benefit expressed as a performance index is minimization of losses.

Similar to capacitor allocation problem employing loss sensitivity factor method, even DG allocation using loss sensitivity factor method has been reported by researchers [42]. The best placement of new distributed units obtained in order to minimize losses on the system for a given load. However this method suffers from drawback of not identifying the global optimum solution. Another method for placing DG is to apply rules of thumb that are often used in sitting shunt capacitors in distribution systems [43]-[44]. A "2/3 rule" is presented to place DG on a radial feeder with uniformly distributed load, where it is suggested to install DG of approximately 2/3 capacity of the incoming generation at approximately 2/3 of the length of line. This rule is simple and easy to use, but it cannot be applied directly to a feeder with other types of load distribution, or to a networked system.

An analytical method was proposed to place DG in radial as well as meshed systems to minimize power loss of the system [35]. In this method separate expressions for radial and network system are derived and a complex procedure based on phasor current is proposed to solve the location problem. However, this method only optimizes location and considers size of DG as fixed. Another analytical approach was developed considering the DGs capable of supplying only real power [6]. This method uses exact loss formula to derive the optimum DG Size and optimum location for minimum power loss.

The work carried out to analyse the impact of single DG source on distribution system with the following objectives is given in this chapter.

1. To compute the Optimum size of DG insertion at various buses using analytical method
2. To evaluate the performance indices like power loss reduction, voltage profile improvement and voltage stability.
3. To propose a new index indicating maximum reduction in power loss with minimum capacity of DG source. Since Minimum capacity of DG insertion is computed, the capital investment will be lower and helpful for decision making from economic perspective.

3.3 Implicit Z-Bus Method

The implicit Z-bus method is the most commonly used method. The method works on the principle of superposition as applied to the system bus voltages [5]. According to the principle of superposition, only one type of source is considered at a time for the calculation of bus voltages. The voltage of each bus is considered to arise from two different contributions, the specified source voltage and equivalent current injection. The loads, co-generators, capacitors and reactors are modelled as current injection sources / sinks at their respective buses. The convergence behaviour of the Z-Bus method is highly dependent upon the number of voltage specified buses in the system. If the only voltage specified bus in the system is the swing bus, the rate of convergence is comparable to the Newton-Raphson approach.

An iterative procedure is used in this method. The component of each bus voltage obtained by activating only the swing bus voltage source represents the no-load system voltage. This component can be determined directly as equal to the swing bus voltage for every bus in the system, however, the other component, affected by load currents and co-generator currents cannot be determined directly. Since load and co-generator currents are affected by bus voltages and vice versa, these quantities must be determined in an iterative manner.

A sensitive matrix method is used to handle the PV buses in the Distribution Systems. The Sensitive Matrix ***M*** is given by the equation 3.1 [5] :

$$M\Delta\overline{Q} = \Delta\overline{V} \text{ ---(3.1)}$$

In the above equation, $\Delta\overline{Q}$ and $\Delta\overline{V}$ are the injected reactive power mismatch vector and the voltage mismatch vector of PV nodes. By neglecting all nonlinearities, and considering nodes from 1 to *n* belong to PV buses, the matrix equations can be formulated as below:

$$\begin{bmatrix} |Z_{11}| & |Z_{12}| & \cdots & |Z_{1n}| \\ |Z_{21}| & |Z_{22}| & \cdots & |Z_{2n}| \\ \vdots & \vdots & \cdots & \vdots \\ |Z_{n1}| & |Z_{n1}| & \cdots & |Z_{nn}| \end{bmatrix} \begin{bmatrix} \Delta I_1 \\ \Delta I_2 \\ \vdots \\ \Delta I_n \end{bmatrix} = \begin{bmatrix} \Delta V_1 \\ \Delta V_2 \\ \vdots \\ \Delta V_n \end{bmatrix} \text{ --(3.2)}$$

In the equation 3.2, Z_{ii} is the self impedance of PV bus *i* , Z_{ij} is the mutual impedance between PV bus *i* and PV bus *j*. The injected current increment is ΔI_i and voltage increment is ΔV_i . Treating the voltage of PV buses as close to 1.0 pu and the phase angles small, the expression for reactive power increment can be written as below:

$$\Delta\overline{Q} = \begin{bmatrix} \Delta Q_1 \\ \Delta Q_2 \\ \vdots \\ \Delta Q_n \end{bmatrix} \approx -\begin{bmatrix} \Delta I_1 \\ \Delta I_2 \\ \vdots \\ \Delta I_n \end{bmatrix} \text{ ---(3.3)}$$

Hence the Matrix M in the equation 3.1 becomes

$$M = -\begin{bmatrix} |Z_{11}| & |Z_{12}| & \cdots & |Z_{1n}| \\ |Z_{21}| & |Z_{22}| & \cdots & |Z_{2n}| \\ \vdots & \vdots & \cdots & \vdots \\ |Z_{n1}| & |Z_{n1}| & \cdots & |Z_{nn}| \end{bmatrix} \text{ ---(3.4)}$$

Z_{ii} and Z_{ij} are the corresponding elements in system nodal impedance matrix Z .

3.3.1 Algorithm for Implict Z-Bus Method of Power Flow

The following steps are executed in the k^{th} iteration for implicit Z-bus method [5]

1. The nodal current injections are calculated for all loads using the known power values, *S*, and the latest values of voltages, *V*, computed or assumed.

$$I_i^{[k]} = \left(\frac{S_i^{sch}}{V_i^{[k-1]}} \right)^* - Y_i V_i^{[k-1]} \quad \text{--(3.5)}$$

   Where $I_i^{[k]}$ and $V_i^{[k-1]}$ are the current and past iterations of the injected current and bus voltage at the i^{th} bus and Y_i is sum of all the shunt elements at node *i*.

2. The vector of voltage deviations, ΔV, is solved by multiplying the current injection vector with the bus impedance matrix.

$$\Delta V_{bus}^{[k]} = Z_{bus} I_{inj}^{[k]} \text{--(3.6)}$$

   Where, Z_{bus} is the n_{bus} x n_{bus} bus impedance matrix.

3. The bus voltages throughout the network are updated by combining the voltage drops with the slack bus voltage at the root node.

$$V_i^{[k+1]} = V_0 + \Delta V_i^{[k]} \text{---(3.7)}$$

4. Power mismatch at each load bus is calculated as

$$\Delta S_i^{[k]} = S_i^{sch} - V_i^{[k]} \left(I_i^{[k]} \right)^* \text{--(3.8)}$$

5. If the condition $\left| \Delta S_i^{[k]} \right| < \varepsilon$ is satisfied for all load buses and the condition $\left| V^{(k)} - V_s \right| < \varepsilon$ for all PV nodes, the power flow calculation is convergent and enters in to step 6. Otherwise, update the voltage of all nodes $\left(V^{[0]} = V^{[k]} \right)$ and the injected reactive power of PV nodes by matrix M and the voltage mismatch vector and repeat the process from Step 1.
6. Calculate the System Power Flows, Losses and out put the results.

The flow chart for implementation of this algorithm is shown in Figure 3.1

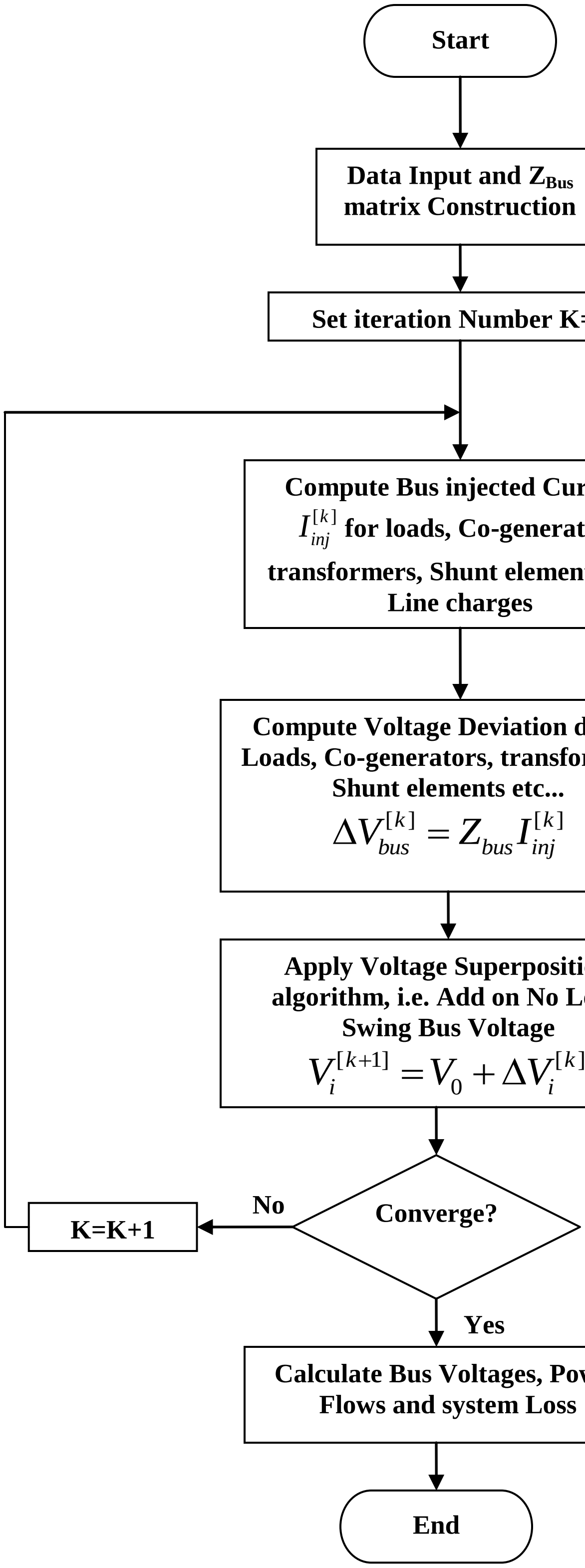


Figure 3.1 Flow Chart for Implicit Z-Bus Load Flow

3.4 Analytical Methods for DG Allocation

Previous studies revealed that inappropriate selection of location and size of Distributed Generation (DG), may lead to greater system losses than the losses without DG. In developing countries, as utilities are already facing the problem of high power loss and poor voltage profile, cannot tolerate the increase in losses resulting from inappropriate sizing of DGs. The insertion of DGs, will release the burden of transmission and distribution network and reduces new investments. This is a huge advantage having long time impact and hence it is very important to find the optimum size of DGs at optimum locations from system planning point of view.

A common strategy for placement of DG is to minimize the power loss of the system. The optimum DG allocation can be treated as optimum active power compensation, like capacitor allocation for reactive power compensation. DG allocation studies are relatively new, unlike capacitor allocation. To evaluate optimum DG size at each bus, many analytical techniques have been developed assuming every load bus can have DG source [35]. Such methods are, however, inefficient due to a large number of load flow computations. Similar to capacitor allocation problem which uses loss sensitivity factor method, even DG allocation using loss sensitivity factor method was attempted [42]. However this method suffers from not identifying the global optimum solution. Another analytical approach was developed exploiting the DGs capability to supply real power [6]. This method uses exact loss formula to derive the optimum DG Size and optimum location.

3.4.1 Location and sizing issues for DG Source

The location of DG source and its capacity for power injection are very crucial for systems behaviour. The wrong location and / or improper capacity will result in higher losses and deteriorates the performance of the system. This fact is illustrated in Figure 3.2. The 3D plot shows of typical power loss versus size of DG at each bus in a 33 bus distribution system [36].

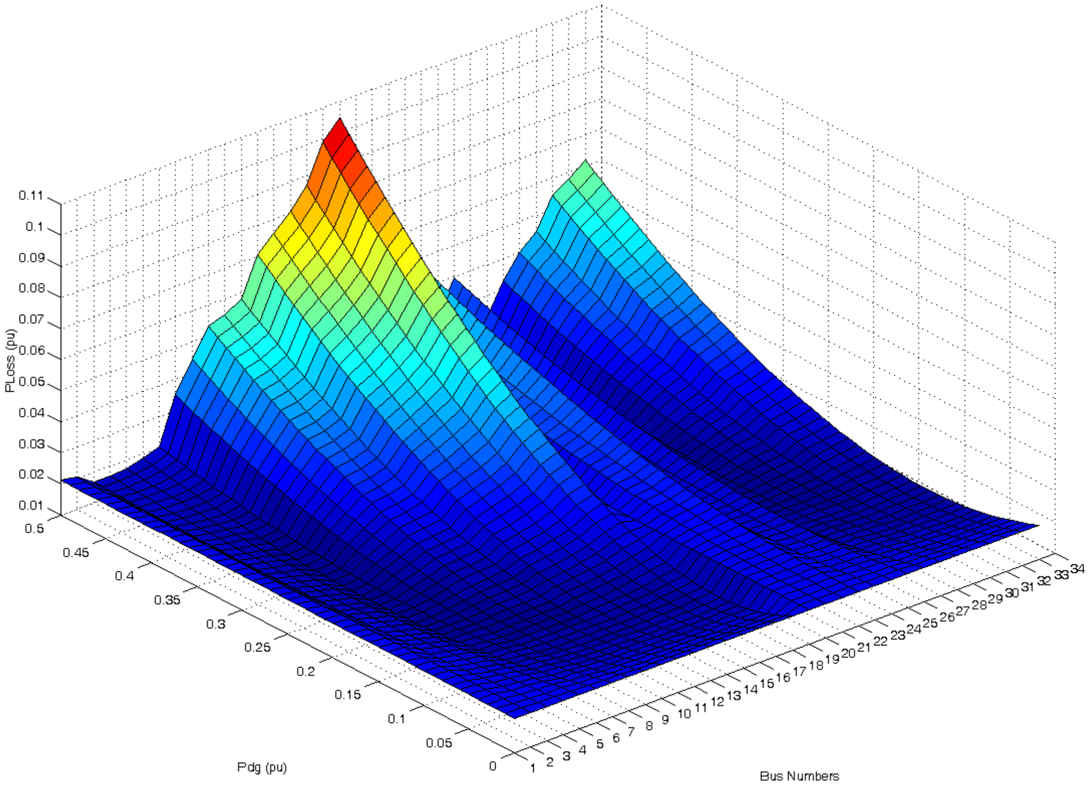


Figure 3. 2 Effect of size and location of DG on System Loss

From the above figure, it is obvious that for a particular bus, as the size of DG is increased, the losses are reduced to a minimum value and increased beyond a size of DG (i.e. the optimal DG size) at that location. If the size of DG is further increased, the losses starts to increase and it is likely that it may overshoot the losses of the base case. This effect is evident because, originally the network is designed for power flows from sending end to the load buses. All the conductor sizes would have been designed to satisfy this requirement. In the modified network, with insertion of DG source, there are ample chances for flow of large current in smaller cross section conductors designed in the original system. Due to this reason, the overall losses in the distribution system increases. Hence it is always necessary to search for optimal location as well as optimal capacity of DG source in a distribution network to enhance the improve operating conditions.

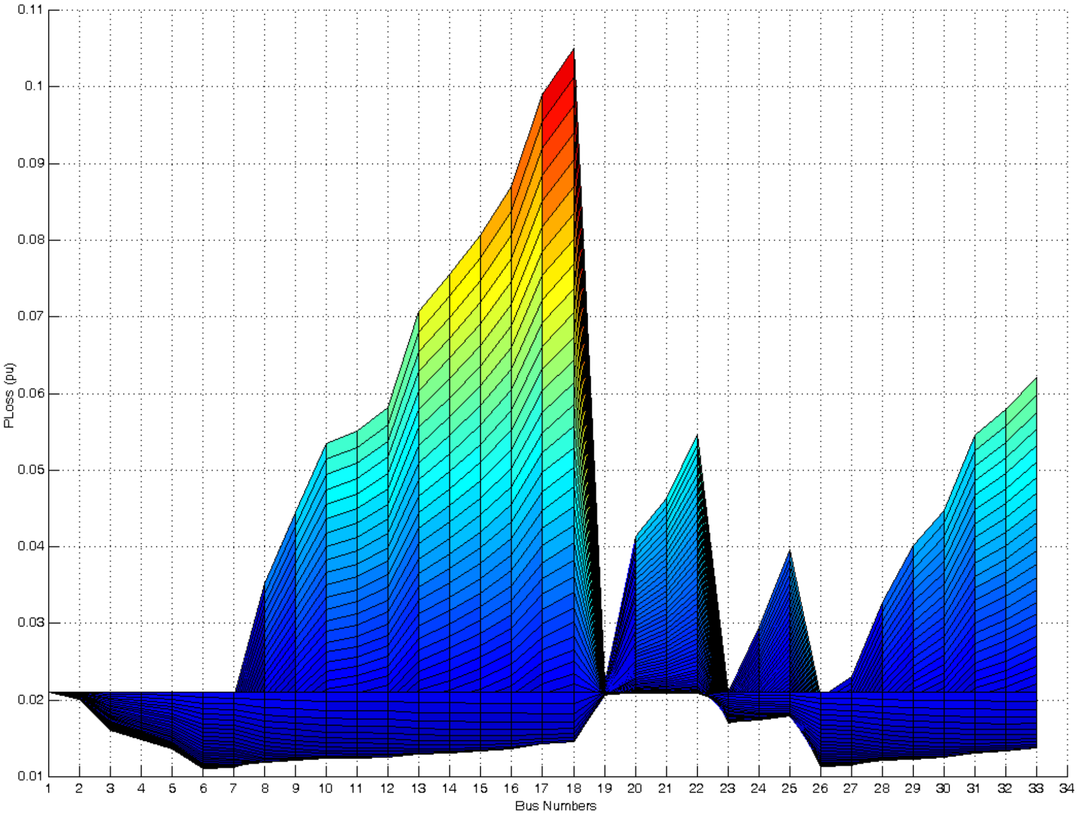


Figure 3.3 Influence of DG Location on System Losses

As discussed in previous section, the location of DG source plays crucial role in reducing the system loss. As seen from Figure 3.3, if DG is located at bus number 6, the power loss will be lowest and if DG is inserted at bus number 18, the power loss will be highest. Hence the location of DG plays an important role in minimizing the losses. Any attempt to install high capacity DG with the purpose of exporting power beyond the substation (reverse flow of power through distribution substation) will lead to very high losses. In order to tackle this aspect, the complete restructuring of the network may become necessary. However any step to redesign the existing network is very expensive and not feasible. Hence the approach to carry out DG insertion by retaining the original network is very much pragmatic. As discussed earlier, one technique is to decide on the most suitable location for DG insertion and subsequently compute the optimal DG capacity at that location. However this may not lead to the best possible solution. The alternative analytical method of by addressing the sizing issue first followed by the location issue is adopted in this work.

3.4.2 Loss Sensitivity Factor Method

Loss Sensitivity factor method is based on the principle of linearization of original nonlinear equation around the initial operating point, which helps to reduce the number of solution space. The real power loss in a system is given by [6].

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n}\left[\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j - P_iQ_j)\right] \quad \text{----------------------(3.9)}$$

Where $\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j)$, $\beta_{ij} = \frac{x_{ij}}{V_iV_j}\sin(\delta_i - \delta_j)$ and $r_{ij} + jx_{ij} = z_{ij}$ are the ij^{th} element of Z_{Bus} matrix.

The sensitivity factor of real power loss with respect to real power injection from DG can be obtained by differentiating the Equation 3.9 with respect to P_i.

$$\alpha_i = \frac{\partial P_L}{\partial P_i} = 2\sum_{j=1}^{n}(\alpha_{ij}P_j - \beta_{ij}Q_j) \quad \text{---(3.10)}$$

Sensitivity factors (α_i) are computed for each bus, with values obtained from the base case power flow. A priority list with ranking for all buses is formed in the descending order of the values of the sensitivity factors. . The highest ranked bus in the priority list is the best location to be investigated. However the first order sensitivity factor involves linearization of the original nonlinear equation around the initial operating condition and oriented towards function which has greater slope at the initial condition. Hence this process may not lead to the global optimum solution. Therefore to obtain the optimum solution, priority list of candidate location serves as a prerequisite.

After forming the priority list, DG is placed at each bus. The capacity of the DG source is varied from lower value to higher value and system losses at every DG size are computed. The DG capacity which results in minimum loss will be finalised for each bus. To reduce computational efforts, the priority list will comprise of around 30 to 40 % of total number of buses.

The step by step process for Loss Sensitivity factor method is given below:

1. Load Flow Solution for base case is obtained.
2. The sensitivity factor using Equation 3.10 is computed and priority list of buses is formed with descending order of sensitivity factor.
3. The bus with the highest priority is selected for placing DG source.
4. The DG size is varied in small steps and system losses are computed. The DG capacity which gives minimum loss is stored for future iterations.
5. The loss computed with previous iteration is compared. If loss in present iteration is less than previous iteration, then this new solution for DG capacity is taken by ignoring previous iteration values..
6. The above Steps 4 and 5 are carried out for all buses in the priority list.

3.4.3 Analytical Method based on Exact Loss Formula

As discussed in the previous section, the loss sensitivity factor is computationally intensive because load flow solution has to be executed each time when DG capacity is incremented. This approach presented in [6] reduces the computational time drastically since load flow has to be run only two times. The first time load flow is run for the base case without presence of DG source. The second time load flow is executed with insertion of DG source into the network. The technique exploits the fact that power loss varies as a parabolic function of power injected at the bus. Hence it is evident that, at minimum loss point, the rate of change of losses with respect to power injected will be zero. The mathematical formulation for this condition is reported in literature [6] and presented below:

$$\frac{\partial P_L}{\partial P_i} = 2\sum_{j=1}^{n}(\alpha_{ij}P_j - \beta_{ij}Q_j) = 0 \quad \text{---}(3.11)$$

From equation 3.11, the following expressions can be deduced.

$$\alpha_{ii}P_i - \beta_{ii}Q_i + \sum_{j=1,\, j\neq i}^{n}(\alpha_{ij}P_j - \beta_{ij}Q_j) = 0 \quad \text{---}(3.12)$$

$$P_i = \frac{1}{\alpha_{ii}}\left[\beta_{ii}Q_i - \sum_{j=1,\, j\neq i}^{n}(\alpha_{ij}P_j - \beta_{ij}Q_j)\right] \text{ --(3.13)}$$

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

$$P_i = (P_{dgi} - P_{li}) \text{ --(3.14)}$$

Where P_{dgi} is the real power injection from DG placed at node *i*, and P_{li} is the Load at Node *i*. Combining Equations (3.13) and (3.14) leads to

$$P_{dgi} = P_{li} + \frac{1}{\alpha_{ii}}\left[\beta_{ii}Q_i - \sum_{j=1,\, j\neq i}^{n}(\alpha_{ij}P_j - \beta_{ij}Q_j)\right] \text{ --------------------------------- (3.15)}$$

The optimum size of DG for each bus *i*, which result in minimum loss in the system is given by equation 3.15. Higher loss will be obtained by selecting any other capacity of DG other than P_{dgi} at bus *i*.

In evaluating the optimum sizes of DG at various locations, using equation 3.15 it was assumed that the values of loss co-efficient will not change. The approximate loss is computed using equation 3.9 for each bus by placing DG of optimum size (P_{dgi}).This loss, however, is a function of loss α_{ij} coefficient and β_{ij}. After insertion of DG sources, into the network, the values of loss coefficients will change due to their dependency on voltage and angle. Another load flow computation has to be done to update values of α_{ij} and β_{ij}. However the analysis carried out has shown that amount of accuracy achieved in the size of DG by updating α_{ij} and β_{ij} is very small and is hence negligible. Also the difference is very minimal when compared with the capacities of distributed generator sources available in the market. Hence this analytical technique requires load flow to be carried out only two times and yields good results. The bus which gives minimum loss after placement of DG is selected as the optimum location for DG. A priority list of bus locations is prepared by arranging all buses with respect to approximate loss.

Algorithm for Analytical method is as below [6]:

1. Load flow studies are conducted for base case without DGs.
2. The optimum size of DG (P_{dgi}) for each bus is computed using Equation 3.15
3. The approximate loss is computed for each bus using Equation 3.9 by placing DG of optimum size (P_{dgi}) obtained in step 2 for that particular bus. Base case values of loss coefficients are used in the computation
4. Arrive at the bus which gives the lowest losses with insertion of DG source at that bus. This bus becomes the optimal site for DG placement.

This approach is adopted in the present work to analyse impact of DG source on distribution network. A computer program has been written in MATLAB to calculate the optimum sizes of DG at various buses and approximate total losses with DG at different locations to identify the best location. An Implicit Z-bus algorithm based load flow program is used to solve the load flow problem. The impact of DG source is evaluated by computing various performance indices and presented in the following sections.

3.5 Performance Indices of Distribution Network

Although in practice, distribution engineers will present some limitations in determining DG location, the existence of an index based on technical impacts indicates where DG could be more beneficial for the distribution network. The benefits of Distributed Generation like Power Loss Reduction, Voltage Profile Improvement, Voltage Stability and reduction in emission gases are quantified with different indices in the literature [9]. These indices are evaluated for different systems. One more index is proposed in this work based on the minimum capacity of DG insertion which will result in maximum possible reduction in system losses. This new index proposed helps the planner to select suitable location for DG source based on the economical perspective.

3.5.1 Power Loss Reduction Index (PLossIn)

One of the major potential benefits offered by DG is the reduction in electrical line losses. The loss can be significant under heavy load conditions. The utility is forced to pass the cost of electrical line losses to all customers in terms of higher energy cost. With the inclusion of DG, line loss in the distribution system can be reduced.

The proposed index for a bus is defined as the ratio of reduction in line losses in the system with DG to the maximum reduction in line losses with optimum size of DG in the system and is expressed as

$$PLossIn=\frac{(PLoss_0-PLoss_{dgi})}{PLoss_0} \text{ --(3.16)}$$

Where $PLoss_0$ is the Power Loss of the system without DG and $PLoss_{dgi}$ is the power loss of the system with DG at i^{th} node.

3.5.2 Voltage Profile Improvement Index (VPIIn)

One of the justifications for introducing DG is to improve the voltage profile of the system and maintain the voltage at customer terminals to within an acceptable range. Voltage profile can be improved because DG can provide a portion of the real and reactive power to the load, thus helping to decrease current along a section of the distribution line, which, in turn, will result in a boost in the voltage magnitude at the customer site. The voltage profile index [38] for i^{th} node is defined as

$$VP_i=\frac{(V_i-V_{\min})\cdot(V_{\max}-V_i)}{(V_{nom}-V_{\min})\cdot(V_{\max}-V_{nom})} \text{ --(3.17)}$$

Where VP_i is the voltage profile of the i^{th} node, $V_{\min}$ and $V_{\max}$ are the minimum and maximum permissible voltages of the system nodes and V_{nom} is the nominal or desired bus voltage, typically taken as 1 pu. The voltage profile index of the system is defined as

$$VPIn=\frac{1}{n}\cdot\sum_{i=1}^{n}VP_i \text{ ---(3.18)}$$

Voltage profile improvement index (VPII) has been defined as the ratio of a measure of the voltage profile of the system with DG to the same measure with no DG employed and is given as

$$VPII_i = \frac{VPIn_{dgi}}{VPIn} \text{ ---(3.19)}$$

Where, $VPIn_{dgi}$ is the voltage profile index of the system with DG at i^{th} node and $VPIn$ is the voltage profile index of the system without DG.

3.5.3 Voltage Stability Index (VSIn)

The decline of voltage stability level is one of important factors which restrict the increase of load served by distribution companies. DGs connected to distribution networks are potential to improve the system voltage stability [5]. The voltage stability level of the distribution network is measured with a voltage stability index as given in Appendix-B. The voltage stability index of any branch given as

$$L_j = \frac{4\left[\left(XP_j - RQ_j\right)^2 + \left(XQ_j + RP_j\right)V_i^2\right]}{V_i^4} \text{ ………………………….……(3.20)}$$

Where L_j stands for the voltage stability index of branch *j*. ($L_j \leq 1$)

The voltage stability index (*VSI*) of total distribution system is defined by

$$VSI = \max\left\{L_1, L_2, \cdots, L_{N-1}\right\} \text{ ……………………………………..…(3.21)}$$

The smaller value of voltage stability index VSI means the voltage stability of the network is better.

3.5.4. Reduction in Power Loss / DG Size Index (redPLoss/PdgIn)

This is a new performance index proposed in this work to evaluate improvement of network performance with DG source. In the planning of Distributed Generator for a distribution network, the size of the DG plays vital role. As the size of the DG is directly related to economics, it is very much required for utilities to get maximum reduction in power loss with lesser size of DG. This index is given as

$$redPLoss/PdgIn = \frac{(PLoss_0 - PLoss_{dgi})}{P_{dgi}} \text{ -----------------------------------(3.22)}$$

Where $PLoss_0$ is the Power Loss of the system without DG

$PLoss_{dgi}$ is the power loss of the system with DG at i^{th} node

P_{dgi} is the size of the Distributed Generator at i^{th} node

By computing this proposed index, the location of DG source with lesser capacity having lower capital cost which results in maximum reduction in power losses can be obtained. As the capital cost depends on the capacity of DG, lower size of DG will be less expensive. This index gives the best possible location to get maximum possible reduction in power loss with lowest capacity DG for single DG source insertion only. Hence this recommendation will be very much helpful for the designer to design the system where locations are highly constrained by DG source potential and also less capital cost is available from economical perspective.

3.6 Case Studies and Results

To verify the effectiveness of analytical approach and performance indices in order to compute the optimum location and size of DG, three different systems, of different sizes and configuration have been taken for study in this work.

3.6.1 Case A: 33 Bus System

The first system is a radial system with 33 buses and 32 branches with the total load of 3.715 MW and 2.3 MVAR. [67]. The single line diagram of 33 bus distribution system is shown in Figure 3.4. System Data is given in Appendix-C.

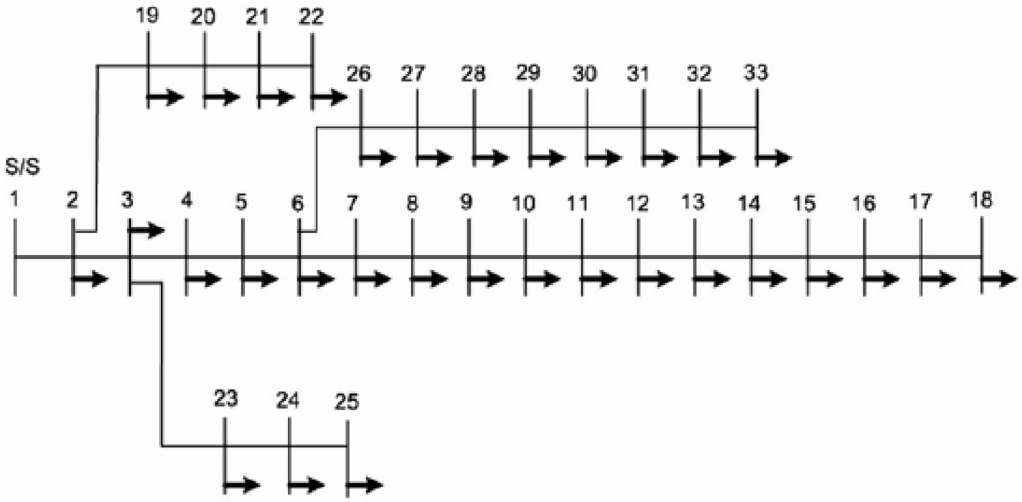


Figure 3.4 Single line diagram of 33 bus distribution system

3.6.2 Allocation of DG Size

Optimum size of DG is calculated using Equation (3.15) at various nodes for the test system. The power base is taken as 10 MVA. Figure 3.5 shows optimum size of DG at various nodes for 33 bus distribution test system. The value of DG size obtained is the value permissible for insertion in order to have a ‘‘possible minimum’’ total loss. This can be used as a lookup table for restricting the sizes of DG for minimizing the total power losses in the system.

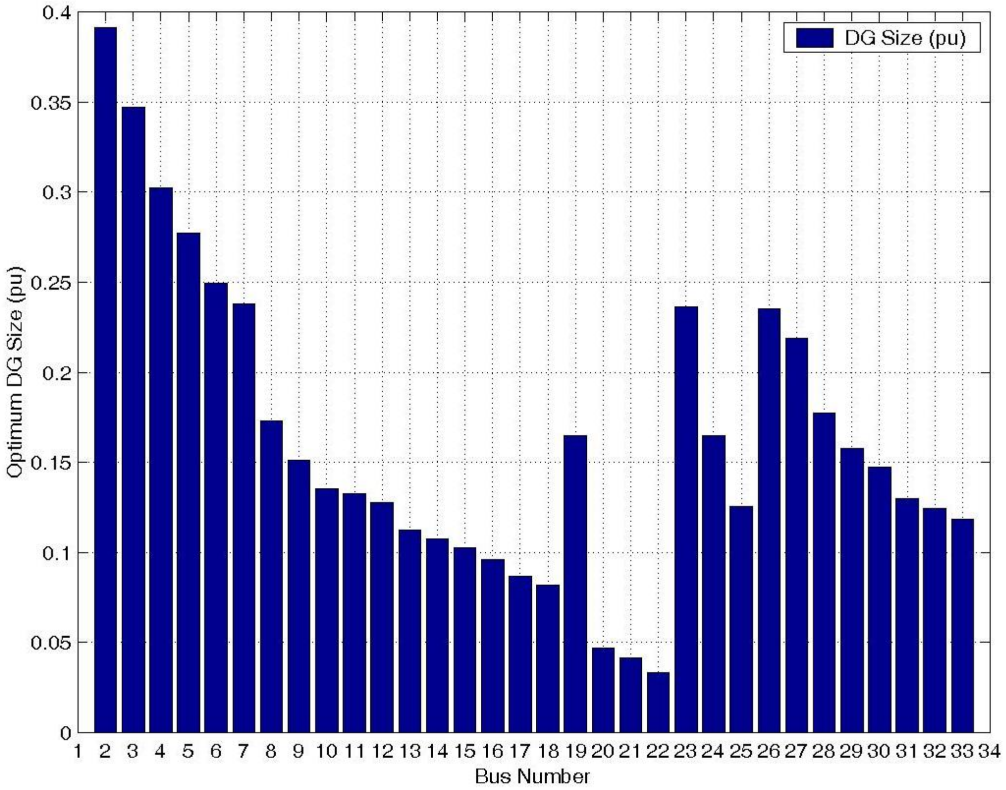


Figure 3.5 Optimum size of DG at various Locations for 33 bus distribution system

In 33 bus distribution test system, the optimum size of DG ranges from 0.0335p.u to 0.3915 p.u as shown in Figure 3.5. The location at which the total power loss is minimum can be identified from approximate Power loss calculated by exact loss equation.

3.6.3 Bus Location Selection for minimum PLoss

Figure 3.6 shows the approximate total power losses for 33 bus distribution system with DGs located at various nodes. It can be observed that the trend of the losses captured with the help of approximate solution to identify the best location has identified bus 6 which will lead to the least total power losses. Placing DG at Bus 7 will result in slightly higher losses than bus 6. It can be seen from the figure that the approximated losses pattern of the system at various nodes follows the accurate losses in all the cases.

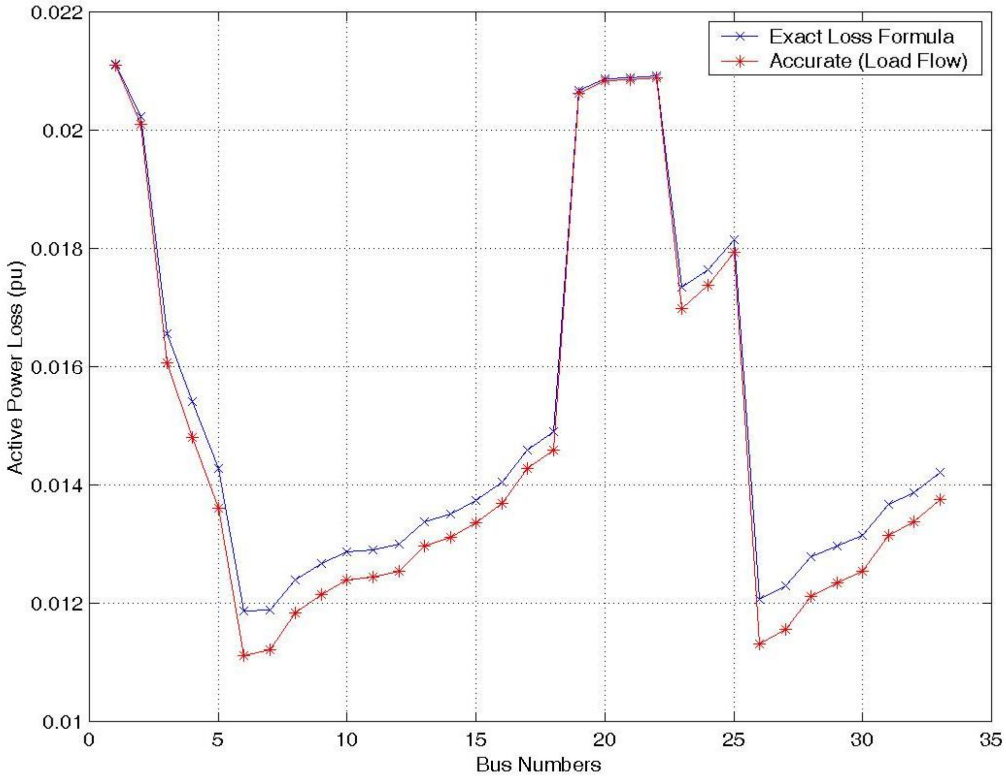


Figure 3.6 P_{Loss} with Exact Loss Formula and Repeated Load Flow

Extending this analysis, 33 bus distribution test system is investigated for optimum size of DGs for the given loading pattern. The analytical approach has yielded size of DG at bus 6 as 0.249 p.u which will give least power loss under the loading pattern considered. The repeated load flow with step size of 0.01 p.u results in size of DG as 0.26 p.u, this small difference (4.17%) is negligible when compared to higher capacities of DG sources available in the market. The summary of analysis is presented in the next section.

3.6.4 Selection of DG Source and Location based on Network Indices

The network designer will be having several objectives and constraints while planning the distribution system. To facilitate such a planning based on focus on any network parameter improvement with DG source, a comparative analysis is conducted in this work and presented in Table 3.1. The Load Increasing Scale (LIS) when equal to 1.0 , represents the nominal loading of the system.

Table 3.1 Comparison of Selection of DG with different Network Indices for 33 Bus System

LIS=1.0	**Base Network**	**min VSI**	**min Ploss**	**max redPLoss/Pdg**	**max VP**
DG at Bus No	---	8	6	18	7
Pdg p.u	---	0.173	0.249	0.0821	0.2378
Ploss p.u	0.0211	0.008351	0.006804	0.012418	0.007135
PlossIn(%)	---	60.42	67.75	41.15	66.18
redPloss/Pdg	---	0.074	0.057	0.106	0.059
VPIIn	---	1.190797	1.190261	1.158767	1.191115
Max VSI	0.0748	0.0445	0.0512	0.046781	0.050852

The findings tabulated above can be summarised as below:

The Base case without DG has power loss of 0.0211 p.u and voltage stability index of 0.0748. If a designer wish to improve the voltage stability of the system, then the best location for insertion of DG is bus 8 which gives the lowest possible VSI as 0.0445. However the reduction in losses and voltage profile improvement will not be highest in this choice.

If a designer opts to achieve highest reduction in losses, then bus 6 is the right selection. With DG size of 0.249 p.u, the losses will reduce to 0.006804 p.u, which is indicated by Power Loss Reduction Index (PlossIn) as 67.75 %, the highest possible reduction for the case under study.

If there are constraints on capital cost investment and resource potential for DG source, then designer has to opt for smallest capacity DG source and try to attempt to get maximum advantage. In this context, bus 18 is the right choice which is having highest redPloss/DG index of 0.106. By insertion of small capacity of DG of 0.0821 p.u at bus 18, it is possible to reduce loss by 41.15% and also improve voltage profile and voltage stability when compared to base case. Hence this recommendation will improve technical parameters and also most feasible from economic perspective.

For systems suffering from poor voltage profile, focus of finding optimal location of DG will be to improve voltage profile. In this regard, insertion of DG at bus 7 which is having highest voltage profile index VPIIn of 1.191115 results in maximum voltage profile improvement in the network. The designer can select a DG size of 0.2378 p.u at bus 7 to achieve this objective.

The above recommendations are very much helpful for the network designer to conceive the most suitable structure depending on the prime objective. The results of the analysis and also the behaviour of the system for increasing loading levels are presented here. Figures 3.7 and Figure 3.8 show various parameters of 33 bus distribution system with DGs located at different locations. As the load increasing scale (LIS) increases, due to heavy load on the system, the voltage stability of the system becomes poorer and is indicated by increase in voltage stability index. Table 3.2 gives the results for location and size of DG for various load increasing scale values.

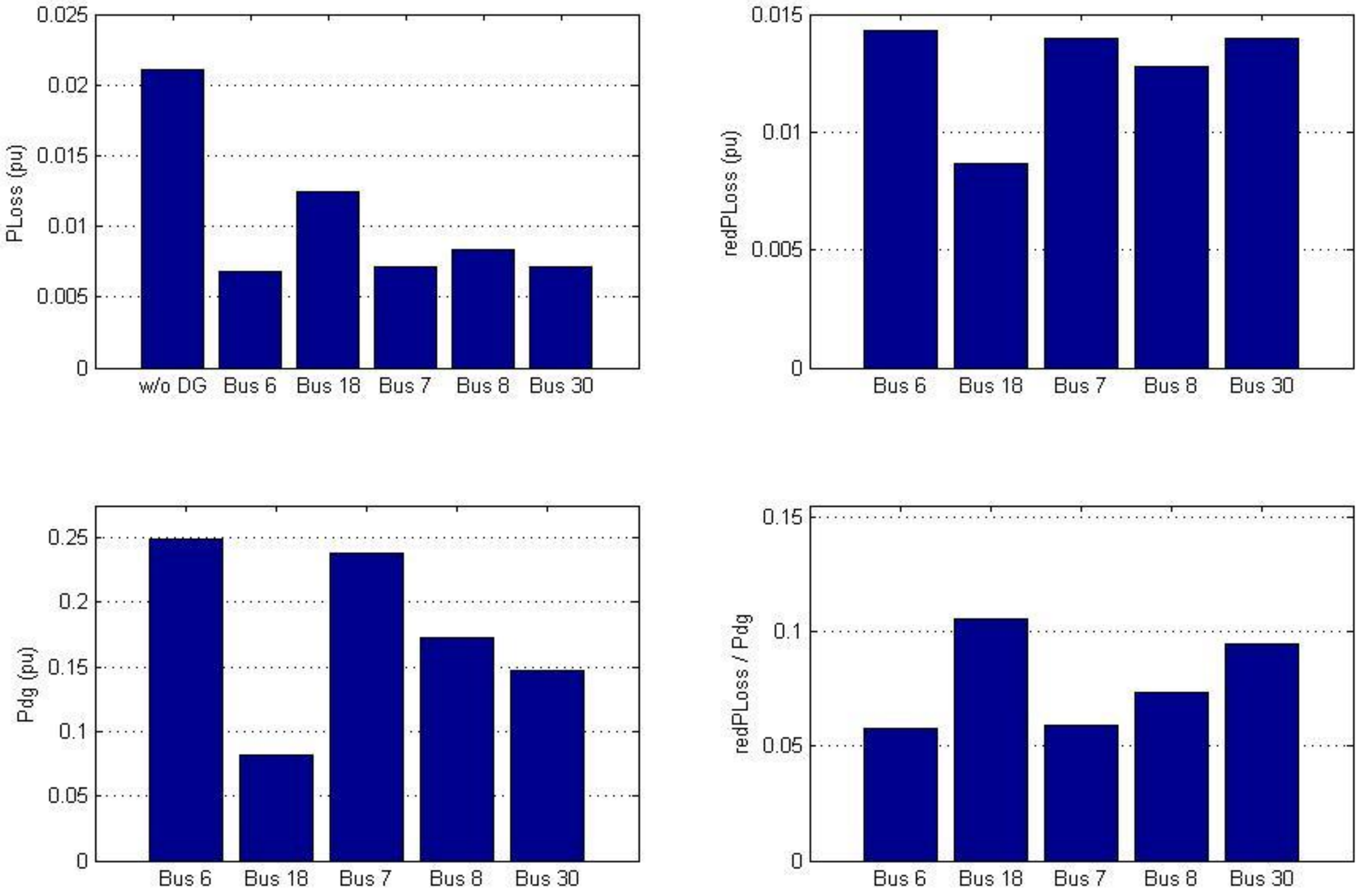


Figure 3.7 PLoss, redPLoss, Pdg and redPLoss/Pdg vs. Bus Locations for 33 bus system

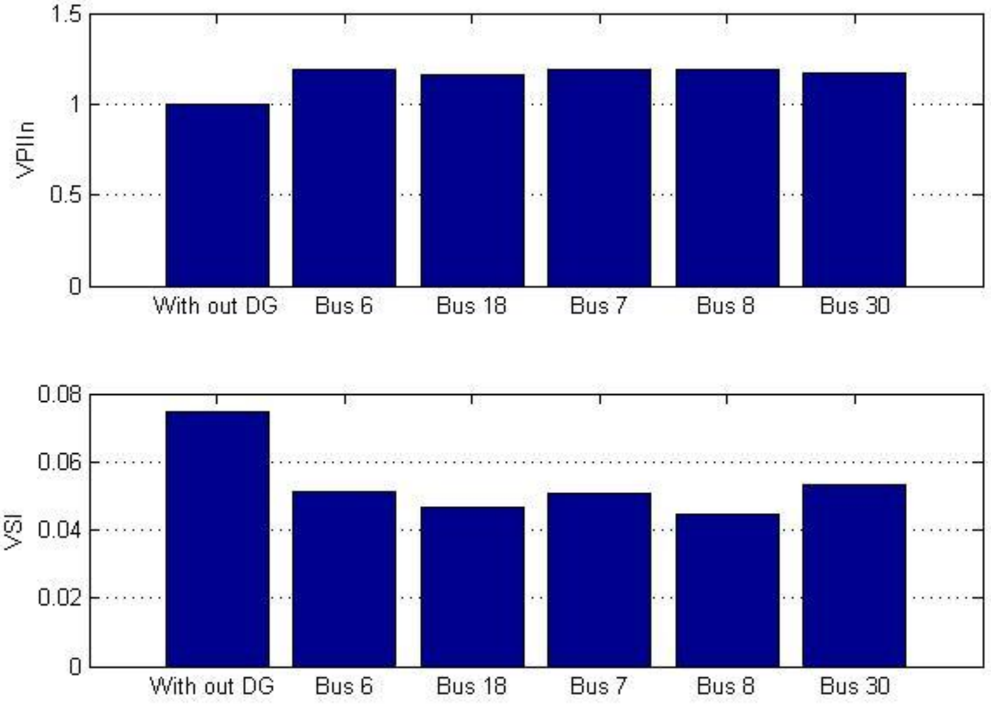


Figure 3.8 VPIIn, VSI vs. Bus Locations for 33 bus system

Table 3.2 Effect of Load Increasing Scale on Network Performance

	Base	VSI						Ploss					
LIS	VSI	Bus	Pdg (pu)	redPloss (%)	redPloss/Pdg	VPIIn	VSI	Bus	Pdg (pu)	redPloss (%)	redPloss/Pdg	VPIIn	VSI
0.5	0.036	8	0.086	59	0.033	1.002	0.0216	6	0.123	66	0.026	1.002	0.025
0.6	0.043	8	0.104	59	0.040	1.003	0.0261	6	0.148	66	0.032	1.003	0.030
0.8	0.059	8	0.138	60	0.056	1.006	0.0352	6	0.198	67	0.044	1.006	0.041
1.0	0.075	8	0.173	60	0.074	1.023	0.0445	6	0.249	68	0.057	1.023	0.051
1.2	0.092	8	0.208	61	0.092	1.034	0.0541	6	0.300	68	0.072	1.034	0.062
1.4	0.110	8	0.243	62	0.113	1.050	0.0639	6	0.352	69	0.087	1.049	0.072
1.6	0.128	8	0.279	63	0.136	1.069	0.0739	6	0.405	70	0.104	1.069	0.083
1.8	0.148	8	0.315	64	0.162	1.094	0.0844	6	0.459	71	0.123	1.094	0.094
2.0	0.170	8	0.351	65	0.191	1.127	0.0948	6	0.514	72	0.144	1.127	0.105
2.2	0.192	8	0.388	66	0.225	1.170	0.1057	6	0.570	73	0.168	1.170	0.116
2.4	0.217	8	0.425	68	0.264	1.228	0.1170	6	0.627	74	0.196	1.228	0.128
2.6	0.245	8	0.463	69	0.310	1.115	0.1286	6	0.688	75	0.227	1.115	0.139
2.8	0.276	8	0.502	71	0.367	1.152	0.1405	6	0.751	77	0.266	1.152	0.151
3.0	0.312	8	0.543	73	0.441	1.204	0.1529	6	0.820	79	0.314	1.204	0.162
3.2	0.358	8	0.587	76	0.549	1.291	0.1658	6	0.898	81	0.382	1.291	0.174
3.4	0.443	8	0.648	81	0.797	1.549	0.1790	6	1.018	85	0.528	1.549	0.187

3.6.5 Case B: 69 Bus System

The second system is the widely used 69 bus and 68 branches radial system with the total load demand of 3.80 MW and 2.69 MVAR [37]. The single line diagram of 69 bus distribution system is shown in Figure 3.9. System Data is given in Appendix-C.

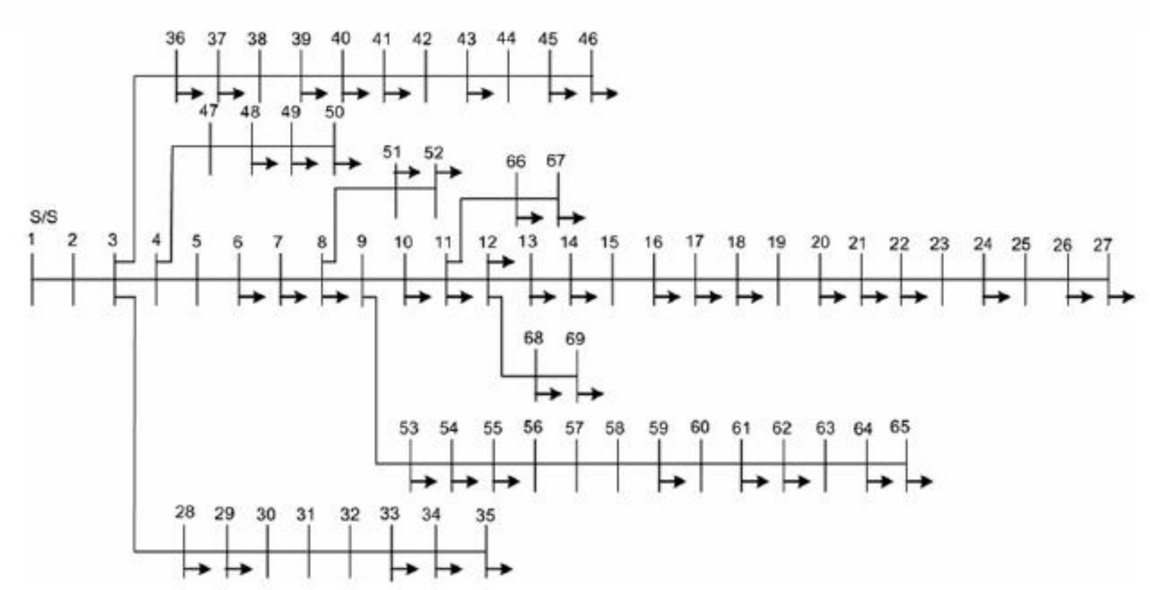


Figure 3.9 Single line diagram of 69 bus distribution system

3.6.6 Allocation of DG Size

Optimum size of DG is calculated using equation (3.15) at various nodes for the 69 bus distribution test system and shown in Figure 3.10. The power base is taken as 100 MVA. The value of DG size obtained is the optimum value permissible to setup in order to have a ‘‘possible minimum’’ total loss. This can be used as a lookup table for restricting the sizes of DG for minimizing the total power losses in the system.

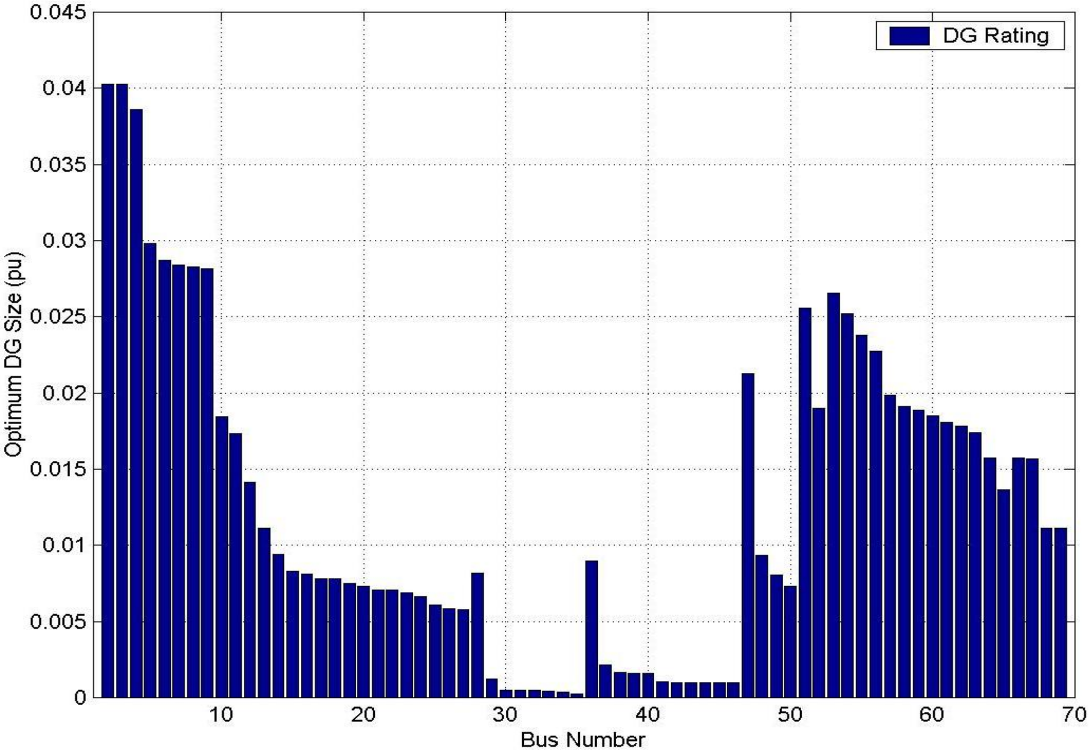


Figure 3.10 Optimum size of DG at various Locations for 69 bus distribution system

In 69 bus distribution test system, the optimum size of DG ranges from 0.00025 to 0.04025 (pu).

3.6.7 Bus Location Selection for minimum PLoss

Figure 3.11 shows the approximate total power losses for 69 bus distribution system with optimum DG sizes obtained at various nodes. Similar to previous test system in this also approximate total power losses trend is similar to Accurate Power losses and can identify the location (bus 61) that would lead to the least total power losses.

Extending this analysis, 69 bus distribution test system is investigated for optimum size of DGs for the given loading pattern. The analytical approach has yielded size of DG at bus 61 as 0.018079 p.u which will give least power loss under the loading pattern considered. The repeated load flow with step size of 0.01 p.u results in size of DG as 0.0192 p.u, this small difference (5.84%)) is negligible when compared to higher capacities of DG sources available in the market. The summary of analysis is presented in the next section.

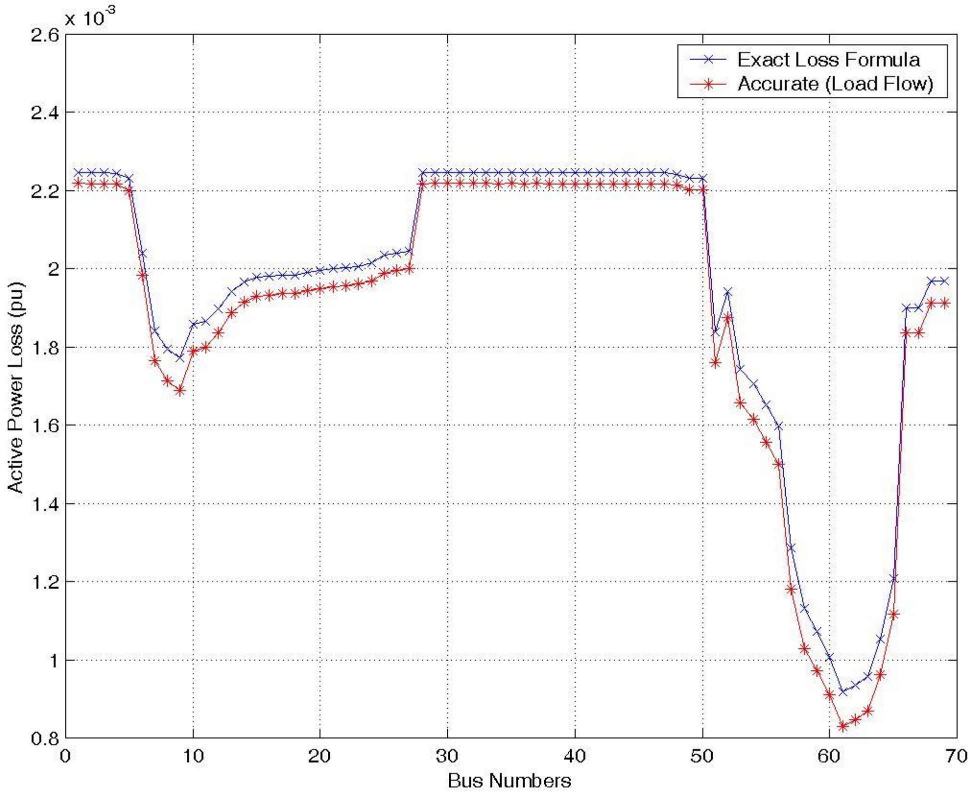


Figure 3.11 P_{Loss} with Exact Loss Formula and Repeated Load Flow

3.6.8 Selection of DG Source and Location based on Network Indices

The network designer will be having several objectives and constraints while planning the distribution system. To facilitate such a planning based on focus on any network parameter improvement with DG source, a comparative analysis is conducted in this work and presented in Table 3.3. The Load Increasing Scale (LIS) when equal to 1.0 , represents the nominal loading of the system.

Table 3.3 Comparison of Selection of DG with different Network Indices for 69 Bus System

LIS=1.0	Base Network	min VSI	min Ploss	max redPLoss/Pdg	max VP
DG at Bus No	---	61	61	65	61
Pdg (pu)	---	0.01808	0.01808	0.013628	0.01808
Ploss (pu)	0.002218	0.000234	0.000234	0.00062	0.000234
PlossIn(%)	---	89.45	89.45	72.03	89.45
redPloss/Pdg	---	0.110	0.110	0.117255	0.110
VPIIn	---	1.05936	1.05936	1.05426	1.05936
Max VSI	0.0901	0.0197	0.0197	0.01986	0.0197

The findings tabulated above can be summarised as below:

The Base case without DG has power loss of 0.002218 p.u and voltage stability index of 0.0901. If a designer wish to improve the voltage stability of the system, then the best location for insertion of DG is bus 61 which gives the lowest possible VSI as 0.0197. However the reduction in losses, voltage profile improvement will not be maximum in this choice.

Similarly bus 61 also results in highest reduction in power loss. With DG size of 0.01808 p.u, the losses will reduce to 0.000234 p.u, which is indicated by Power Loss Reduction Index (PlossIn) as 89.45 %, the highest possible reduction for the case under study.

In the same manner, bus 61 is a good choice for voltage profile improvement too. It has highest voltage profile index VPIIn of 1.05936 results in maximum voltage profile improvement in the network.

If there are constraints on capital cost investment and resource potential for DG source, then designer has to opt for smallest capacity DG source and try to attempt to get maximum advantage. In this context, bus 65 is the right choice which is having highest redPloss/DG index of 0.1117255. By insertion of small capacity of DG of 0.013628 p.u at bus 65, it is possible to reduce loss by 72.03% and also improve voltage profile and voltage stability when compared to base case. Hence this recommendation will improve technical parameters and also most feasible from economic perspective.

The above recommendations are very much helpful for the network designer to conceive the most suitable structure depending on the prime objective. The results of the analysis and also the behaviour of the system for increasing loading levels are presented here.

Figures 3.12 and Figure 3.13 show the various parameters of 69 bus distribution system with DGs located at different locations. As the load increasing scale (LIS) increases, the voltage stability of the system becomes poorer and is indicated by increase in voltage stability index. Table 3.4 gives the results for location and size of DG for various load increasing scale values.

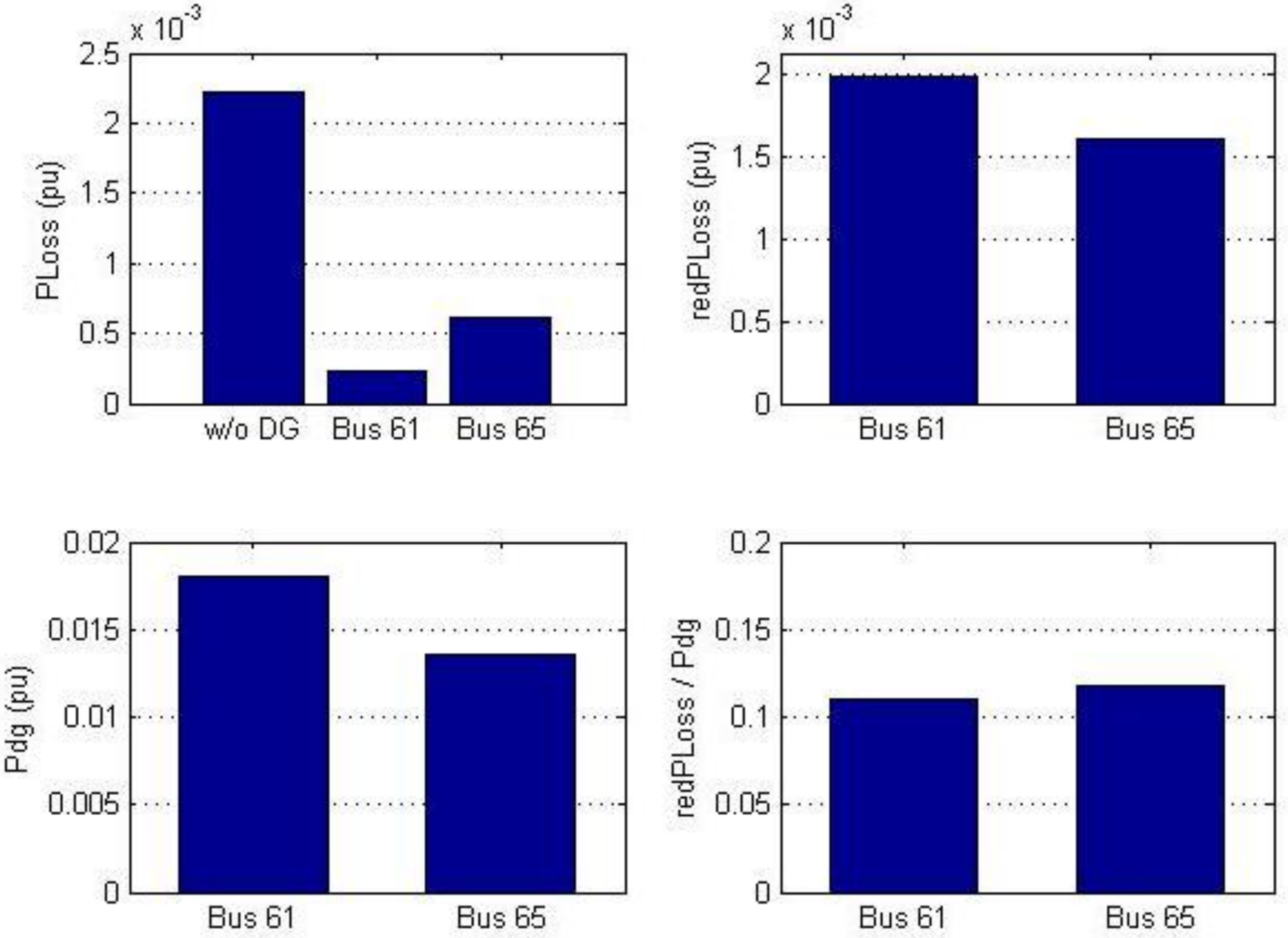


Figure 3.12 **PLoss, redPLoss, Pdg and redPLoss/Pdg vs. Bus Locations for 69 bus system**

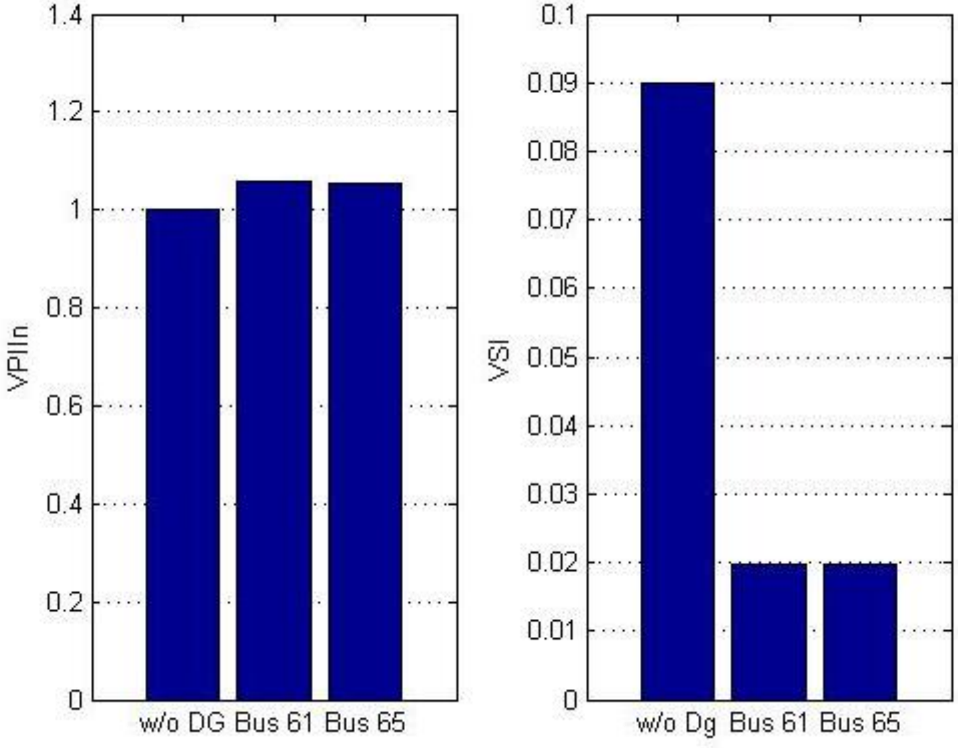


Figure 3.13 VPIIn, VSI vs. Bus Locations for 69 bus system

Table 3.4 Effect of Load Increasing Scale on Network Performance

	Base	**VSI**						**Ploss**					
LIS	VSI	Bus	Pdg (pu)	redPloss (%)	redPloss/Pdg	VPIIn	VSI	Bus	Pdg (pu)	redPloss (%)	redPloss/Pdg	VPIIn	VSI
0.5	0.0429	61	0.0091	89	0.0504	1.0008	0.0097	61	0.0091	89	0.0504	1.0008	0.0097
0.6	0.0520	61	0.0109	89	0.0615	1.0012	0.0117	61	0.0109	89	0.0615	1.0012	0.0117
0.8	0.0707	61	0.0145	89	0.0849	1.0022	0.0157	61	0.0145	89	0.0849	1.0022	0.0157
1.0	0.0901	61	0.0181	89	0.1098	1.0035	0.0197	61	0.0181	89	0.1098	1.0035	0.0197
1.2	0.1122	61	0.0217	90	0.1394	1.0053	0.0238	61	0.0217	90	0.1394	1.0053	0.0238
1.4	0.1343	61	0.0252	90	0.1700	1.0075	0.0279	61	0.0252	90	0.1700	1.0075	0.0279
1.8	0.1840	61	0.0323	91	0.2433	1.0139	0.0362	61	0.0323	91	0.2433	1.0139	0.0362
2.0	0.2113	61	0.0358	91	0.2865	1.0182	0.0404	61	0.0358	91	0.2865	1.0182	0.0404
2.2	0.2409	61	0.0393	92	0.3359	1.0234	0.0446	61	0.0393	92	0.3359	1.0234	0.0446
2.4	0.2754	61	0.0428	92	0.3974	1.0303	0.0489	61	0.0428	92	0.3974	1.0303	0.0489
2.6	0.3142	61	0.0462	93	0.4719	1.0390	0.0533	61	0.0462	93	0.4719	1.0390	0.0533
2.8	0.3600	61	0.0496	93	0.5684	1.0507	0.0577	61	0.0496	93	0.5684	1.0507	0.0577
3.0	0.4181	61	0.0528	94	0.7070	1.0679	0.0621	61	0.0528	94	0.7070	1.0679	0.0621
3.2	0.5278	61	0.0558	95	1.0387	1.1074	0.0666	61	0.0558	95	1.0387	1.1074	0.0666

3.6.9 Case C: 90 Bus System

The third system is a 90 bus and 89 branches radial system with the total load demand of 19.45 MW and 9.72 MVAR [5]. The single line diagram of 90 bus distribution system is shown in Figure 3.14. System Data is given in Appendix-C.

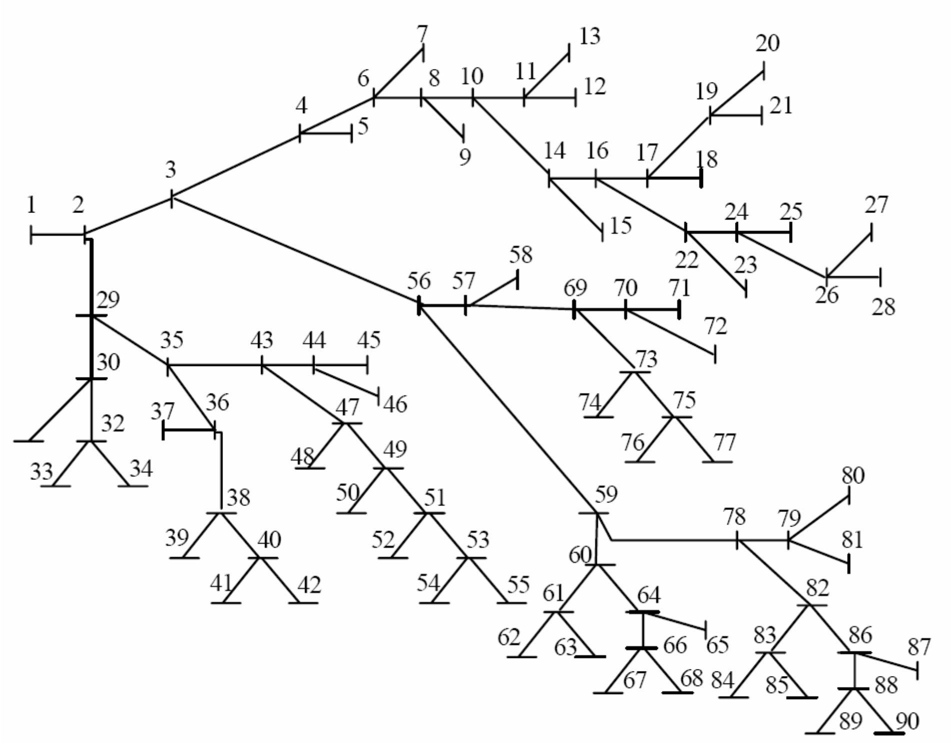


Figure 3.14 Single line diagram of 90 bus distribution system

3.6.10 Allocation of DG Size

Optimum size of DG is calculated using equation 3.15 at various nodes for the 90 bus distribution test system and shown in Figure 3.15. The value of DG size obtained is the value permissible for insertion in order to have a ‘‘possible minimum’’ total loss. This can be used as a lookup table for restricting the sizes of DG for minimizing the total power losses in the system.

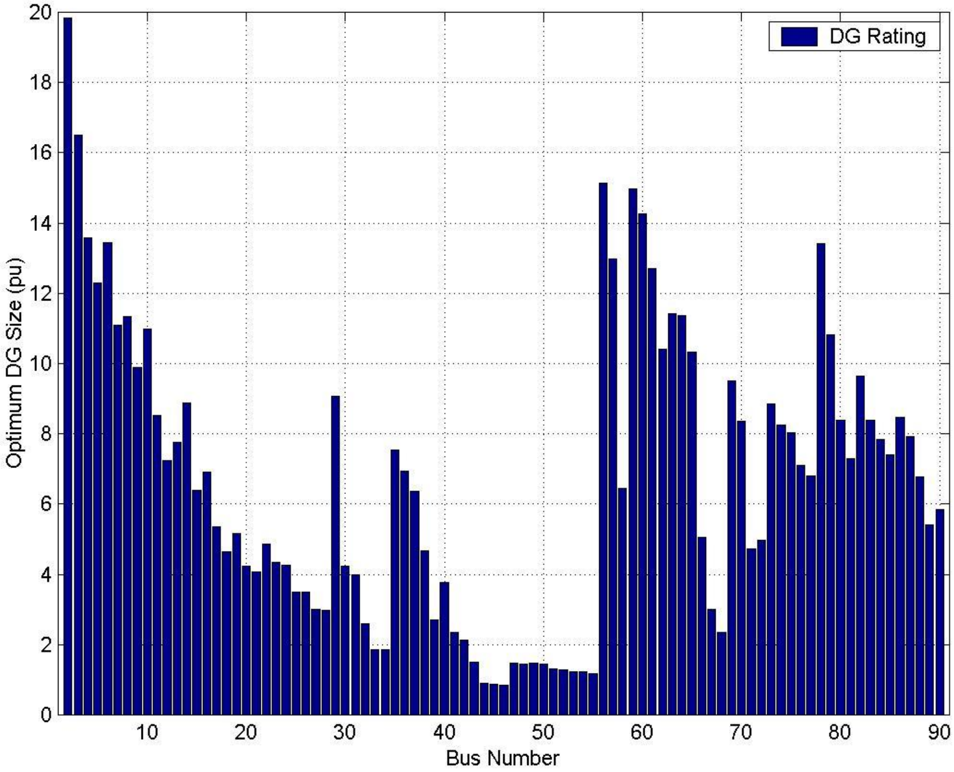


Figure 3.15 Optimum size of DG at various Locations for 90 bus system

3.6.11 Bus Location Selection for minimum PLoss

Figure 3.16 shows the approximate total power losses for 90 bus distribution system with optimum DG sizes obtained at various nodes. Similar to previous test systems in this also approximate total power losses trend is similar to Accurate Power losses and can identify the location as bus 10 that would lead to the least total power losses.

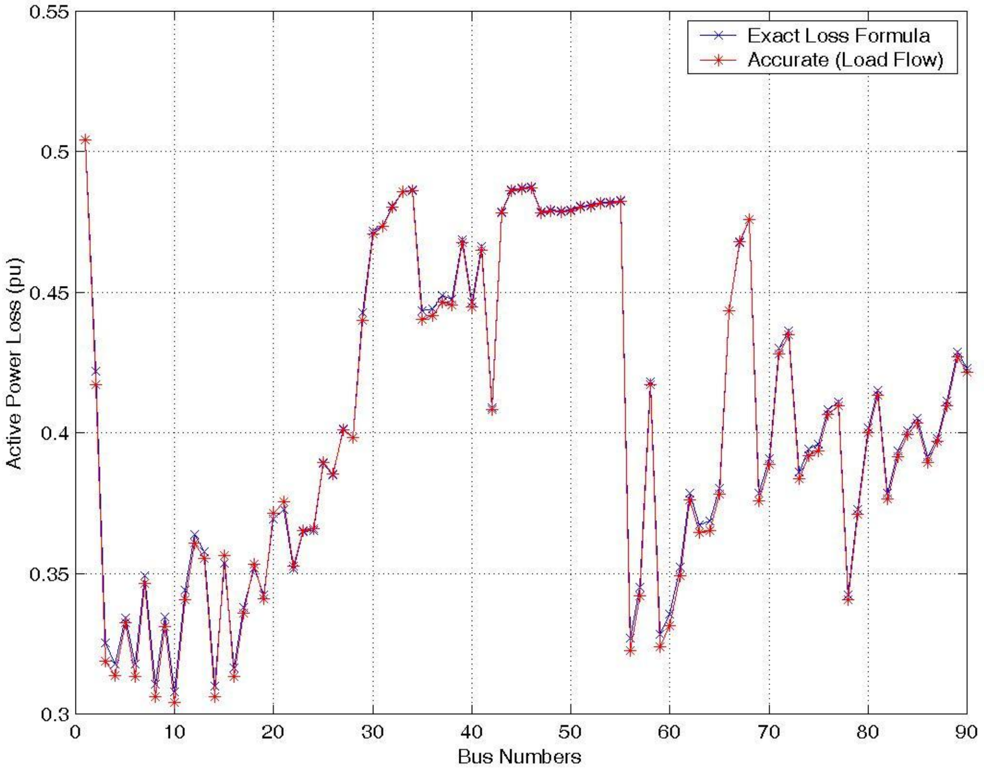


Figure 3.16 P_{Loss} with Exact Loss Formula and Repeated Load Flow

In 90 bus distribution test system, the best location is bus 10 with lowest power loss and the second best location is bus 14 with slightly higher power losses as shown in Figure 3.16. The size of the DG obtained at bus 10 is 10.98096 p.u. However repeated load flow with a step size of 0.5 p.u at bus 10 gives the optimum size as 11.00 p.u and this small difference (0.173%) is negligible.

3.6.12 Selection of DG Source and Location based on Network Indices

The network designer will be having several objectives and constraints while planning the distribution system. To facilitate such a planning based on focus on any network parameter improvement with DG source, a comparative analysis is conducted in this work and presented in Table 3.5 for 90 bus system. The Load Increasing Scale (LIS) when equal to 1.0 , represents the nominal loading of the system.

Table 3.5 Comparison of Selection of DG with different Network Indices for 69 Bus System

LIS=1.0	**Base Network**	**min VSI**	**min Ploss**	**max redPLoss/Pdg**	**max VP**
DG at Bus No	---	42	10	42	4
Pdg (pu)	---	2.13	10.98	2.13	13.58
Ploss (pu)	0.504114	0.393381	0.237571	0.393381	0.246657
PlossIn(%)	---	21.97	52.87	21.97	51.07
redPloss/Pdg	---	0.052066	0.024273	0.052066	0.018964
VPIIn	---	1.038971	1.164278	1.038971	1.165091
Max VSI	0.2367	0.1059	0.2289	0.1059	0.227845

In similar manner with the recommendations made for 33 bus and 69 bus systems, the best choice of DG locations are as below:

Designer can opt for bus number 42 with lowest voltage stability index to get highest improvement in voltage stability. DG insertion at bus 10 with maximum power loss reduction index of 52.87% is the best candidate for maximum loss reduction. It is also observed that DG insertion at bus number 42 will be more economical because it has highest reduction of Ploss/ Pdg index which means with smaller capacity of DG, maximum benefit of reduction in power loss can be achieved. This selection is very appropriate from capital investment. If designer wishes to improve the voltage profile, then bus 4 is the optimum choice with maximum voltage profile index of 1.165091.

Figures 3.17 and 3.18 show the various parameters of 90 bus distribution system with DGs located at different locations. As the load increasing scale (LIS) increases, the voltage stability of the system becomes poorer and is indicated by increase in voltage stability index. Table 3.6 gives the results for location and size of DG for various load increasing scale values.

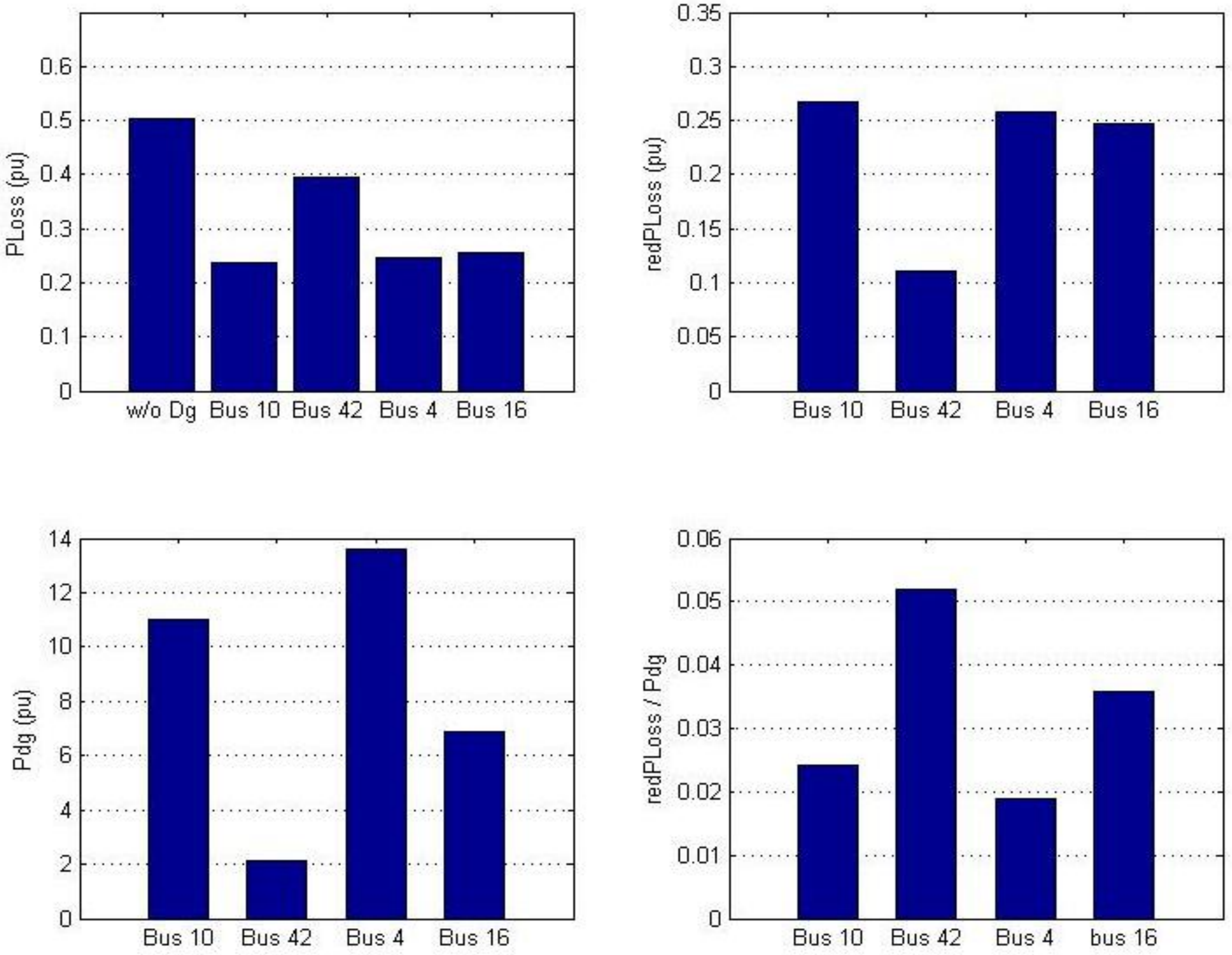


Figure 3.17 PLoss, redPLoss, Pdg and redPLoss/Pdg vs. Bus Locations for 90 bus system

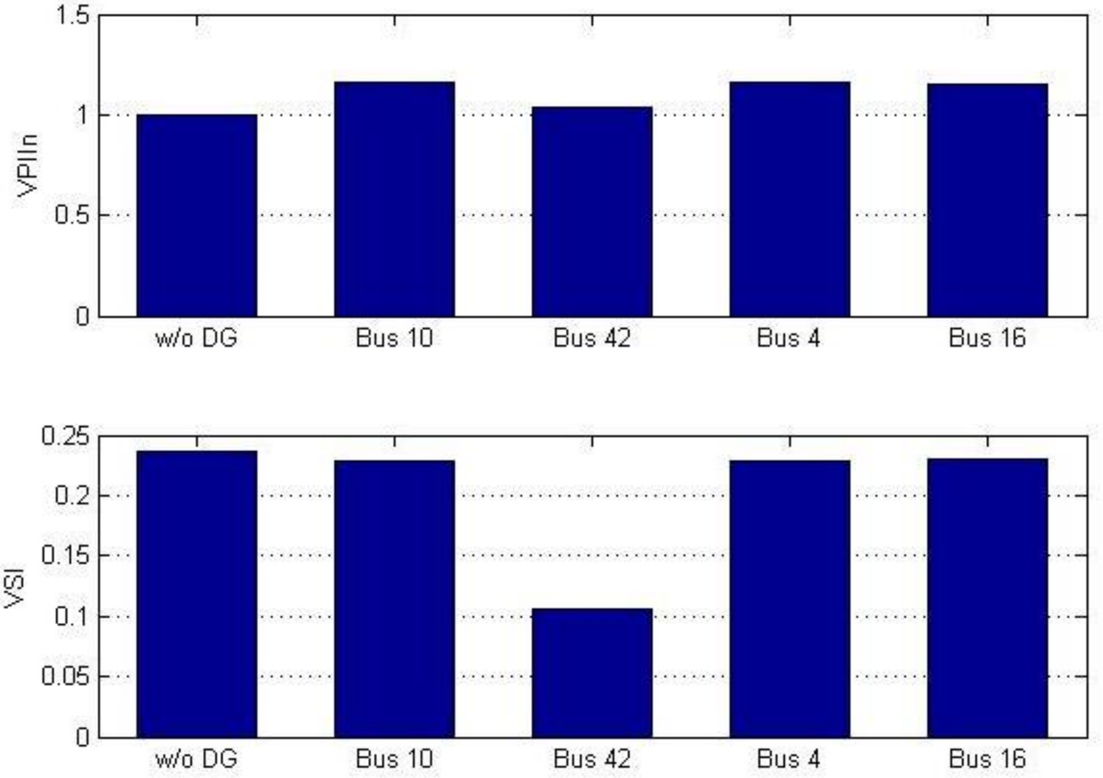


Figure 3.18 VPIIn, VSI vs. Bus Locations for 90 bus system

The Figure 3.5 to Figure 3.18 show the plots of optimal DG size, variation of the power loss with bus location, the performance indices at different bus location. Based on these figures the designer can analyse and decide on the best location for insertion of DG source.

Table 3.6 Effect of Load Increasing Scale on Network Performance

	Base	VSI						Ploss					
LIS	VSI	Bus	Pdg (pu)	redPloss (%)	redPloss/Pdg	VPIIn	VSI	Bus	Pdg (pu)	redPloss (%)	redPloss/Pdg	VPIIn	VSI
0.5	0.1047	42	1.07	21	0.022	1.00159	0.0510	10	5.48	51	0.011	1.00734	0.1033
0.6	0.1285	42	1.28	21	0.028	1.00240	0.0616	10	6.57	52	0.013	1.01094	0.1264
0.7	0.1535	42	1.49	21	0.033	1.00345	0.0724	10	7.67	52	0.016	1.01542	0.1504
0.8	0.1798	42	1.70	21	0.039	1.00477	0.0834	10	8.77	52	0.018	1.02092	0.1754
0.9	0.2075	42	1.92	22	0.045	1.00641	0.0946	10	9.88	53	0.021	1.02755	0.2015
1.0	0.2367	42	2.13	22	0.052	1.03897	0.1059	10	10.98	53	0.024	1.16428	0.2289
1.1	0.2678	42	2.34	22	0.059	1.01090	0.1175	10	12.09	53	0.027	1.04495	0.2575
1.2	0.3008	42	2.55	23	0.067	1.01393	0.1293	10	13.19	54	0.031	1.05617	0.2876
1.3	0.3361	42	2.76	23	0.076	1.01764	0.1413	10	14.30	54	0.034	1.06947	0.3193
1.4	0.3741	42	2.96	23	0.086	1.02222	0.1536	10	15.42	54	0.038	1.08528	0.3528
1.5	0.4153	42	3.17	24	0.097	1.02791	0.1661	10	16.53	55	0.042	1.10413	0.3883
1.6	0.4603	42	3.37	25	0.109	1.03506	0.1788	10	17.65	55	0.047	1.12680	0.4263
1.7	0.5100	42	3.57	25	0.124	1.04421	0.1919	10	18.77	56	0.052	1.15434	0.4670
1.8	0.5659	42	3.77	26	0.141	1.05619	0.2053	10	19.89	56	0.057	1.18835	0.5111
1.9	0.6306	42	3.96	27	0.163	1.07249	0.2190	10	21.03	57	0.064	1.23147	0.5593
2.0	0.7090	42	4.14	29	0.193	1.09628	0.2331	10	22.17	58	0.071	1.28856	0.6129
2.1	0.8185	42	4.30	32	0.244	1.13776	0.2476	10	23.33	59	0.083	1.37386	0.6743

3.7 Conclusive Remarks

- The Impact of DG source insertion on distribution system performance has been investigated with the help of network performance indices. These indices will help in judgement of any parameter improvement with insertion of DG sources. The optimal location and size of DG sources is computed to help the system designer.
- A Comparative table for comprehensive analysis has been prepared. This table serves as a guiding tool for the system designer to choose the appropriate location and corresponding size to obtain maximum possible improvement in any network parameter of his interest.
- A new index which indicates the suitable location which gives maximum reduction in system losses to the smallest capacity of DG size is proposed. This index will be very much helpful for systems which are having lower DG harnessing potential and also constraint on reduction in capital cost exists. In this regard this index will be a trade-off between technical perspective and economical perspective.

To validate the analysis and proposals made in this work, three systems with different load demand are considered. The data for 33 bus, 69 bus and 90 bus system are taken from reported literature. The studies conducted have demonstrated the flexibility for the designer in choosing the location and size of DG source according to his objective.

CHAPTER 4

CRITERIA FOR MULTIPLE DG SOURCE INSERTION TO DISTRIBUTION SYSTEM

4.1 Introduction

The allocation of multiple DG sources to distribution system is a very complex phenomenon. In literature many techniques have been developed to address placement of multiple DGs . In one of the approaches, the optimal locations and size of DG's in a distribution system are determined using ant colony optimization. A cost based model decides the optimal size and location of the distributed generation sources in a power distribution system. The objective is defined as minimization of DG investment cost and total operation cost of the system. The model considered time varying load over a year, as well as the optimal operation strategy of DG sources in the system providing minimization of DG investment and operating cost of the system [11].

The placement of DGs has to be done so that voltage collapse is prevented at most sensitive buses. The algorithm comprises of installing certain capacity of DGs at these buses and determination of voltage collapse point or maximum loading. An iterative procedure was developed to investigate the impact of DGs on static voltage stability and arriving at suitable solutions [12].

As insertion of DGs improve many system parameters, the determination of the extent of improvement in each parameter is vital in decision making process. The multi objective function defined comprises of the objectives as (a) minimize real power, reactive power loss (b) voltage deviation index. Evolutionary programming was adopted for solving the objective function. The approach incorporated load models for analysis [13].

With the deregulation of energy market and the concern for environment protection, more and more distributed generation sources with clean technologies is embedded in the distribution network. However the capacity of DG inserted at any location depends on potential of energy generation at the location and also the economic aspects. The distribution network operators always wish to play safe by avoiding the negative effects of high level penetration. The technical and economical impacts must be assessed before deciding the allocation of DG sources. To facilitate this objective, computation of indices related to system improvement will be very much essential. By this approach the efficient management of distribution system can be achieved [14].

Since process of multiple DG source allocation is quite cumbersome, artificial intelligence techniques had been attempted to arrive at suitable solution. The focus for the approach was to obtain solution achieving reduction in power losses and improvement in voltage profile. The model aimed at allocation of multiple DGs from overall management perspective including control and protection was proposed by Qudaih and Syafaruddin Hiyama [15].

The network reconfiguration at the power distribution systems with distributed generation results in reduced system losses. The conventional power distribution systems have a radial network and unidirectional power flows. The distribution system with DG sources has a locally looped network and bidirectional power flow. Therefore, DG into the power distribution system can cause operational problems and impact on existing operational schemes. In this context, Joon –Ho Choi and Jae-Chul Kim have reported the importance and necessity of selection of appropriate operational scheme from many alternatives is essential in safeguarding system security [16].

The integrated operation of DG sources with utility grid can be successful only when distribution automation is in place. Since real time operation can be monitored and appropriate control actions can be executed in automated schemes, network performance will substantially improve in the process. Joon –Ho Choi and Jae-Chul

Kim have proposed operational strategies for network reconfiguration with DGs in automated distribution systems [17].

The cost of transmission and distribution losses needs to be accounted by means of allocating the losses to consumers. The allocation of power losses to consumers connected to radial distribution networks before and after network reconfiguration in a deregulated environment is to be done in justifiable manner. The approach to allocate losses allocation with identification of the real and imaginary parts of current in each branch and network reconfiguration based on the fuzzy multi objective optimization had been developed by J.S. Savier and D. Das [18].

The network reconfiguration will change the power flow in different branches of the system. The algorithm employed to decide on network re-configuration involves aspects of loss minimization and voltage profile improvement during network reconfiguration process had been analysed and effective solutions have been computed [19] [82]-[88]. The artificial intelligence techniques have been very much useful in analysis of distribution system with distributed generation sources. The adoption of genetic algorithm helps in getting solutions which optimises desired objective function [20] [89]-[92] .

The Multiple DG Source insertion is a complex problem and has to be addressed accounting technical, geographical and economical issues. The multiple DG insertions give rise to large number of near optimal solutions to minimise power loss. Hence a guided search will be helpful to arrive at solution. In this regard, the work carried out to develop the criteria for multiple DG source insertion to distribution systems with the following objectives is newly proposed in this thesis and procedure of implementation is presented in this chapter.

1. To compute the optimal locations for multiple DG source insertion
2. To recommend the most suitable capacity for the DG source injection at optimal locations. This recommendation is made through computation of a new index proposed in this work termed as Network Performance Enhancement Index (NPEI) based on technical parameters.

3. To suggest the optimal locations of DG sources based on the operating cost so that the planner can choose the possible locations on economical perspective.
4. To determine the operating schedule of DG sources under varying load pattern.

4.2 Power Flow Analysis

The requirement for reliability, accuracy, less storage capacity and fast algorithm play a vital role in any power flow analysis technique. The algorithms described in previous chapters are not efficient for multiple DG source insertion because of huge computation involved. Hence for multiple DG problems a fast power flow algorithm with approximation formulas to reduce the number of iterations have been developed in the recent past [77]. The complex voltages and currents are solved by basic phasor relationships. This algorithm is employed in the present work.

4.1.1 Mathematical Formulation

A three-phase, balanced radial distribution feeder with *n* buses, *l* laterals and sub laterals is used for formulation of power flow technique. In the network, both distributed generators and capacitors are included for analysis.

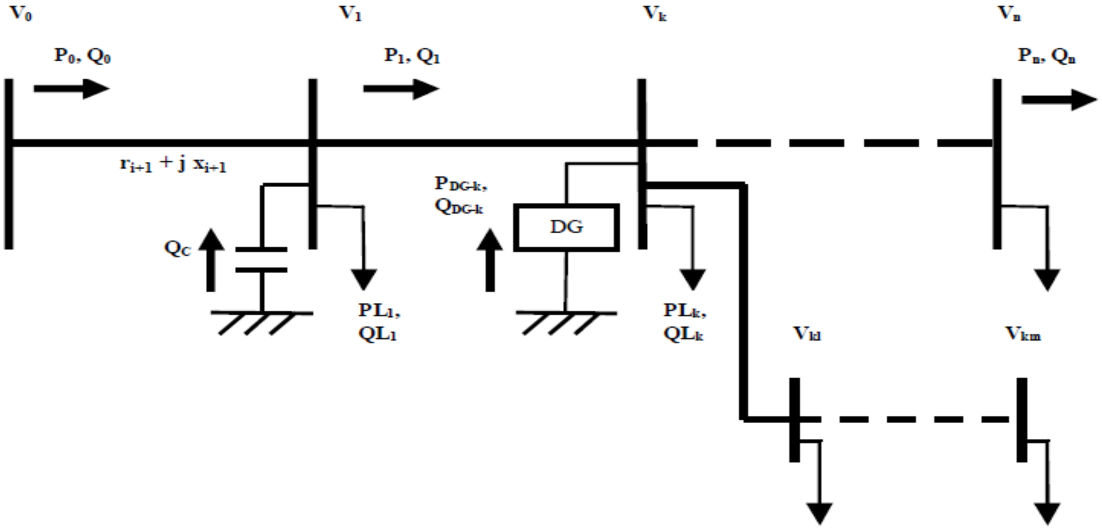


Figure 4.1 Radial distribution feeder model including DG and Capacitor

The power flow can be represented by the expressions given below [77]:

$$P_{i+1} = P_i - \frac{r_{i+1}(P_i^2+Q_i^2)}{V_i^2} - P_{L_{i+1}} + \mu_P A P_{i+1} \tag{4.1}$$

$$Q_{i+1} = Q_i - \frac{x_{i+1}(P_i^2+Q_i^2)}{V_i^2} - Q_{L_{i+1}} + \mu_q A Q_{i+1} \tag{4.2}$$

$$V_{i+1}^2 = V_i^2 - 2(r_{i+1}P_i + x_{i+1}Q_i) + (r_{i+1}^2 + x_{i+1}^2) \times (P_i^2 + Q_i^2)/V_i^2 \tag{4.3}$$

While solving the above equations, the conditions to be satisfied are as follows:

1) At the end of the main feeder, laterals and sub laterals

$$P_n = Q_n = 0$$

$$P_{km} = Q_{km} = 0$$

2) The voltage at bus *k* is the same voltage of its lateral

$$V_k = V_{k0}$$

The real and reactive power losses of each section connecting two buses are:

$$P_{Loss_{i+1}} = ((P_i^2 + Q_i^2)/V_i^2)r_{i+1} \tag{4.4}$$

$$Q_{Loss_{i+1}} = ((P_i^2 + Q_i^2)/V_i^2)x_{i+1} \tag{4.5}$$

4.2.2 Algorithm for Distribution Power Flow Solution

The power flow solution considering laterals and sublaterals with distributed generation and capacitors has been developed in literature [77]. In this approach reported the feeders are classified into two types:

(a) *Power Flow Solution for Single Line Feeders*

The procedure for power flow analysis with the expressions listed in previous section is as below:

Step 1: The feeder parameters are taken as input data.

Step 2: The sum of active and reactive power loads for all buses is computed along with the sum of all resistances and inductive reactances of each section connecting two buses.

Step 3: The sending end real power, reactive power and voltage is assumed as

$$P_0 = \sum_{i=0}^{n} P_{L_{i+1}} + P_{factor} \tag{4.6}$$

$$Q_0 = \sum_{i=0}^{n} Q_{L_{i+1}} + Q_{factor} \quad \text{--(4.7)}$$

$$V_0 = 1 + j0, p.u. \quad \text{--(4.8)}$$

where,

$$P_{factor} = \frac{\frac{\left(\left(\sum_{i=0}^{n} P_{L_{i+1}}\right)^2 + \left(\sum_{i=0}^{n} Q_{L_{i+1}}\right)^2\right) \sum_{i=0}^{n} r_{i+1}}{V_0^2}}{n-1} \quad \text{----------------------(4.9)}$$

$$Q_{factor} = \frac{\frac{\left(\left(\sum_{i=0}^{n} P_{L_{i+1}}\right)^2 + \left(\sum_{i=0}^{n} Q_{L_{i+1}}\right)^2\right) \sum_{i=0}^{n} x_{i+1}}{V_0^2}}{n-1} \quad \text{--------------------(4.10)}$$

In a practical system, every system is having loss and more than two buses will exist in any network, the approximation factors will be helpful in reducing number of iterations. The losses computed will be closer to the actual values. Hence the values P_O & Q_O computed in equations 4.6 and 4.7 are used in the initial iteration.

Step 4: Power flow equations 4.1 to 4.3 are applied for the feeder.

Step5: If the absolute values of Pn and Qn of the last bus are within desired tolerance, then the power flow solution is said to be converged, else go to next step 6 is executed.

Step 6: For the first bus in the main feeder the power values are updated as:

$$P_{0,new} = P_{0,old} - P_n \quad \text{---------------------------------------(4.11)}$$

$$Q_{0,new} = Q_{0,old} - Q_n \quad \text{---------------------------------------(4.12)}$$

Afterwards, these updates values become initial values and procedure is repeated from step 4 till convergence is reached.

(b) *Power Flow Solution for Laterals and Sub lateral Feeders*

The process for network with laterals and sublateral feeders is enumerated below:

Step 1: The parameters of main, laterals and sublaterals are taken as input data.

Step 2: The sum of real and reactive power loads on sub laterals are represented as loads on corresponding laterals. Similarly sum of real and reactive power loads on laterals are represented as loads on pertaining main feeder.

Step 3: The procedure for power flow solution for main feeder as discussed earlier is carried out.

Step 4: The farthest bus with lateral is considered and the bus voltage computed in step 3 is used for performing power flow for laterals in same manner as described for main feeder.

Step 5: The same procedure as step 4 is adopted for sublaterals also.

Step 6: The total real and reactive power injected into the sub lateral is determined and represented as a load on its lateral.

Step 7: The power flow solution on the lateral is carried out once more. In case of existence of another sublateral, the steps 5 and 6 are executed. If not, step 8 is performed.

Step 8: From the results of most recent power flow solution, the total real and reactive power injected into the lateral is computed and represented on the main feeder.

Step 9: The power flow solution is found for the main feeder. If there are more than one lateral in the system, step 4 is executed again else step 10 is carried out

Step 10: The power flow solutions are arrived for laterals and sublaterals with the bus voltages computed in step 9. After this step, power flow solution will be completed.

4.2.3 Advantages of Fast Power Flow Solutions for multiple DG Scenario

In the power flow solution technique reported in previous sections, the approximation formulas help to reduce the number of iterations, hence more suitable to solve complex network. Another advantage is the computation time required for solution convergence is also less [77]. The analysis involving multiple DGs is very much intensive. In this context, the reported technique is very much suitable for solving distribution network with multiple distributed generation sources effectively. Therefore this method of power flow solution is employed in this work for recommendations of strategies for DG locations and capacities.

4.3 Genetic Algorithm Application to Multiple DG Selection

The problem of multiple DG insertion to distribution system is a combinatorial optimization problem. The solution methodologies involve large amount of computations and hence methods to reduce the search space have to be adopted. Genetic Algorithms are one such technique which can be employed to address this problem effectively. In this section, brief account of relevance of genetic algorithm for multiple DG selection in distribution system is presented. Because of the combinatorial nature of the problem and of the discreteness of the objective function, this optimisation process involves a large amount of calculations and a large computation time when using traditional approaches. For this reason, genetic algorithms (GA) have been adopted in order to overcome some limits of traditional procedures. GAs are able to reach a good solution (with very high probability to be the best one) by a finite number of evolution steps performed on a finite set of possible solutions [52].

Genetic Algorithm is a general-purpose search techniques based on principles inspired from the genetic and evolution mechanisms observed in natural systems and populations of living beings. Their basic principle is the maintenance of a population of solutions to a problem (genotypes) as encoded information individuals that evolve in time. Generally, GA comprises three different phases of search:

Phase 1: creating an initial population;

Phase 2: evaluating a fitness function;
Phase 3: producing a new population.

A genetic search starts with a randomly generated initial population within which each individual is evaluated by means of a fitness function. Individual in this and subsequent generations are duplicated or eliminated according to their fitness values. Further generations are created by applying GA operators. This eventually leads to a generation of high performing individuals. There are usually three operators in a typical genetic algorithm: the first is the production operator (elitism) which makes one or more copies of any individual that posses a high fitness value; otherwise, the individual is eliminated from the solution pool; the second operator is the recombination (also known as the ' crossover') operator. This operator selects two individuals within the generation and a crossover site and carries out a swapping operation of the string bits to the right hand side of the crossover site of both individuals. Crossover operations synthesize bits of knowledge gained from both parents exhibiting better than average performance. Thus, the probability of a better offspring is greatly enhanced; the third operator is the 'mutation' operator. This operator acts as a background operator and is used to explore some of the invested points in the search space by randomly flipping a 'bit' in a population of strings. Since frequent application of this operator would lead to a completely random search, a very low probability is usually assigned to its activation.

4.3.1 Merits of Genetic Algorithm

A GA has a number of advantages. It can quickly scan a vast solution set. Bad proposals do not affect the end solution negatively as they are simply discarded. The inductive nature of the GA means that it doesn't have to know any rules of the problem - it works by its own internal rules. This is very useful for complex problems like solving distribution network with multiple DG sources . The greatest advantage of GAs is the fact that they find a solution through evolution [82-83].

Hence in this work genetic algorithm is employed in search of DG locations for multiple DG sources insertion based on system planning policy. A new performance index termed as Network Performance Enhancement Index (NPEI) is used as the fitness function for genetic algorithm. The NPEI plays an important role in capacity allocation of distribution generation sources.

4.4 Network Performance Enhancement Index (NPEI)

In order to calculate the proposed Network Performance Enhancement Index by relating the different technical issues, relevance (weighting) factors are presented in this section. Several indices based on technical parameters as reported in earlier literature [78]. These indices are employed in this work with suitable combinations in arriving at the proposed index NPEI. The indices considered in computing NPEI are described below:

4.4.1 Real power loss index ($\mathrm{IL_{P}}$)

Real power loss index ($\mathrm{IL_P}$)

$$\mathrm{IL_P^K} = 1 - \frac{\mathrm{Re\{Losses^k\}}}{\mathrm{Re\{Losses^0\}}} \text{ ---(4.13)}$$

where $\mathrm{Losses^k}$ are the total complex power losses for the *k* th distribution network configuration, $\mathrm{Losses^0}$ and is the total complex power losses for the distribution network without DG. A beneficial DG location should decrease the total network losses, which means near unity values for $\mathrm{IL_{P.}}$

4.4.2 Reactive power loss index ($\mathrm{IL_Q}$)

$$\mathrm{IL_Q^K} = 1 - \frac{\mathrm{Im\{Losses^k\}}}{\mathrm{Im\{Losses^0\}}} \text{ ---(4.14)}$$

where $\mathrm{Losses^k}$ are the total complex power losses for the *k* th distribution network configuration, $\mathrm{Losses^0}$ and is the total complex power losses for the distribution network without DG. A beneficial DG location should decrease the total network losses, which means near unity values for $\mathrm{IL_{Q.}}$

4.4.3 Voltage profile improvement Index (IVD)

$$\mathrm{IVD}^{\mathrm{K}} = 1 - \mathrm{Max}\left(\left|\mathrm{V}_{\emptyset_0}\right| - \left|\mathrm{V}_{\emptyset_\mathrm{i}}{}^{\mathrm{K}}\right| / \left|\mathrm{V}_{\emptyset_0}\right|\right)_{\mathrm{i}=1}^{\mathrm{NN}-1} \text{ ------------------------------(4.15)}$$

where $\emptyset$ are the phases a, b, c and; $\mathrm{V}_{\emptyset_0}$ are the voltages at the root node (equal in magnitude for the three phases); $\mathrm{V}_{\emptyset_\mathrm{i}}{}^{\mathrm{K}}$ are the voltages at node for the *k*th distribution network configuration; and NN is the number of nodes. This index could be also used to find prohibitive locations for DG considering pre established voltage drop limits. A DG configuration that presents the largest improvement will receive an IVD equal to unity.

4.4.4 Voltage regulation index (IVR)

$$\mathrm{IVR}^{\mathrm{K}} = 1 - \frac{\sum_{\mathrm{i}=1}^{\mathrm{NN}-1} \mathrm{Max}\left(\left\|\frac{\left(\left|\mathrm{V}_{\emptyset_\mathrm{i}}{}^{\mathrm{k}}\right| - \left|\mathrm{V}_{\emptyset_\mathrm{i}}{}^{\mathrm{Kmin}}\right|\right)}{\left|\mathrm{V}_{\emptyset_\mathrm{i}}{}^{\mathrm{Kmin}}\right|}\right\|\right)}{\mathrm{NN}-1} \text{ -------------------------------(4.16)}$$

where $\mathrm{V}_{\emptyset_\mathrm{i}}{}^{\mathrm{Kmin}}$ are voltages at node i, for the *k*th distribution network configuration considering minimum demand. Minimum demand level considered is 10% of the maximum. Loads were modeled as constant power. This index shows the difference between nodal voltages during maximum and minimum demand. It is desirable to have this variation as small as possible (i.e., close to unity values for index IVR)

4.4.5 Voltage stability index (VSI)

The Voltage Stability Index indicates the healthy status of the system [5]. Hence this index is included for performance analysis and computation of proposed comprehensive index NPEI. The mathematical aspects of voltage stability index is given in Appendix – B.

$$L_j = \frac{4\left[\left(XP_j - RQ_j\right)^2 + \left(XQ_j + RP_j\right)V_i^2\right]}{V_i^4} \text{ -- (4.17)}$$

$\mathrm{VSI}_\mathrm{K} = \max \{L_1, L_2, \ldots\ldots\ldots\ldots L_{n-1}\}$ -- (4.18) where, VSI_k is the voltage stability index of the k^{th} configuration of distribution network with DG. X and R are the reactance and resistance value respectively. The critical value for voltage stability index is 1.

4.4.6 Computation of NPEI

The proposed index NPEI is given by

$$NPEI^k = \left\{w_1 \mathrm{IL}_\mathrm{P}^\mathrm{K} + w_2 \mathrm{IL}_\mathrm{Q}^\mathrm{K} + w_3 \mathrm{IVD}^\mathrm{K} + w_4 \mathrm{IVR}^\mathrm{K} + \mathrm{w5VSI}^\mathrm{K}\right\} \text{-------------}(4.19)$$

Where w_i is the weightage factor such that,

$$\sum_{i=1}^{4} w_i = 1.0 \wedge w_i \in [0,1\ ]$$

These weightage factors are intended to give the corresponding importance to each technical issue (impact indices) due to the presence of DG. Close to unity values for the Network Performance Enhancement Index means higher benefits due to DG insertion.

As reported in [78], the objectives of system design and operation vary from one network to another network. Hence the expertise of the practicing professionals in the area of distribution systems is the basis for selecting the weighting factors. Also different utilities have varied principles of design and operation. Hence these factors need to be flexible in adopting to such a situation. Also the best interest of DG operator has to be protected in the process of deciding the weighting factors.

Generally the active power loss reduction is the major concern and hence it will be attached with higher weightage. Accordingly the other parameters are attached with suitable weightage factors depending on the designer's choice. For this purpose, the guideline reported in [78] is adopted in this work.

4.5 Economical Aspects of DG Insertion

Distributed generation has several economic advantages over power from the grid, particularly for on-site power production:

- On-site production avoids transmission and distribution costs, which otherwise amount to about 30% of the cost of delivered electricity.

- Onsite power production by fossil fuels generates waste heat that can be used by the customer.
- Distributed generation may also be better positioned to use inexpensive fuels such as landfill gas.

The relative price of retail electricity compared with fuel costs is critical to the competitiveness of any distributed-generation option. This ratio varies greatly from country to country and largely dependent on availability of resources. Many DG technologies can be very flexible in their operation, size, and expandability. A distributed generation plant can operate during periods of high electricity prices (peak periods) and then switch off during periods of low prices. The ease of installation of DG allows capacity to be expanded readily to take advantage of anticipated high prices. The DG technologies which are potentially superior are given below:

- Photovoltaic Systems
- Wind Power Generation
- Fuel Cells

The economics for integrated operation of utility and DG sources depend on several factors listed below [10]:

- Utility structure and system characteristics
- Regulation and legislation
- Location and ownership of DG

4.5.1 Pricing and Location of DG sources

From the point of view of the electricity network, however, distributed generation offers maximum economic efficiency gains because of its flexibility in location. A distributed generator brings value to a distribution system insofar as its location defers expansion of distribution assets, reduces distribution-system losses, or delivers network support or ancillary services. Location-based pricing for distributed generation falls into three categories:

- Connection Charges
- Energy Charges

- Congestion related pricing

In this work the economics of DG source insertion is accounted as Operational Costs of DG sources which is the price agreed between the utility and DG operator considering all aspects involving cost of generation and distribution. It is evident that different DG technologies have different operational costs. Hence recommendation of appropriate technology for various locations selected for DG source insertion is the key aspect from overall savings achievable in network operation.

4.6 Trade off between NPEI and Economics

As discussed in the earlier sections, the proposed index NPEI suggests the locations for DGs based on improvement of technical parameters. However those locations may not be the best suited from cost of operation. Hence in this work the alternative locations which have better savings in operational costs are also recommended. This approach provides flexibility to the network designer to execute trade-off between technical and economical criteria to finalization of DG locations and their capacities.

4.7 Load Variation in Distribution System

The load on the distribution system will be varying depending on the following factors:

- Customer factors: type of consumption, type of electric heating, size of building, electric appliances, number of employees, etc.
- Time factors: time of day, day of week and time of year.
- Climate factors: temperature, humidity, solar radiation, etc.

To account for the load variation on the distribution network, a daily load curve pattern is considered in this work. To meet such varying load demand, the optimal generation from the different DG sources inserted into the network is computed with the help of proposed index NPEI.

4.8 Developed Methodology for Multiple DG Insertion

The power flow technique discussed in earlier section is used for solving the power flow for radial distribution feeders taking into account embedded distribution generation sources. This power flow results are used in calculating the fitness function Values in Genetic Algorithm to suggest the best locations for Multiple DGs. The Network Performance Enhancement Index is used as the fitness function for Genetic algorithm. The Capacity of DGs to be connected in such recommended locations are chosen from market available ratings. The combination of DG capacities which gives highest NPEI is the top priority choice. However due to geographical, social constraints, it may not be possible to implement the best solution. Hence a priority list is prepared to enable the designer to go for the most feasible solution.

4.8.1 Algorithm for Multiple DG Allocation

The following Algorithm is developed with the help of Power flow solution algorithm and Genetic algorithm and is used to get the appropriate results. The developed algorithm is as follows:

Step 1: First read the network data which include the loads connected to the different nodes and the resistances and reactance's between the nodes.

Step 2: Run the power flow algorithm to obtain the base case, i.e. without DGs.

Step 3: Now read the market available DG capacities to be inserted in the system.

Step 4: Generate the bus numbers where the DGs need to be inserted using genetic algorithm.

Step 5: Again run the power flow for the system with DGs inserted in the obtained bus locations.

Step 6: Calculate the Network Performance Enhancement Index (NPEI).

Step 7: Repeat step 5 & 6 for all combinations of GA population. NPEI acts as the fitness function for GA. The objective is to maximise the value of NPEI.

Step 8: Best five combinations having the highest values for NPEI are sorted out by iterating.

Step 9: For every best result, increase the capacity of the DG with a fixed % of their individual capacities and do the same for the maximum number of iterations. Since DG sources are functioning as supplement to utility, and the limited power generating potential, the constraint on power generation is put as upper limit of DG capacity will be 20% and 15% of the total load at every node for cases of insertion of 3 number of DG sources and 5 number of DG Sources respectively.

This algorithm can be run with different capacities of DGs and the results can be compared. The best combination will be having the highest value of NPEI which indicates that the value of real and reactive power loss will be the least. Also the voltage profile will be improved. The priority list is prepared with first five best combinations which are sorted out in descending order of NPEI value .

4.8.2 Economic Analysis

In order to get the best combination along with the economic benefits a detailed cost analysis of operating cost from utility and DG sources is done. The Utility Penalty factors may be included based on availability of data. As different DG technologies located at various locations are having different operating costs, the combination of such operating costs is considered in this analysis

When DGs are inserted into the system the load is supplied partly by the DG and the rest is met from the grid. So the total cost will be the cost of the utility power drawn and the power from the DG. Then the savings obtained is computed by comparing it with the base case, i.e. without DG. Thus the savings are computed for the first five best combinations and sorted out in descending order.

The Design engineer can analyse the best technical solution based on NPEI and best economical solution based on cost analysis. Then he can exercise trade-off between the two approaches while finalising the scheme for multiple DG insertion to distribution system. The flow chart for computing NPEI is given in Figure 4.2. The flow chart for calculation of cost savings is given in Figure 4.3. The flow chart for trade-off between technical choice and economical choice is given in Figure 4.4.

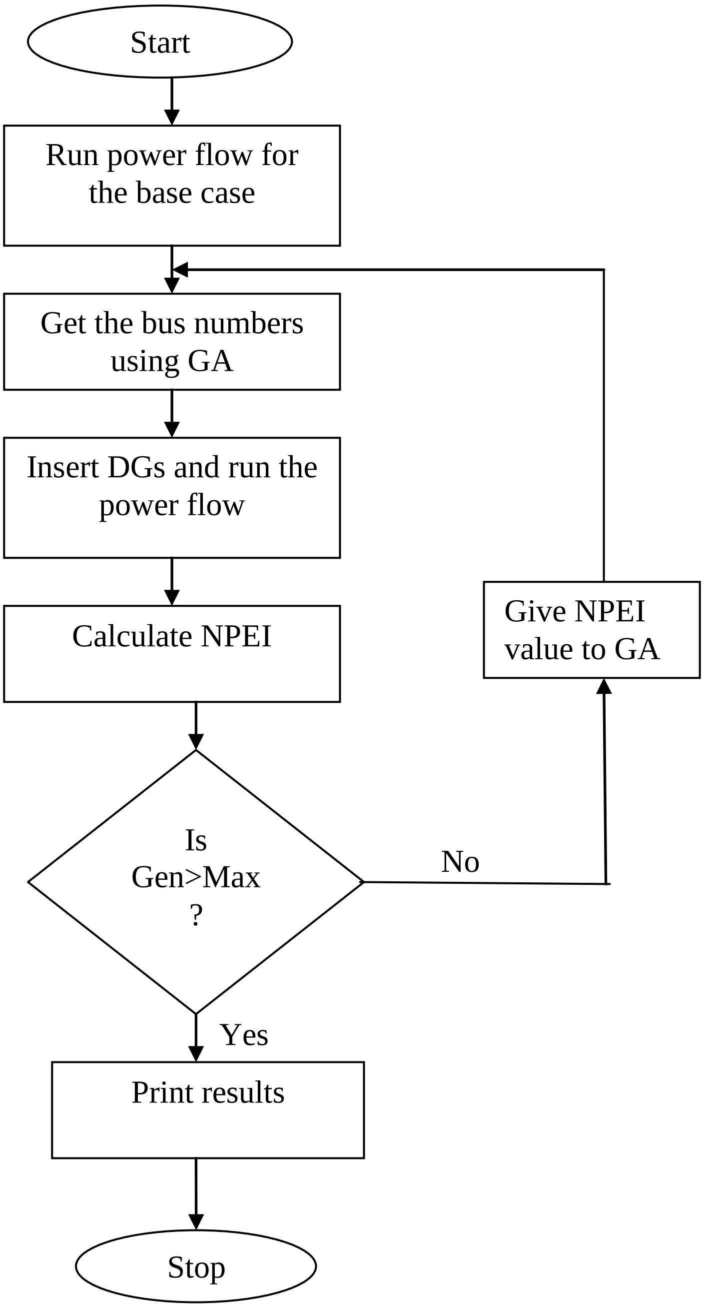


Figure 4.2. Flow Chart for Computation of NPEI

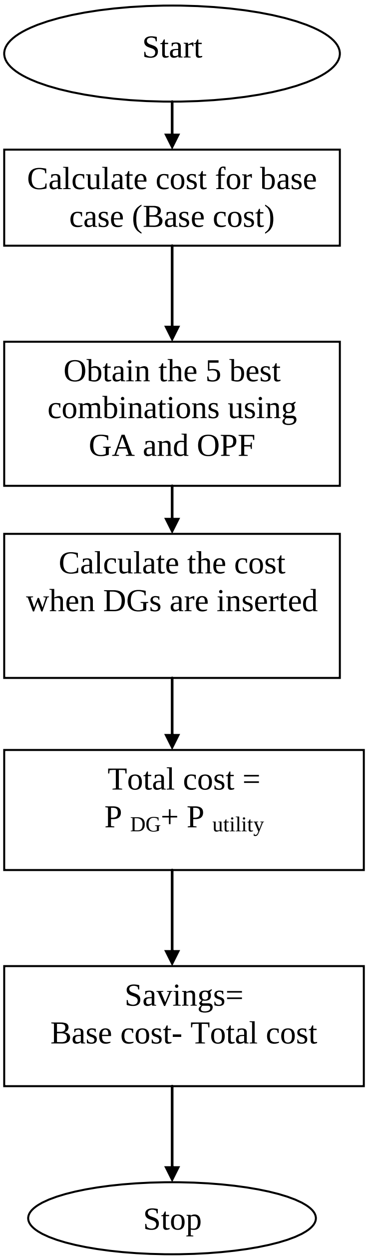


Figure 4.3 Flow chart for Computation of Savings

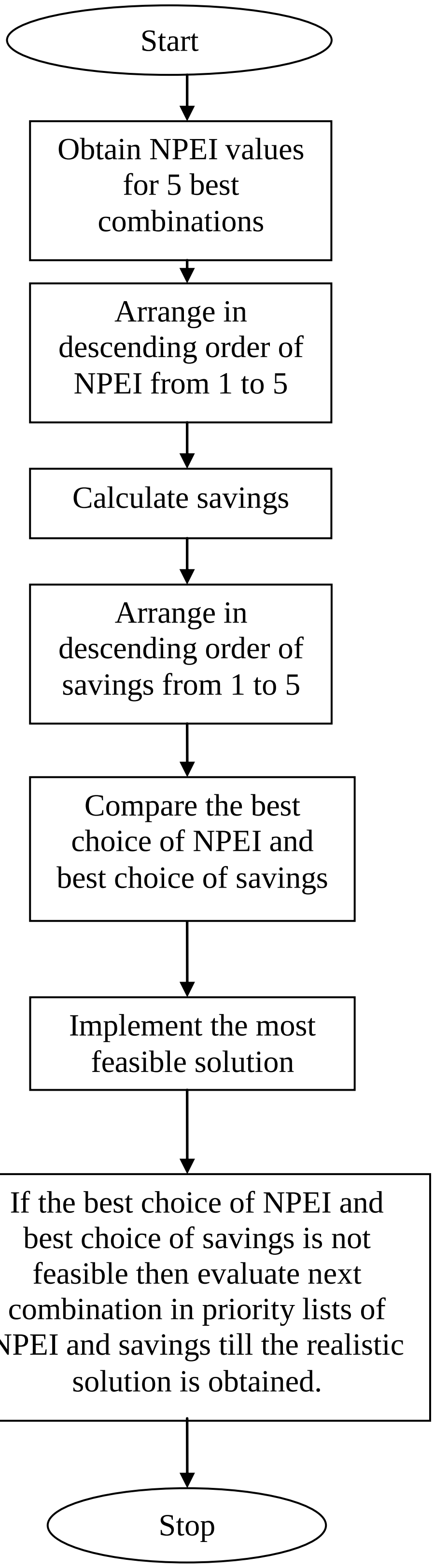


Figure 4.4 Flow chart for Trade-off Between NPEI and Economics

4.9 Case Studies and Results

The proposed algorithm is developed in the MATLAB environment. The algorithm is tested on three systems namely 33 bus, 69 bus and 90 bus systems reported in literature [67][37][5]. In each system the algorithm is run for both insertion of 3 number of DG sources and 5 number of DG sources. Economic analysis is also done by calculating the savings obtained. Also the voltage plots for the best combinations are obtained. The load usually varies in an hourly basis which is also taken into account for the analysis. In this case a particular load curve is taken into consideration and analysis is done. The load curve is considered as same for all the three systems, 33 bus, 69 bus and 90 bus. When the total DG capacity is less compared to the load then power is taken from the grid and the DG is used at its rated value. When the total DG capacity is more than the load at a particular instant then the entire load is met by the DG alone. No power will be taken from the grid. Then considering trade-off between NPEI and the savings obtained, the best combination can be selected. The Figure 4.5 gives load pattern considered for analysis. Table 4.1 lists the percentage of load in particular duration of a day.

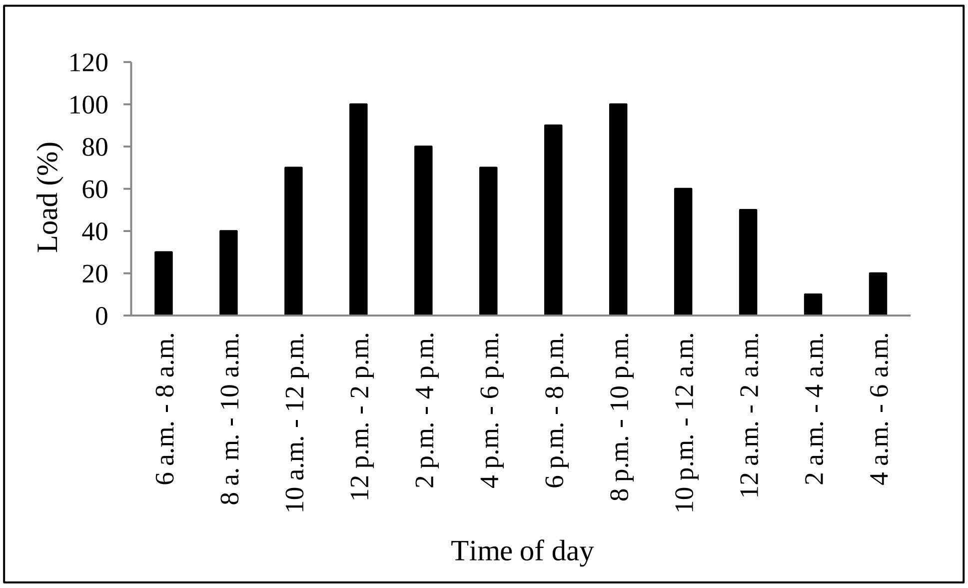


Figure 4.5. Load Curve Pattern

Table 4.1 Load Demand Variation

Time of day	Load (%)
6 a.m. - 8 a.m.	30
8 a. m. - 10 a.m.	40
10 a.m. - 12 p.m.	70
12 p.m. - 2 p.m.	100
2 p.m. - 4 p.m.	80
4 p.m. - 6 p.m.	70
6 p.m. - 8 p.m.	90
8 p.m. - 10 p.m.	100
10 p.m. - 12 a.m.	60
12 a.m. - 2 a.m.	50
2 a.m. - 4 a.m.	10
4 a.m. - 6 a.m.	20

4.9.1 33 Bus System

The first test system contains 33 buses and 32 branches. It is a radial system with the total load of 3.72 MW and 2.3 MVAR [67]. Three different cases are considered wherein the total DG capacities are 1 MW, 2 MW and 3 MW. The designer can choose capacities based on potential and appropriate short circuit level. Then economic analysis is also done to find out the best combination and the voltage plot for that particular combination is obtained. The single line diagram is as shown in Figure 4.6:

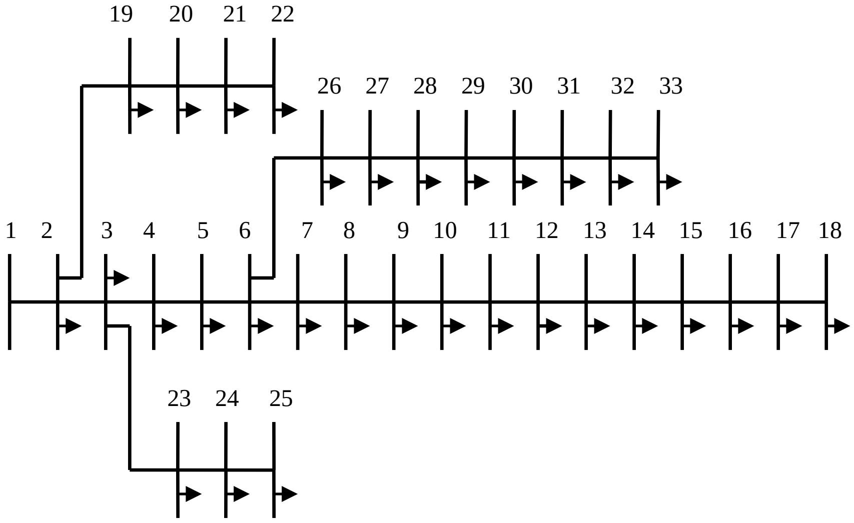


Figure 4.6 33 Bus Test System

The selection of weightage factors for calculating NPEI are flexible and essentially depends on the designer's choice. Following the guideline presented in reported literature [78], the weightage factors are considered in this work are given below:

Table 4.2 Weightage Factors for Computation of NPEI

IL_P W_1	**IL_Q** W_2	**IVD** W_3	**IVR** W_4	**VSI** W5
0.33	0.10	0.15	0.10	0.32

The results obtained are tabulated below. First the base case values are obtained. Then first five best combinations are sorted out in order of NPEI values. Then for the same combinations economic analysis is done. While doing economical analysis, the operating cost of utility is considered as Indian Rupees (Rs.) 4 per hour, and DG sources with different technologies and corresponding operating costs as Indian Rupees 1, 1.5 and 2 per hour and the network planner can exercise trade-off subsequently.

Table 4.3 Results of Base Case without DG sources

Base Case

P_{load} (MW)	Q_{load} (MVar)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)	P_{loss} (MW)	Q_{loss} (MVar)	Cost (Rs/hr)
3.715	2.3	3.916355	2.437342	0.201355	0.137342	15665.42

Table 4.4 Priority List with DG sources with decreasing order of NPEI

With DG : 3 DG

Total DG Size = 1 MW : (In the decreasing order of NPEI)

P_{DG} total (MW)	DG Sizes (MW)	Bus No	NPEI	P_{loss} (MW)	Q_{loss} (MW)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)
1	0.375	15	0.4704475	0.08796	0.06074	2.80296	2.36074
	0.375	32					
	0.250	30					
1	0.125	17	0.4702946	0.08809	0.06075	2.80309	2.36075
	0.250	15					
	0.625	31					
1	0.125	29	0.4701488	0.08811	0.06084	2.80311	2.36084
	0.500	32					
	0.375	16					
1	0.250	17	0.4694849	0.08870	0.06207	2.80370	2.36207
	0.250	30					
	0.500	32					
1	0.125	15	0.4676611	0.08940	0.06273	2.80440	2.36273
	0.125	17					
	0.750	31					

Table 4.5 Priority List with DG sources with decreasing order of Savings

With DG : 3 DG case

Total DG size = 1 MW : (in the decreasing order of savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	1	0.375	15	1437.5	11211.84	3016.1	1
		0.375	32				
		0.250	30				
2	1	0.125	29	1625.0	11212.44	2828.0	3
		0.500	32				
		0.375	16				
3	1	0.250	17	1625.0	11214.80	2825.6	4
		0.250	30				
		0.500	32				
4	1	0.125	17	1750.0	11212.36	2703.1	2
		0.250	15				
		0.625	31				
5	1	0.125	15	1812.5	11217.60	2635.3	5
		0.125	17				
		0.750	31				

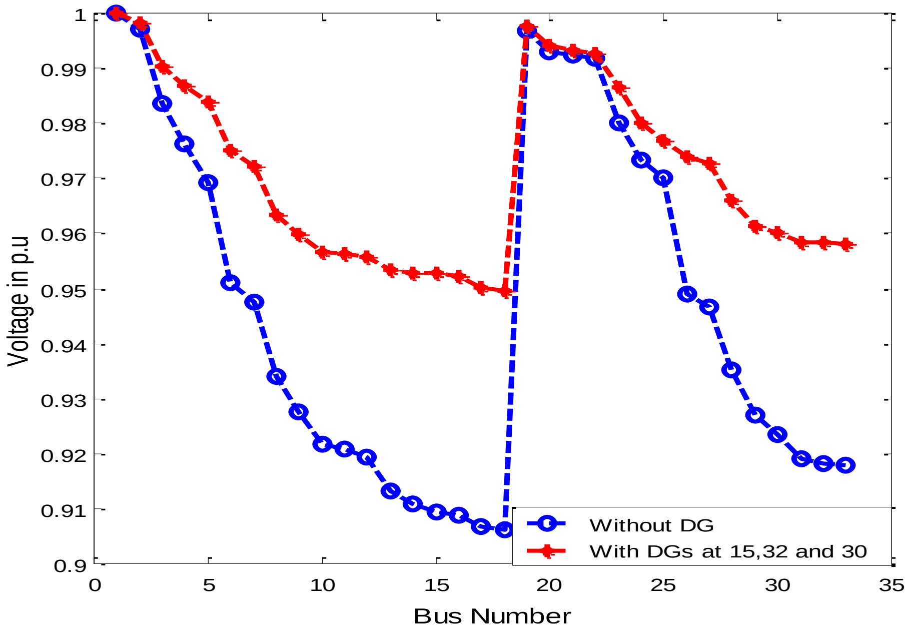


Figure 4.7 Voltage plot with DGs at 15, 32 and 30

4.9.2 Discussions on the Analysis for 3 Numbers of DGs with Total Size of 1 MW.

From the above table with decreasing order of NPEI, it can be seen that a priority list of combination of buses have been formed with decreasing values of NPEI. The group of buses having highest value of NPEI is the best choice. However, due to geographical, social and environmental constraints, it may not be feasible to implement this best choice. Hence the designer is having flexibility to opt for next group in the table which is the next best solution with slightly lower value of NPEI. Like this five alternatives have been recommended to form the priority list.

Similarly priority list from the point of savings in operating cost has been prepared. This table also comprises of five best alternatives. In case of constraints on economics, the first combination of buses in this table can be selected. Here also the flexibility exists to choose any of the five alternatives depending on feasibility of implementation.

Since both good technical performance and savings of operating cost are important, there exists scope for trade-off between NPEI and economics. From Table 4.4 and 4.5 it can be seen that bus numbers 15, 32 and 30 with capacities of 0.375 MW, 0.375 MW and 0.250 MW are the best choice from both technical and economical perspective. However if it is not possible to install DG source in any of these three buses due to constraints on geographical, social and environmental constraints, then next alternative has to be searched. As given in Table 4.4, the group of buses 17, 15 and 31 stands second in NPEI priority list, but they occupy fourth priority from economic point of view. From the Table 4.5, the second best combination from economic perspective is 29, 32 and 16. In this context the system operators have to perform trade off and decide upon their objective of improvement in technical performance or achieving maximum possible savings in operating cost.

Hence the proposed approach incorporates all possibilities encountered in decision making process and gives high flexibility for the designer to implement most feasible solution from the recommended priority list. To reflect more possibilities, the analysis is further carried out with 3 Numbers of DG sources with higher total capacity DGs of 2 MW and 3 MW and also 5 numbers of DG sources to facilitate insertion of more numbers of micro- DGs into the system and presented below:

With DG : 3 DG case

Total DG size = 2 MW : (in the decreasing order of NPEI)

P_{DG} total (MW)	DG Sizes (MW)	Bus No	NPEI	P_{loss} (MW)	Q_{loss} (MW)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)
2	0.750	25	0.5197097	0.06647	0.04694	1.78146	2.34694
	0.750	31					
	0.500	15					
2	0.500	32	0.5101088	0.07147	0.05028	1.78647	2.35027
	0.500	15					
	1.000	24					
2	0.250	17	0.5016535	0.07497	0.05387	1.78997	2.35387
	1.000	24					
	0.750	32					
2	0.250	25	0.4918172	0.07857	0.05452	1.79356	2.35452
	0.500	32					
	1.250	10					
2	0.250	17	0.4709327	0.08765	0.06174	1.80264	2.36173
	0.250	32					
	1.500	7					

With DG : 3 DG case

Total DG size = 2 MW: (in the decreasing order of savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	2	0.750	25	2875.0	7125.84	5664.6	1
		0.750	31				
		0.500	15				
2	2	0.500	32	3250.0	7145.88	5269.5	2
		0.500	15				
		1.000	24				
3	2	0.250	17	3250.0	7159.88	5255.5	3
		1.000	24				
		0.750	32				
4	2	0.250	25	3500.0	7174.24	4991.2	4
		0.500	32				
		1.250	10				
5	2	0.250	17	3625.0	7210.56	4829.9	5
		0.250	32				
		1.500	7				

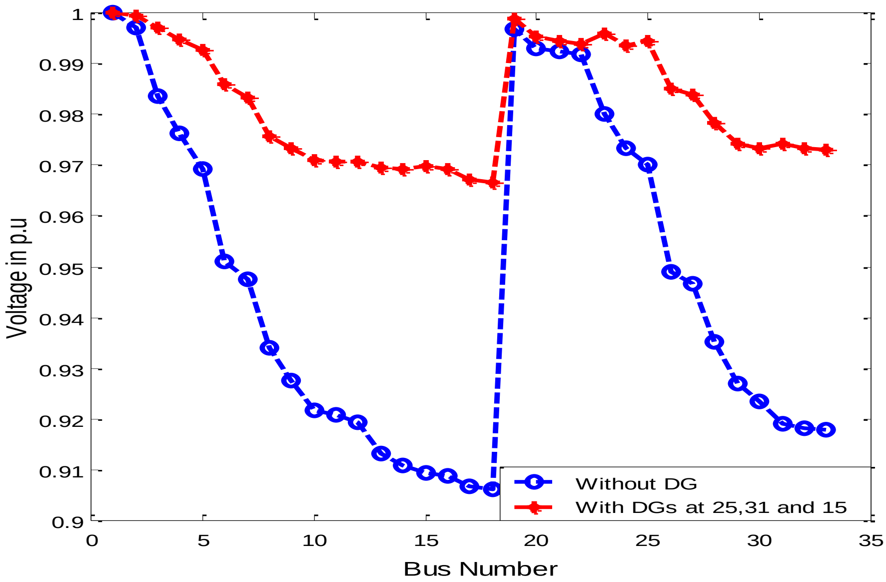


Figure 4.8 Voltage plot with DGs at 25, 31 and 15

With DG : 3 DG case

Total DG size = 3 MW : (in the decreasing order of NPEI)

P_{DG} total (MW)	DG Sizes (MW)	Bus No	NPEI	P_{loss} (MW)	Q_{loss} (MW)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)
3	0.750	14	0.5027690	0.07397	0.05209	0.78896	2.35208
	0.750	32					
	1.500	3					
3	0.375	16	0.4962622	0.07664	0.05467	0.79164	2.35467
	0.750	31					
	1.875	3					
3	1.125	11	0.4882350	0.08122	0.05660	0.79621	2.35660
	1.125	3					
	0.750	31					
3	0.375	15	0.4851649	0.08175	0.05856	0.79674	2.35855
	1.500	2					
	1.125	30					
3	0.375	25	0.4773007	0.08467	0.06101	0.79966	2.36100
	0.375	16					
	2.250	6					

With DG : 3 DG case

Total DG size = 3 MW: (in the decreasing order of savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	3	1.125	11	4312.5	3184.84	8168.1	3
		1.125	3				
		0.750	31				
2	3	0.750	14	4875.0	3155.84	7634.6	1
		0.750	32				
		1.500	3				
3	3	0.375	15	4875.0	3186.96	7603.4	4
		1.500	2				
		1.125	30				
4	3	0.375	16	5250.0	3166.56	7248.8	2
		0.750	31				
		1.875	3				
5	3	0.375	25	5437.5	3198.64	7029.3	5
		0.375	16				
		2.250	6				

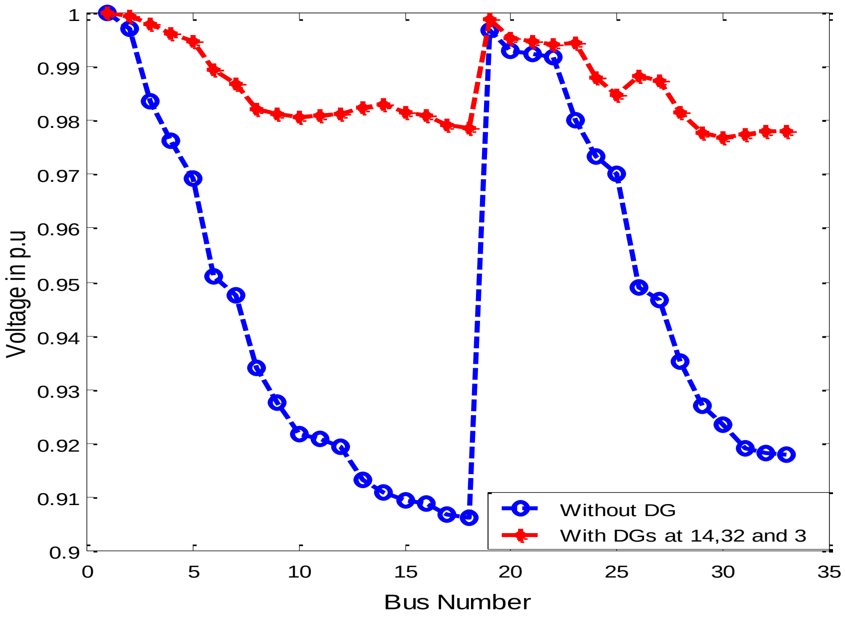


Figure 4.9 Voltage plot with DGs at 14, 32 and 3

With DG: 5 DG case

Total DG size: 1 MW: (in the decreasing order of NPEI)

P_{DG} total (MW)	DG Sizes (MW)	Bus No	NPEI	P_{loss} (MW)	Q_{loss} (MW)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)
1	0.4	32	0.47155	0.08773	0.06019	2.80272	2.36019
	0.2	30					
	0.2	16					
	0.1	18					
	0.1	14					
1	0.3	30	0.47141	0.08776	0.06092	2.80276	2.36092
	0.3	32					
	0.2	16					
	0.1	31					
	0.1	18					
1	0.2	14	0.47131	0.08781	0.06028	2.80281	2.36027
	0.2	17					
	0.2	30					
	0.2	33					
	0.2	32					
1	0.5	32	0.47121	0.08788	0.06033	2.80288	2.36033
	0.2	17					
	0.1	30					
	0.1	14					
	0.1	15					
1	0.3	15	0.47104	0.08792	0.06037	2.80292	2.36037
	0.4	31					
	0.1	33					
	0.1	30					
	0.1	17					

With DG : 5 DG case

Total DG size = 1 MW: (in the decreasing order of savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	1	0.5	32	1275.0	11211.52	3178.9	4
		0.2	17				
		0.1	30				
		0.1	14				
		0.1	15				
2	1	0.4	32	1325.0	11210.88	3129.5	1
		0.2	30				
		0.2	16				
		0.1	18				
		0.1	14				
3	1	0.3	15	1325.0	11211.68	3128.7	5
		0.4	31				
		0.1	33				
		0.1	30				
		0.1	17				
4	1	0.3	30	1350.0	11211.04	3104.4	2
		0.3	32				
		0.2	16				
		0.1	31				
		0.1	18				
5	1	0.2	14	1500.0	11211.24	2954.2	3
		0.2	17				
		0.2	30				
		0.2	33				
		0.2	32				

With DG: 5 DG case

Total DG size: 2 MW: (in the decreasing order of NPEI)

P_{DG} total (MW)	DG Sizes (MW)	Bus No	NPEI	P_{loss} (MW)	Q_{loss} (MW)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)
2	0.6	25	0.52580	0.06436	0.04487	1.77936	2.34487
	0.6	31					
	0.4	14					
	0.2	18					
	0.2	29					
2	0.4	29	0.52545	0.06520	0.04499	1.78020	2.34499
	0.4	32					
	0.4	25					
	0.4	10					
	0.4	16					
2	0.8	31	0.52418	0.06503	0.04551	1.78003	2.34550
	0.4	25					
	0.4	14					
	0.2	17					
	0.2	24					
2	0.6	12	0.52073	0.06719	0.04657	1.78218	2.34657
	0.8	31					
	0.2	17					
	0.2	25					
	0.2	24					
2	1.0	30	0.51522	0.06973	0.04886	1.78473	2.34885
	0.4	25					
	0.2	9					
	0.2	14					
	0.2	18					

With DG : 5 DG case

Total DG size = 2 MW: (in the decreasing order of savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	2	1.0	30	2550.0	7138.92	5976.5	5
		0.4	25				
		0.2	9				
		0.2	14				
		0.2	18				
2	2	0.8	31	2650.0	7120.12	5895.3	3
		0.4	25				
		0.4	14				
		0.2	17				
		0.2	24				
3	2	0.6	12	2650.0	7128.72	5886.7	4
		0.8	31				
		0.2	17				
		0.2	25				
		0.2	24				
4	2	0.6	25	2700.0	7117.44	5847.9	1
		0.6	31				
		0.4	14				
		0.2	18				
		0.2	29				
5	2	0.4	29	3000.0	7120.8	5544.6	2
		0.4	32				
		0.4	25				
		0.4	10				
		0.4	16				

With DG: 5 DG case

Total DG size: 3 MW: (in the decreasing order of NPEI)

P_{DG} total (MW)	DG Sizes (MW)	Bus No	NPEI	P_{loss} (MW)	Q_{loss} (MW)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)
3	0.6	2	0.52148	0.06688	0.04617	0.78187	2.34617
	0.6	8					
	0.6	25					
	0.6	14					
	0.6	32					
3	1.2	2	0.52034	0.06656	0.04651	0.78156	2.34650
	0.6	14					
	0.6	25					
	0.3	30					
	0.3	32					
3	0.9	13	0.51672	0.06788	0.04714	0.78288	2.34714
	0.9	2					
	0.6	31					
	0.3	24					
	0.3	25					
3	0.9	30	0.51579	0.06883	0.04838	0.78383	2.34837
	1.2	2					
	0.3	17					
	0.3	25					
	0.3	13					
3	1.5	3	0.51332	0.06973	0.04843	0.78472	2.34843
	0.6	31					
	0.3	13					
	0.3	18					
	0.3	25					

With DG: 5 DG case

Total DG size = 3 MW: (in the decreasing order of savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	3	1.5	3	3825.0	3138.88	8701.5	5
		0.6	31				
		0.3	13				
		0.3	18				
		0.3	25				
2	3	1.2	2	3975.0	3126.24	8564.2	2
		0.6	14				
		0.6	25				
		0.3	30				
		0.3	32				
3	3	0.9	30	3975.0	3135.32	8555.1	4
		1.2	2				
		0.3	17				
		0.3	25				
		0.3	13				
4	3	0.9	13	4050.0	3131.52	8483.9	3
		0.9	2				
		0.6	31				
		0.3	24				
		0.3	25				
5	3	0.6	2	4500.0	3127.48	8037.9	1
		0.6	8				
		0.6	25				
		0.6	14				
		0.6	32				

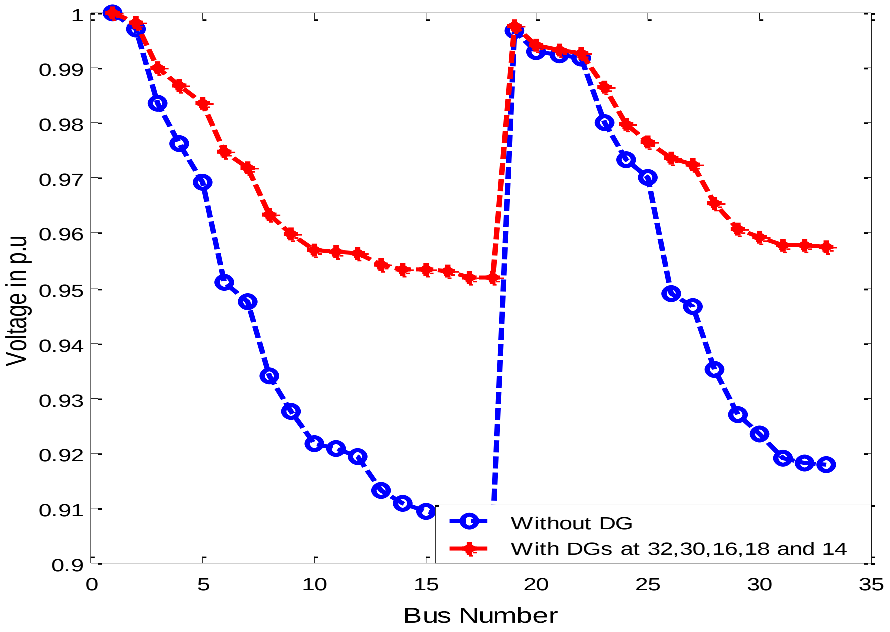


Figure 4.10 Voltage plot with DGs at 32, 30, 16, 18 and 14

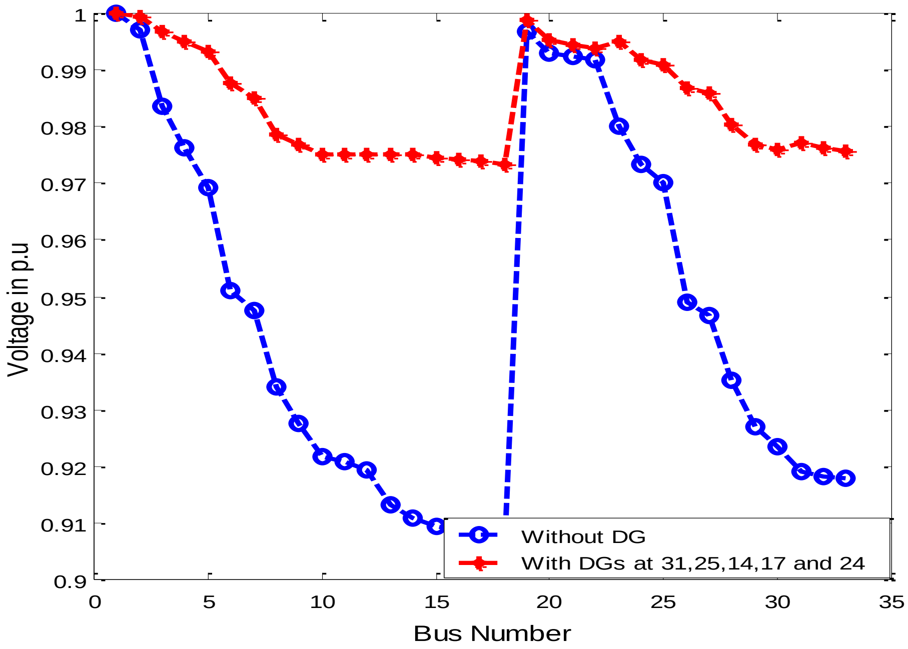


Figure 4.11 Voltage plot with DGs at 31, 25, 14, 17 and 24

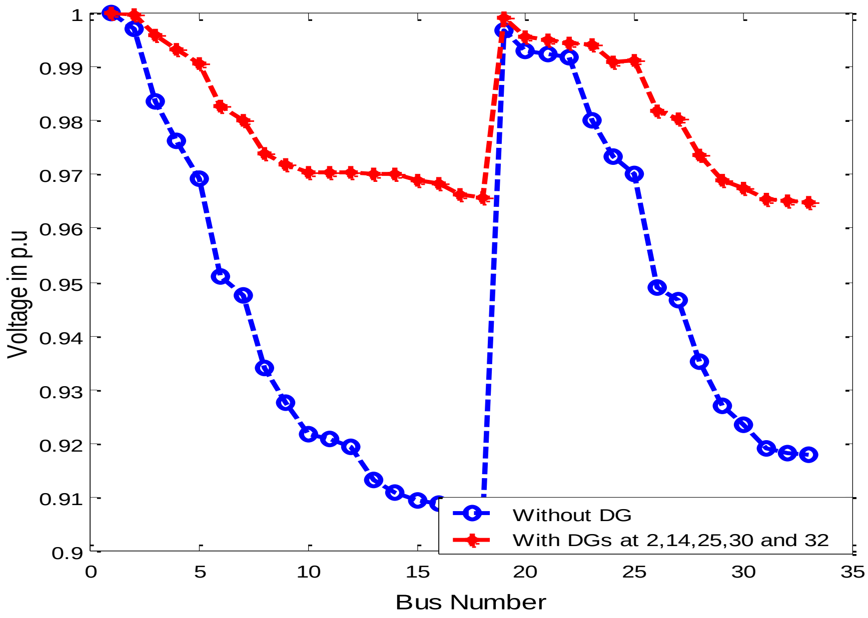


Figure 4.12 Voltage plot with DGs at 2, 14, 25, 30 and 32

4.9.3 Load variation

In 33 bus system when the total DG capacity is 1 MW, it can meet only 10% and 20% of the load. For 30% and more the total DG capacity is less compared to the total load. When the total DG capacity is 2 MW, it can meet 10%, 20%, 30%, 40% and 50% of the load. For 60% and more the total DG capacity is less compared to the total load. When the total DG capacity is 3 MW, it can meet 10%, 20%, 30%, 40%, 50%, 60%, 70% and 80% of the system load. For more than 90 % of system load, the total DG capacity is less compared to the total load. Between zero and the maximum capacity, the DG can be tuned to any capacity.

From the analysis carried out, it is observed that, during the time period wherein the overall system load is less such that it can be met with DGs installed locally, it is beneficial to meet the load from DG power and reduce the power supplied from utility. This decision helps to reduce the system losses and also results in savings in operation cost. However the necessary schemes to handle contingencies have to be taken care in implementation. The results of the analysis and savings in operating cost in Indian Ruppes (Rs.) per hour are tabulated below:

33 bus system: Total DG capacity = 1 MW (Bus no: 15, 32 and 30)

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am ($P_{load}> P_{DG}$)	30	1.115	0.375 0.375 0.250	0.50211	0.19132	2.35232	0.07683	0.05233	13462.6
8 am-10 am ($P_{load}> P_{DG}$)	40	1.486	0.375 0.375 0.250	0.50830	0.56001	2.35046	0.07402	0.05046	11987.9
10 am-12 ($P_{load}> P_{DG}$)	70	2.601	0.375 0.375 0.250	0.52226	1.66730	2.34587	0.06681	0.04587	7558.7
12 -2 pm ($P_{load}> P_{DG}$)	100	3.715	0.375 0.375 0.250	0.47045	2.80296	2.36074	0.08796	0.06074	3016.1
2 pm- 4 pm ($P_{load}> P_{DG}$)	80	2.972	0.375 0.375 0.250	0.51676	2.04039	2.34709	0.06839	0.04709	6066.3
4 pm- 6pm ($P_{load}> P_{DG}$)	70	2.601	0.375 0.375 0.250	0.52226	1.66730	2.34587	0.06681	0.04587	7558.7
6 pm-8 pm ($P_{load}> P_{DG}$)	90	3.344	0.375 0.375 0.250	0.50114	2.41803	2.35142	0.07453	0.05142	4555.8
8 pm-10 pm ($P_{load}> P_{DG}$)	100	3.715	0.375 0.375 0.250	0.47045	2.80296	2.36074	0.08796	0.06074	3016.1
10 pm- 12 ($P_{load}> P_{DG}$)	60	2.229	0.375 0.375 0.250	0.52062	1.29707	2.34660	0.06807	0.04660	9039.6
12- 2 am ($P_{load}> P_{DG}$)	50	1.858	0.375 0.375 0.250	0.51511	0.92833	2.34837	0.07084	0.04837	10514.6
2 am-4 am ($P_{load}< P_{DG}$)	10	0.372	0.140 0.140 0.092	0.53283	0.06182	2.34219	0.06232	0.04220	14884.1
4 am- 6 am ($P_{load}< P_{DG}$)	20	0.743	0.279 0.279 0.185	0.51756	0.06971	2.34736	0.06971	0.04736	14319.1

33 bus system: Total DG capacity = 2 MW (Bus no: 25, 31 and 15)

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am $(P_{load}<P_{DG})$	30	1.115	0.418 0.418 0.279	0.51645	0.06962	2.34717	0.07013	0.04717	13783.9
8 am-10 am $(P_{load}< P_{DG})$	40	1.486	0.557 0.557 0.372	0.50121	0.07720	2.35170	0.07720	0.05170	13220.1
10 am-12 $(P_{load}> P_{DG})$	70	2.601	0.750 0.750 0.500	0.49720	0.67931	2.35292	0.07882	0.05292	10073.2
12 -2 pm $(P_{load}> P_{DG})$	100	3.715	0.750 0.750 0.500	0.51971	1.78146	2.34694	0.06647	0.04694	5664.6
2 pm- 4 pm $(P_{load}> P_{DG})$	80	2.972	0.750 0.750 0.500	0.50742	1.04562	2.35005	0.07362	0.05006	8607.9
4 pm- 6pm $(P_{load}> P_{DG})$	70	2.601	0.750 0.750 0.500	0.49720	0.67931	2.35292	0.07882	0.05292	10073.2
6 pm-8 pm $(P_{load}> P_{DG})$	90	3.344	0.750 0.750 0.500	0.51129	1.41436	2.34905	0.07087	0.04905	7133.0
8 pm-10 pm $(P_{load}> P_{DG})$	100	3.715	0.750 0.750 0.500	0.51971	1.78146	2.34694	0.06647	0.04694	5664.6
10 pm- 12 $(P_{load}> P_{DG})$	60	2.229	0.750 0.750 0.500	0.48404	0.31403	2.35667	0.08504	0.05667	11534.3
12- 2 am $(P_{load}< P_{DG})$	50	1.858	0.697 0.697 0.464	0.48318	0.08496	2.35692	0.08546	0.05693	12655.1
2 am-4 am $(P_{load}< P_{DG})$	10	0.372	0.140 0.140 0.092	0.53491	0.06058	2.34127	0.06108	0.04128	14889.1
4 am- 6 am $(P_{load}< P_{DG})$	20	0.743	0.279 0.279 0.185	0.52809	0.06458	2.34357	0.06458	0.04358	14339.6

33 bus system: Total DG capacity = 3 MW (Bus no: 14, 32 and 3)

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am ($P_{load} < P_{DG}$)	30	1.115	0.279 0.279 0.557	0.52261	0.06650	2.34518	0.06700	0.04518	13601.9
8 am-10 am ($P_{load} < P_{DG}$)	40	1.486	0.372 0.372 0.742	0.51397	0.07101	2.34783	0.07101	0.04784	12967.4
10 am-12 ($P_{load} < P_{DG}$)	70	2.601	0.650 0.650 1.301	0.49095	0.08084	2.35485	0.08134	0.05485	11115.0
12 -2 pm ($P_{load} > P_{DG}$)	100	3.715	0.750 0.750 1.500	0.50277	0.78896	2.35208	0.07397	0.05209	7634.6
2 pm- 4 pm ($P_{load} < P_{DG}$)	80	2.972	0.743 0.743 1.486	0.48587	0.08348	2.35647	0.08348	0.05647	10501.9
4 pm- 6pm ($P_{load} < P_{DG}$)	70	2.601	0.650 0.650 1.301	0.49095	0.08084	2.35485	0.08134	0.05485	11115.0
6 pm-8 pm ($P_{load} > P_{DG}$)	90	3.344	0.750 0.750 1.500	0.50001	0.42001	2.35249	0.07651	0.05249	9110.4
8 pm-10 pm ($P_{load} > P_{DG}$)	100	3.715	0.750 0.750 1.500	0.50277	0.78896	2.35208	0.07397	0.05209	7634.6
10 pm- 12 ($P_{load} < P_{DG}$)	60	2.229	0.557 0.557 1.115	0.49755	0.07843	2.35281	0.07843	0.05282	11729.2
12- 2 am ($P_{load} < P_{DG}$)	50	1.858	0.465 0.465 0.928	0.50529	0.07447	2.35046	0.07497	0.05047	12349.0
2 am-4 am ($P_{load} < P_{DG}$)	10	0.372	0.093 0.093 0.186	0.53509	0.06036	2.34113	0.06086	0.04113	14819.5
4 am- 6 am ($P_{load} < P_{DG}$)	20	0.743	0.186 0.186 0.371	0.53014	0.06341	2.34281	0.06341	0.04282	14204.8

33 bus system: Total DG capacity = 1 MW (Bus no: 32, 30, 16, 18 and 14)

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am (P_{load}> P_{DG})	30	1.115	0.400 0.200 0.200 0.100 0.100	0.50045	0.19187	2.35298	0.07738	0.05298	11772.9
8 am-10 am (P_{load}> P_{DG})	40	1.486	0.400 0.200 0.200 0.100 0.100	0.50702	0.56042	2.35097	0.07442	0.05097	10298.7
10 am-12 (P_{load}> P_{DG})	70	2.601	0.400 0.200 0.200 0.100 0.100	0.52227	1.66725	2.34584	0.06675	0.04585	5871.4
12 -2 pm (P_{load}> P_{DG})	100	3.715	0.400 0.200 0.200 0.100 0.100	0.47155	2.80272	2.36019	0.08773	0.06019	1329.5
2 pm- 4 pm (P_{load}> P_{DG})	80	2.972	0.400 0.200 0.200 0.100 0.100	0.51720	2.04020	2.34686	0.06820	0.04686	4379.6
4 pm- 6pm (P_{load}> P_{DG})	70	2.601	0.400 0.200 0.200 0.100 0.100	0.52227	1.66725	2.34584	0.06675	0.04585	5871.4
6 pm-8 pm (P_{load}> P_{DG})	90	3.344	0.400 0.200 0.200 0.100 0.100	0.50227	2.41772	2.35097	0.07423	0.05097	2869.5
8 pm-10 pm (P_{load}> P_{DG})	100	3.715	0.400 0.200 0.200 0.100 0.100	0.47155	2.80272	2.36019	0.08773	0.06019	1329.5
10 pm- 12 (P_{load}> P_{DG})	60	2.229	0.400 0.200 0.200 0.100 0.100	0.52019	1.29716	2.34677	0.06817	0.04677	7351.8
12- 2 am (P_{load}> P_{DG})	50	1.858	0.400 0.200 0.200 0.100 0.100	0.51425	0.92858	2.34872	0.07109	0.04872	8826.1
2 am-4 am (P_{load}< P_{DG})	10	0.372	0.150 0.074 0.074 0.037 0.037	053254	0.06192	2.34230	0.06242	0.04231	14925.5
4 am- 6 am (P_{load}< P_{DG})	20	0.743	0.297 0.149 0.149 0.074 0.074	0.51648	0.07008	2.34777	0.07008	0.04778	14400.8

33 bus system: Total DG capacity = 2 MW (Bus no: 25, 31, 14, 18 and 29)

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am $(P_{load}< P_{DG})$	30	1.115	0.335 0.335 0.223 0.111 0.111	0. 51191	0.07168	2.34878	0.07218	0.04878	13874.2
8 am-10 am $(P_{load}< P_{DG})$	40	1.486	0.446 0.446 0.296 0.149 0.149	0. 49350	0.08061	2.35437	0.08061	0.05437	13336.7
10 am-12 $(P_{load}> P_{DG})$	70	2.601	0.600 0.600 0.400 0.200 0.200	0.48901	0.68309	2.35581	0.08260	0.05582	10233.0
12 -2 pm $(P_{load}> P_{DG})$	100	3.715	0.600 0.600 0.400 0.200 0.200	0.52580	1.77936	2.34487	0.06436	0.04487	5847.9
2 pm- 4 pm $(P_{load}> P_{DG})$	80	2.972	0.600 0.600 0.400 0.200 0.200	0.50300	1.04793	2.35173	0.07594	0.05174	8773.7
4 pm- 6pm $(P_{load}> P_{DG})$	70	2.601	0.600 0.600 0.400 0.200 0.200	0.48901	0.68309	2.35581	0.08260	0.05582	10233.0
6 pm-8 pm $(P_{load}> P_{DG})$	90	3.344	0.600 0.600 0.400 0.200 0.200	0.51140	1.41491	2.34926	0.07142	0.04927	7305.8
8 pm-10 pm $(P_{load}> P_{DG})$	100	3.715	0.600 0.600 0.400 0.200 0.200	0.52580	1.77936	2.34487	0.06436	0.04487	5847.9
10 pm- 12 $(P_{load}> P_{DG})$	60	2.229	0.600 0.600 0.400 0.200 0.200	0.47278	0.31901	2.36055	0.09002	0.06056	11689.4
12- 2 am $(P_{load}< P_{DG})$	50	1.858	0.557 0.557 0.372 0.186 0.186	0.47169	0.08998	2.36086	0.09048	0.06087	12796.7
2 am-4 am $(P_{load}< P_{DG})$	10	0.372	0.112 0.112 0.074 0.037 0.037	0.53446	0.06083	2.34147	0.06133	0.04148	14920.3
4 am- 6 am $(P_{load}< P_{DG})$	20	0.743	0.223 0.223 0.149 0.074 0.074	0.52600	0.06557	2.34435	0.06557	0.04435	14400.4

33 bus system: Total DG capacity = 3 MW (Bus no: 2, 8, 25, 14 and 32)

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am $(P_{load}< P_{DG})$	30	1.115	0.223 0.223 0.223 0.223 0.223	0.52144	0.06704	2.34595	0.06755	0.04596	13724.7
8 am-10 am $(P_{load}< P_{DG})$	40	1.486	0.296 0.296 0.296 0.296 0.296	0.51212	0.07779	2.34896	0.07179	0.04897	13134.2
10 am-12 $(P_{load}< P_{DG})$	70	2.601	0.520 0.520 0.520 0.520 0.521	0.48549	0.08312	2.35737	0.08363	0.05737	11430.9
12 -2 pm $(P_{load}> P_{DG})$	100	3.715	0.600 0.600 0.600 0.600 0.600	0.52148	0.78187	2.34617	0.06688	0.04617	8037.9
2 pm- 4 pm $(P_{load}< P_{DG})$	80	2.972	0.594 0.594 0.594 0.595 0.595	0.47969	0.08613	2.35918	0.08613	0.05918	10865.9
4 pm- 6pm $(P_{load}< P_{DG})$	70	2.601	0.520 0.520 0.520 0.520 0.521	0.48549	0.08312	2.35737	0.08363	0.05737	11430.9
6 pm-8 pm $(P_{load}> P_{DG})$	90	3.344	0.600 0.600 0.600 0.600 0.600	0.49720	0.42149	2.35379	0.07800	0.05380	9479.4
8 pm-10 pm $(P_{load}> P_{DG})$	100	3.715	0.600 0.600 0.600 0.600 0.600	0.52148	0.78187	2.34617	0.06688	0.04617	8037.9
10 pm- 12 $(P_{load}< P_{DG})$	60	2.229	0.446 0.446 0.446 0.446 0.445	0.49313	0.08027	2.35498	0.08027	0.05499	12001.3
12- 2 am $(P_{load}< P_{DG})$	50	1.858	0.372 0.372 0.372 0.371 0.371	0.50212	0.07578	2.35215	0.07628	0.05215	12576.0
2 am-4 am $(P_{load}< P_{DG})$	10	0.372	0.074 0.074 0.074 0.075 0.075	0.53508	0.06043	2.34123	0.06093	0.04124	14864.9
4 am- 6 am $(P_{load}< P_{DG})$	20	0.743	0.149 0.149 0.149 0.148 0.148	0.52975	0.06365	2.34317	0.06365	0.04318	14297.1

4.9.4 69 Bus System

The second test system is a 69 bus-68 branches radial system with the total load demand of 3.74 MW and 2.69 MVAR [37]. Three different cases are considered wherein the total DG capacities are 1 MW, 2 MW and 3 MW. The single line diagram is as shown in Figure 4.13.

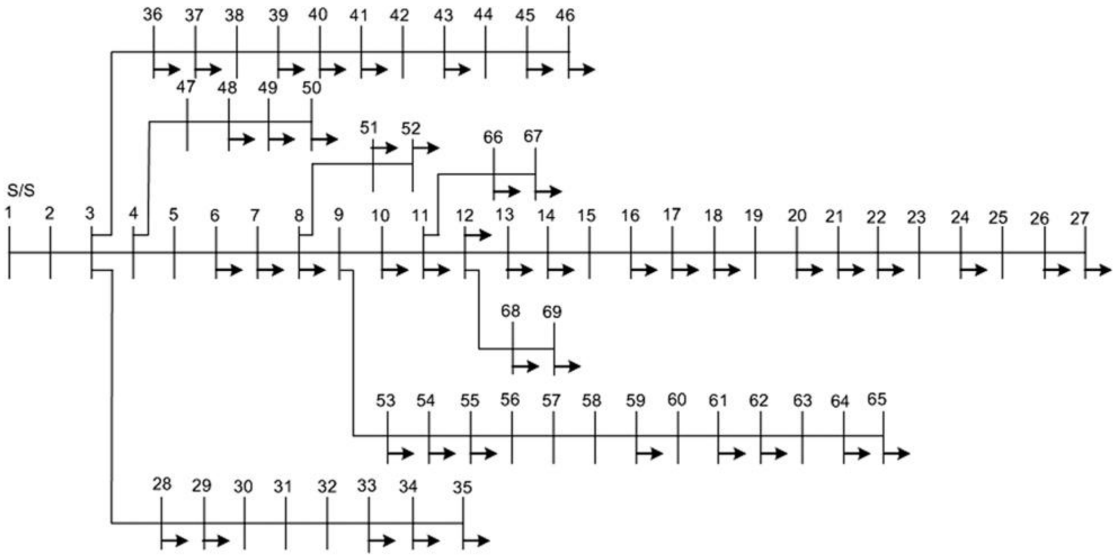


Figure 4.13 69 Bus Test System

The results obtained are tabulated below.

<u>Base Case</u>

<u>Without DG</u>

P $_{load}$ (MW)	Q $_{load}$ (MVar)	P $_{utility}$ (MW)	Q $_{utility}$ (MW)	P $_{loss}$ (MW)	Q $_{loss}$ (MVar)	Cost (Rs/hr)
3.74	2.69	3.99808	2.80840	0.25788	0.11370	15992.30

With DG : 3 DG case

Total DG size = 1 MW : (in the decreasing order of NPEI)

P_{DG} total (MW)	DG Sizes (MW)	Bus No	NPEI	P_{loss} (MW)	Q_{loss} (MW)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)
1	0.125	23	0.3818479	0.15794	0.06877	2.89812	2.76347
	0.125	68					
	0.750	62					
1	0.125	21	0.3809684	0.15842	0.06898	2.89860	2.76367
	0.250	68					
	0.625	60					
1	0.250	21	0.3807597	0.15840	0.06911	2.89858	2.76380
	0.250	64					
	0.500	62					
1	0.375	62	0.3807580	0.15840	0.06911	2.89858	2.76380
	0.375	64					
	0.250	21					
1	0.125	21	0.3800962	0.15896	0.06909	2.89914	2.76379
	0.500	62					
	0.375	64					

With DG : 3 DG case

Total DG size = 1 MW : (in the decreasing order of savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	1	0.375	62	1437.5	11594.32	2960.5	4
		0.375	64				
		0.250	21				
2	1	0.250	21	1625.0	11594.32	2773.0	3
		0.250	64				
		0.500	62				
3	1	0.125	21	1625.0	11596.56	2770.7	5
		0.500	62				
		0.375	64				
4	1	0.125	21	1750.0	11594.40	2647.9	2
		0.250	68				
		0.625	60				
5	1	0.125	23	1812.5	11592.48	2587.3	1
		0.125	68				
		0.750	62				

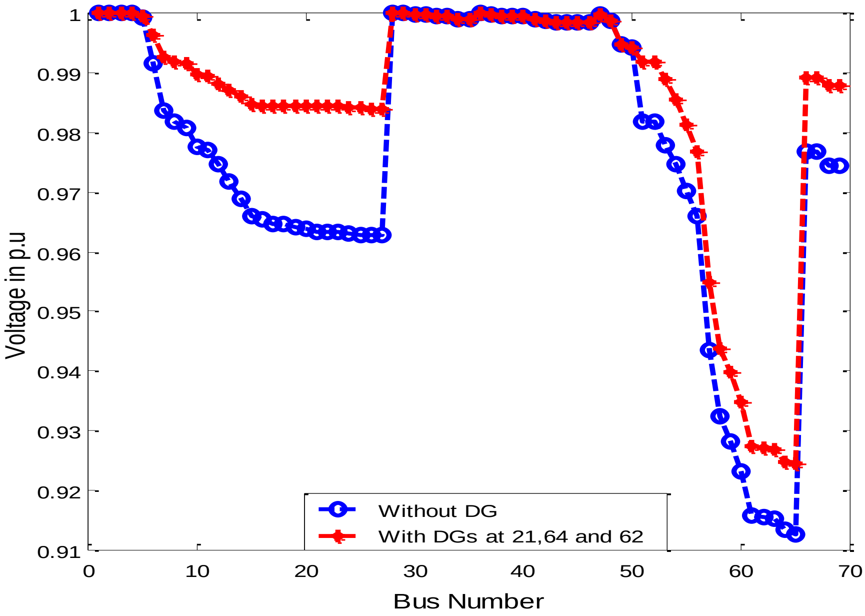


Figure 4.14 Voltage plot with DGs at 21, 64 and 62

With DG : 3 DG case

Total DG size = 2 MW : (in the decreasing order of NPEI)

P_{DG} total (MW)	DG Sizes (MW)	Bus No	NPEI	P_{loss} (MW)	Q_{loss} (MW)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)
2	0.500	19	0.3874551	0.15506	0.06743	1.89523	2.76212
	0.500	49					
	1.000	62					
2	0.250	21	0.3871419	0.15516	0.06759	1.89533	2.76228
	0.500	36					
	1.250	62					
2	0.250	21	0.3870512	0.15523	0.06751	1.89541	2.76220
	1.000	62					
	0.750	46					
2	0.750	62	0.3845084	0.15656	0.06812	1.89674	2.76281
	0.750	50					
	0.500	17					
2	0.250	21	0.3817341	0.15799	0.06920	1.89816	2.76388
	0.250	40					
	1.500	57					

With DG : 3 DG case

Total DG size = 2 MW: (in the decreasing order of savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	2	0.750	62	2875.0	7586.96	5530.3	4
		0.750	50				
		0.500	17				
2	2	0.500	19	3250.0	7580.92	5161.4	1
		0.500	49				
		1.000	62				
3	2	0.250	21	3250.0	7581.64	5160.7	3
		1.000	62				
		0.750	46				
4	2	0.250	21	3500.0	7581.32	4911.0	2
		0.500	36				
		1.250	62				
5	2	0.250	21	3625.0	7592.64	4774.7	5
		0.250	40				
		1.500	57				

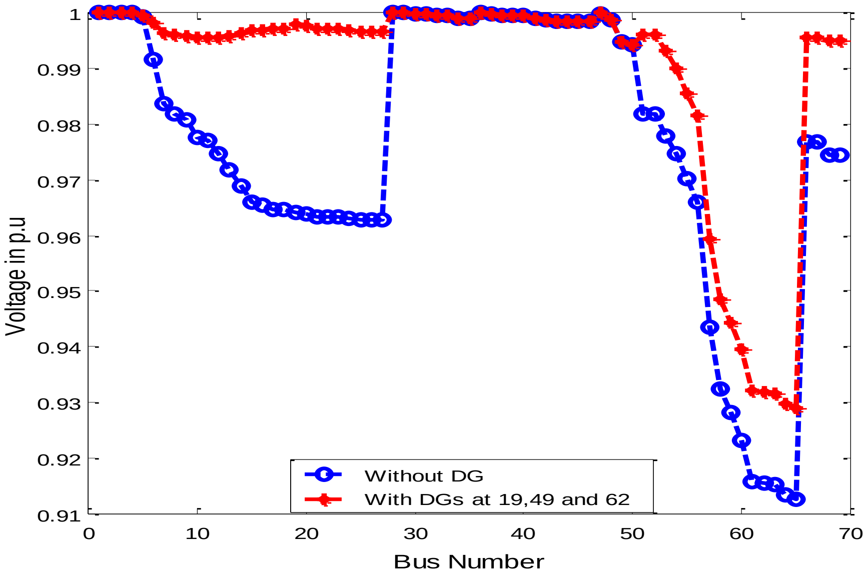


Figure 4.15 Voltage plot with DGs at 19, 49 and 62

With DG : 3 DG case

Total DG size = 3 MW : (in the decreasing order of NPEI)

P_{DG} total (MW)	DG Sizes (MW)	Bus No	NPEI	P_{loss} (MW)	Q_{loss} (MW)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)
3	0.375	18	0.3884005	0.15447	0.06729	0.89465	2.76198
	1.500	3					
	1.125	62					
3	0.375	18	0.3873195	0.15503	0.06756	0.89520	2.76225
	0.375	36					
	2.250	9					
3	0.375	18	0.3860664	0.15567	0.06781	0.89585	2.76250
	0.750	31					
	1.875	9					
3	0.750	12	0.3811458	0.15866	0.06868	0.89884	2.76337
	0.750	62					
	1.500	34					
3	1.125	2	0.3794305	0.15948	0.06929	0.89966	2.76398
	1.125	62					
	0.750	12					

With DG : 3 DG case

Total DG size = 3 MW: (in the decreasing order of savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	3	1.125	2	4312.5	3598.64	8081.2	5
		1.125	62				
		0.750	12				
2	3	0.375	18	4875.0	3578.60	7538.7	1
		1.500	3				
		1.125	62				
3	3	0.750	12	4875.0	3595.36	7521.9	4
		0.750	62				
		1.500	34				
4	3	0.375	18	5250.0	3583.40	7158.9	3
		0.750	31				
		1.875	9				
5	3	0.375	18	5437.5	3580.80	6974.0	2
		0.375	36				
		2.250	9				

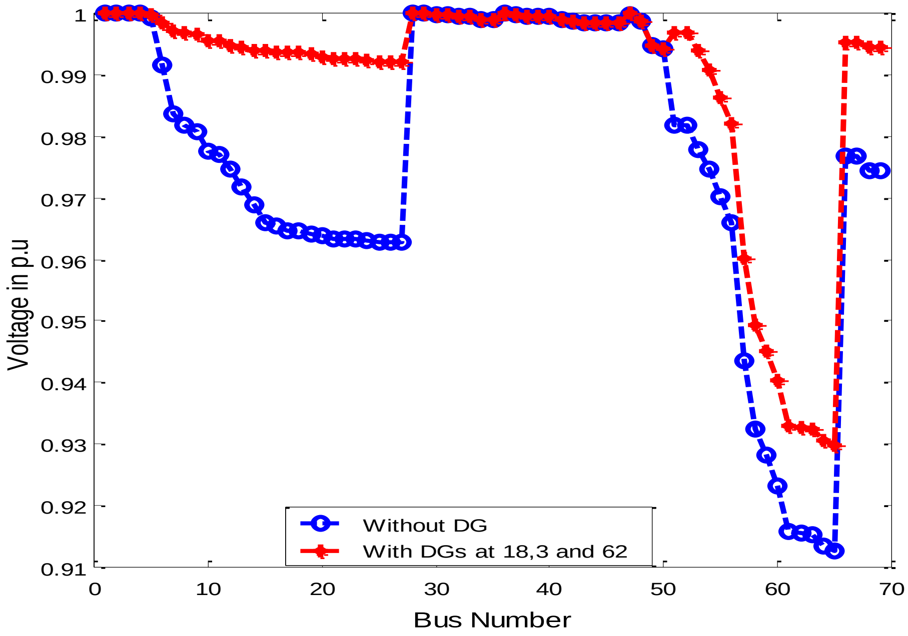


Figure 4.16 Voltage plot with DGs at 18, 3 and 62

<u>With DG: 5 DG case</u>

<u>Total DG size: 1 MW:</u> (in the decreasing order of NPEI)

Pdg total (MW)	DG Sizes (MW)	Bus No	NPEI	Ploss (MW)	Qloss (MW)	Putility (MW)	Qutility (MW)
1	0.4	62	0.38182	0.15785	0.06886	2.89804	2.76355
	0.2	21					
	0.2	64					
	0.1	68					
	0.1	65					
1	0.3	64	0.38171	0.15791	0.06889	2.89809	2.76358
	0.4	60					
	0.1	24					
	0.1	68					
	0.1	21					
1	0.5	60	0.38166	0.15793	0.06890	2.89812	2.76359
	0.2	21					
	0.1	64					
	0.1	65					
	0.1	68					
1	0.3	64	0.38141	0.15806	0.06896	2.89824	2.76365
	0.3	62					
	0.2	21					
	0.1	51					
	0.1	68					
1	0.2	68	0.38090	0.15838	0.06906	2.89856	2.76375
	0.2	60					
	0.2	18					
	0.2	64					
	0.2	62					

With DG : 5 DG case

Total DG size = 1 MW: (in the decreasing order of savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	1	0.5	60	1275.0	11592.48	3124.8	3
		0.2	21				
		0.1	64				
		0.1	65				
		0.1	68				
2	1	0.4	62	1325.0	11592.16	3075.1	1
		0.2	21				
		0.2	64				
		0.1	68				
		0.1	65				
3	1	0.3	64	1325.0	11592.36	3074.9	2
		0.4	60				
		0.1	24				
		0.1	68				
		0.1	21				
4	1	0.3	64	1350.0	11592.96	3049.3	4
		0.3	62				
		0.2	21				
		0.1	51				
		0.1	68				
5	1	0.2	68	1500.0	11594.24	2898.1	5
		0.2	60				
		0.2	18				
		0.2	64				
		0.2	62				

With DG: 5 DG case

Total DG size: 2 MW: (in the decreasing order of NPEI)

P_{DG} total (MW)	DG Sizes (MW)	Bus No	NPEI	P_{loss} (MW)	Q_{loss} (MW)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)
2	1.0 0.4 0.2 0.2 0.2	62 32 16 48 21	0.38872	0.15432	0.06717	1.89449	2.76186
2	0.6 0.8 0.2 0.2 0.2	28 62 19 64 21	0.38852	0.15442	0.06722	1.89460	2.76191
2	0.6 0.6 0.4 0.2 0.2	50 62 18 64 60	0.38842	0.15449	0.06723	1.89467	2.76192
2	0.8 0.4 0.4 0.2 0.2	62 32 18 51 9	0.38826	0.15456	0.06731	1.89473	2.76200
2	0.4 0.4 0.4 0.4 0.4	62 60 64 48 19	0.38747	0.15495	0.06756	1.89511	2.76225

With DG : 5 DG case

Total DG size = 2 MW: (in the decreasing order of savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	2	1.0	62	2550.0	7577.96	5864.3	1
		0.4	32				
		0.2	16				
		0.2	48				
		0.2	21				
2	2	0.6	28	2650.0	7578.40	5763.9	2
		0.8	62				
		0.2	19				
		0.2	64				
		0.2	21				
3	2	0.8	62	2650.0	7578.92	5763.4	4
		0.4	32				
		0.4	18				
		0.2	51				
		0.2	9				
4	2	0.6	50	2700.0	7578.68	5713.6	3
		0.6	62				
		0.4	18				
		0.2	64				
		0.2	60				
5	2	0.4	62	3000.0	7580.44	5411.9	5
		0.4	60				
		0.4	64				
		0.4	48				
		0.4	19				

With DG: 5 DG case

Total DG size: 3 MW: (in the decreasing order of NPEI)

P_{DG} total (MW)	DG Sizes (MW)	Bus No	NPEI	P_{loss} (MW)	Q_{loss} (MW)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)
3	0.9	4	0.38834	0.15454	0.06725	0.89471	2.76194
	0.9	62					
	0.6	2					
	0.3	11					
	0.3	21					
3	0.9	62	0.38834	0.15454	0.06725	0.89471	2.76194
	1.2	4					
	0.3	11					
	0.3	2					
	0.3	21					
3	1.5	4	0.38818	0.15462	0.06729	0.89480	2.76198
	0.6	62					
	0.3	11					
	0.3	18					
	0.3	64					
3	1.2	2	0.38792	0.15473	0.06741	0.89490	2.76210
	0.6	63					
	0.6	62					
	0.3	21					
	0.3	48					
3	0.6	50	0.38523	0.15633	0.06788	0.89651	2.76257
	0.6	28					
	0.6	9					
	0.6	17					
	0.6	62					

With DG : 5 DG case

Total DG size = 3 MW: (in the decreasing order of savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	3	1.5	4	3825.0	3579.20	8588.1	3
		0.6	62				
		0.3	11				
		0.3	18				
		0.3	64				
2	3	0.9	62	3975.0	3578.84	8438.5	2
		1.2	4				
		0.3	11				
		0.3	2				
		0.3	21				
3	3	1.2	2	3975.0	3579.60	8437.7	4
		0.6	63				
		0.6	62				
		0.3	21				
		0.3	48				
4	3	0.9	4	4050.0	3578.84	8363.5	1
		0.9	62				
		0.6	2				
		0.3	11				
		0.3	21				
5	3	0.6	50	4500.0	3586.04	7906.3	5
		0.6	28				
		0.6	9				
		0.6	17				
		0.6	62				

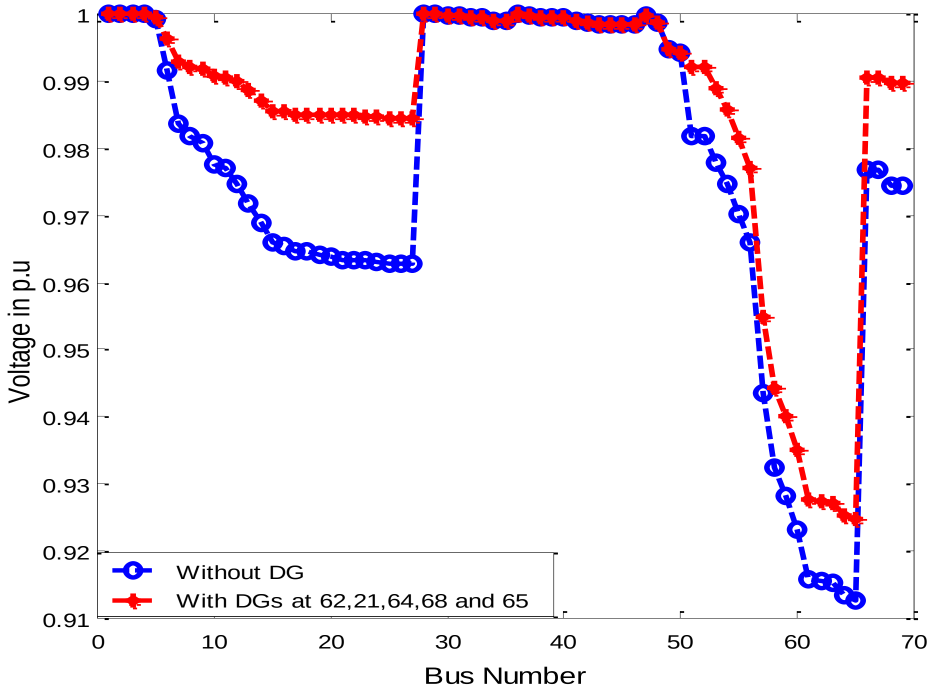


Figure 4.17 Voltage plot with DGs at 62, 21, 64, 68 and 65

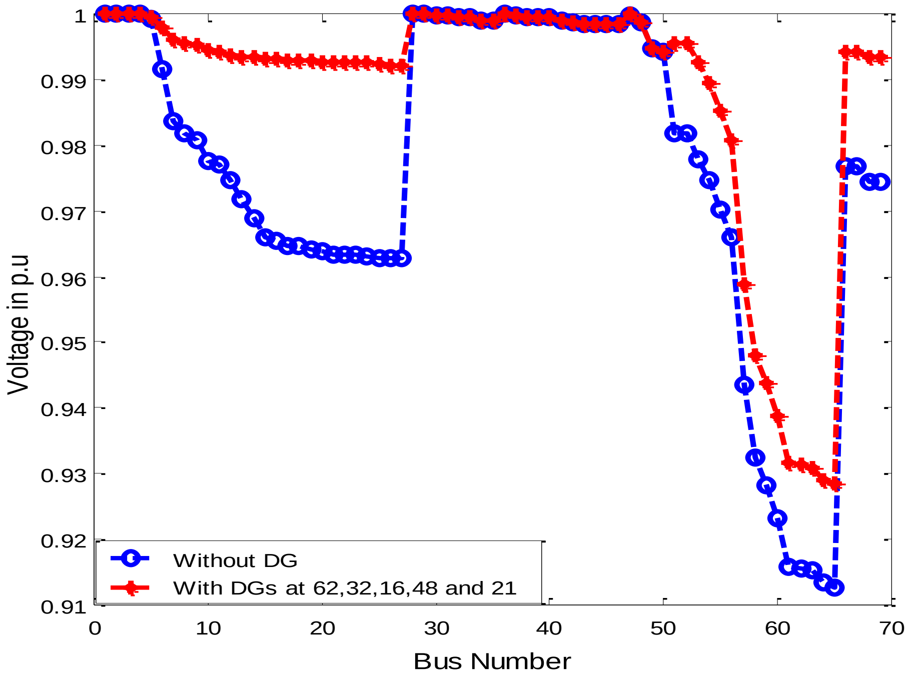


Figure 4.18 Voltage plot with DGs at 62, 32, 16, 48 and 21

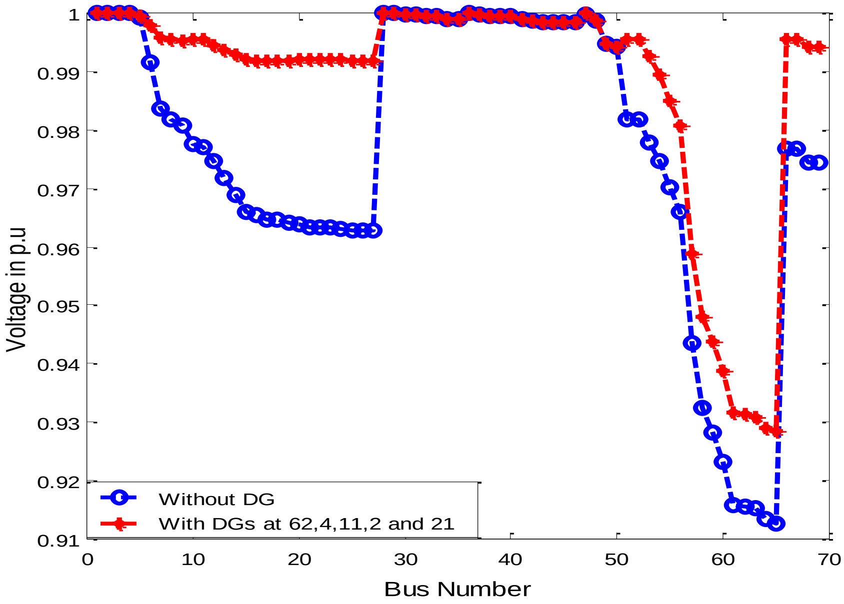


Figure 4.19 Voltage plot with DGs at 62, 4, 11, 2 and 21

4.9.5 Load variation

In 69 bus system when the total DG capacity is 1 MW, it can meet only 10% and 20% of the total system load.. When the total DG capacity is 2 MW, it can meet 10%, 20%, 30%, 40% and 50% of total system load. When the total DG capacity is 3 MW, it can meet 10%, 20%, 30%, 40%, 50%, 60%, 70% and 80% of the total system load. When the total system load exceeds the total DG capacity, then remaining load demand has to be met from utility. For 90% and more the total DG capacity is less compared to the total load. Between zero and the maximum capacity the DG can be tuned to any capacity.

69 bus system: Total DG capacity = 1 MW (Bus no: 23, 68 and 62)

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am $(P_{load}> P_{DG})$	30	1.122	0.125 0.125 0.750	0.53744	0.19726	2.72906	0.07521	0.03436	13390.8
8 am-10 am $(P_{load}> P_{DG})$	40	1.496	0.125 0.125 0.750	0.52998	0.57495	2.73035	0.07888	0.03566	11880.0
10 am-12 $(P_{load}> P_{DG})$	70	2.618	0.125 0.125 0.750	0.47930	1.72368	2.74122	0.10555	0.04652	7285.1
12 -2 pm $(P_{load}> P_{DG})$	100	3.740	0.125 0.125 0.750	0.38185	2.89812	2.76347	0.15794	0.06877	2587.3
2 pm- 4 pm $(P_{load}> P_{DG})$	80	2.992	0.125 0.125 0.750	0.45246	2.11215	2.74730	0.12000	0.05261	5731.2
4 pm- 6pm $(P_{load}> P_{DG})$	70	2.618	0.125 0.125 0.750	0.47930	1.72368	2.74122	0.10555	0.04652	7285.1
6 pm-8 pm $(P_{load}> P_{DG})$	90	3.366	0.125 0.125 0.750	0.42005	2.50358	2.75470	0.13742	0.06001	4165.5
8 pm-10 pm $(P_{load}> P_{DG})$	100	3.740	0.125 0.125 0.750	0.38185	2.89812	2.76347	0.15794	0.06877	2587.3
10 pm- 12 $(P_{load}> P_{DG})$	60	2.244	0.125 0.125 0.750	0.50079	1.33806	2.73639	0.09395	0.04170	8827.6
12- 2 am $(P_{load}> P_{DG})$	50	1.870	0.125 0.125 0.750	0.51773	0.95518	2.73278	0.08510	0.03809	10359.1
2 am-4 am $(P_{load}< P_{DG})$	10	0.374	0.047 0.047 0.280	0.56281	0.06126	2.72250	0.06124	0.02780	15069.8
4 am- 6 am $(P_{load}< P_{DG})$	20	0.748	0.094 0.094 0.560	0.55134	0.06776	2.72559	0.06772	0.03090	14366.3

69 bus system: Total DG capacity = 2 MW (Bus no: 19, 49 and 62)

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am ($P_{load}<P_{DG}$)	30	1.122	0.281 0.281 0.560	0.54444	0.07115	2.72677	0.07109	0.03207	15705.9
8 am-10 am ($P_{load}< P_{DG}$)	40	1.496	0.374 0.374 0.748	0.52756	0.08036	2.73084	0.08028	0.03615	13239.9
10 am-12 ($P_{load}> P_{DG}$)	70	2.618	0.500 0.500 1.000	0.47055	0.72863	2.74360	0.11051	0.04891	9827.8
12 -2 pm ($P_{load}> P_{DG}$)	100	3.740	0.500 0.500 1.000	0.38746	1.89523	2.76212	0.15506	0.06743	5161.4
2 pm- 4 pm ($P_{load}> P_{DG}$)	80	2.992	0.500 0.500 1.000	0.44783	1.11457	2.74848	0.12243	0.05379	8284.0
4 pm- 6pm ($P_{load}> P_{DG}$)	70	2.618	0.500 0.500 1.000	0.47055	0.72863	2.74360	0.11051	0.04891	9827.8
6 pm-8 pm ($P_{load}> P_{DG}$)	90	3.366	0.500 0.500 1.000	0.42046	1.50340	2.75464	0.13724	0.05995	6728.7
8 pm-10 pm ($P_{load}> P_{DG}$)	100	3.740	0.500 0.500 1.000	0.38746	1.89523	2.76212	0.15506	0.06743	5161.4
10 pm- 12 ($P_{load}> P_{DG}$)	60	2.244	0.500 0.500 1.000	0.48820	0.34547	2.73994	0.10137	0.04525	11360.4
12- 2 am ($P_{load}< P_{DG}$)	50	1.870	0.468 0.468 0.934	0.50575	0.09220	2.73609	0.09210	0.04140	12585.5
2 am-4 am ($P_{load}< P_{DG}$)	10	0.374	0.094 0.094 0.186	0.56369	0.06060	2.72212	0.06058	0.02743	15142.9
4 am- 6 am ($P_{load}< P_{DG}$)	20	0.748	0.187 0.187 0.374	0.55640	0.06458	2.72387	0.06454	0.02917	14518.5

69 bus system: Total DG capacity = 3 MW (Bus no: 18, 3, and 62)

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am $(P_{load}<P_{DG})$	30	1.122	0.140 0.561 0.421	0.54916	0.06824	2.72537	0.06818	0.03067	13895.8
8 am-10 am $(P_{load}< P_{DG})$	40	1.496	0.187 0.748 0.561	0.53644	0.07499	2.72827	0.07491	0.03357	13261.3
10 am-12 $(P_{load}<P_{DG})$	70	2.618	0.327 1.309 0.982	0.47640	0.10715	2.74208	0.10701	0.04739	11309.2
12 -2 pm $(P_{load}> P_{DG})$	100	3.740	0.375 1.500 1.125	0.38840	0.89465	2.76198	0.15447	0.06729	7538.7
2 pm- 4 pm $(P_{load}< P_{DG})$	80	2.992	0.374 1.496 1.122	0.44883	0.12201	2.74846	0.12185	0.05377	10642.3
4 pm- 6pm $(P_{load}< P_{DG})$	70	2.618	0.327 1.309 0.982	0.47640	0.10715	2.74208	0.10701	0.04739	11309.2
6 pm-8 pm $(P_{load}> P_{DG})$	90	3.366	0.375 1.500 1.125	0.42125	0.50285	2.75457	0.13669	0.05988	9105.9
8 pm-10 pm $(P_{load}> P_{DG})$	100	3.740	0.375 1.500 1.125	0.38840	0.89465	2.76198	0.15447	0.06729	7538.7
10 pm- 12 $(P_{load}< P_{DG})$	60	2.244	0.281 1.122 0.841	0.50009	0.09439	2.73660	0.09427	0.04191	11968.7
12- 2 am $(P_{load}< P_{DG})$	50	1.870	0.234 0.935 0.701	0.52011	0.08369	2.73200	0.08359	0.03731	12619.0
2 am-4 am $(P_{load}< P_{DG})$	10	0.374	0.047 0.187 0.140	0.56412	0.06038	2.72202	0.06036	0.02732	15143.3
4 am- 6 am $(P_{load}< P_{DG})$	20	0.748	0.094 0.374 0.280	0.55836	0.06334	2.72329	0.06339	0.02859	14523.9

69 bus system: Total DG capacity = 1 MW(Bus no: 62, 21, 64 , 68 and 65)

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am (P_{load}> P $_{DG}$)	30	1.122	0.400 0.200 0.200 0.100 0.100	0.53830	0.19679	2.72871	0.07473	0.03402	13880.1
8 am-10 am (P_{load}> P $_{DG}$)	40	1.496	0.400 0.200 0.200 0.100 0.100	0.53072	0.57451	2.73006	0.07845	0.03537	12369.3
10 am-12 (P_{load}> P $_{DG}$)	70	2.618	0.400 0.200 0.200 0.100 0.100	0.47982	1.72340	2.74110	0.10527	0.04641	7773.7
12 -2 pm (P_{load}> P $_{DG}$)	100	3.740	0.400 0.200 0.200 0.100 0.100	0.38182	2.89804	2.76355	0.15785	0.06886	3075.1
2 pm- 4 pm (P_{load}> P $_{DG}$)	80	2.992	0.400 0.200 0.200 0.100 0.100	0.45281	2.11193	2.74725	0.11978	0.05256	6219.6
4 pm- 6pm (P_{load}> P $_{DG}$)	70	2.618	0.400 0.200 0.200 0.100 0.100	0.47982	1.72340	2.74110	0.10527	0.04641	7773.7
6 pm-8 pm (P_{load}> P $_{DG}$)	90	3.366	0.400 0.200 0.200 0.100 0.100	0.42022	2.50343	2.75472	0.13727	0.06002	4653.5
8 pm-10 pm (P_{load}> P $_{DG}$)	100	3.740	0.400 0.200 0.200 0.100 0.100	0.38182	2.89804	2.76355	0.15785	0.06886	3075.1
10 pm- 12 (P_{load}> P $_{DG}$)	60	2.244	0.400 0.200 0.200 0.100 0.100	0.50146	1.33772	2.73621	0.09362	0.04152	9316.4
12- 2 am (P_{load}> P $_{DG}$)	50	1.870	0.400 0.200 0.200 0.100 0.100	0.51832	0.95480	2.73255	0.08471	0.0.785	10848.1
2 am-4 am (P_{load}< P $_{DG}$)	10	0.374	0.150 0.075 0.075 0.037 0.037	0.56286	0.06121	2.72245	0.06119	0.02776	15252.5
4 am- 6 am (P_{load}< P $_{DG}$)	20	0.748	0.298 0.150 0.150 0.075 0.075	0.55179	0.30654	2.72540	0.06745	0.03070	13774.4

69 bus system: Total DG capacity = 2 MW (Bus no: 62, 32, 16, 48, and 21)

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am ($P_{load} < P_{DG}$)	30	1.122	0.562 0.224 0.112 0.112 0.112	0.54614	0.07013	2.72634	0.07006	0.03165	14281.8
8 am-10 am ($P_{load} < P_{DG}$)	40	1.496	0.748 0.298 0.150 0.150 0.150	0.53071	0.07852	2.73007	0.07844	0.03538	13777.7
10 am-12 ($P_{load} > P_{DG}$)	70	2.618	1.000 0.400 0.200 0.200 0.200	0.47467	0.72621	2.74259	0.10809	0.04790	10537.5
12 -2 pm ($P_{load} > P_{DG}$)	100	3.740	1.000 0.400 0.200 0.200 0.200	0.38872	1.89449	2.76186	0.15432	0.06717	5864.3
2 pm- 4 pm ($P_{load} > P_{DG}$)	80	2.992	1.000 0.400 0.200 0.200 0.200	0.45123	1.11269	2.74772	0.12056	0.05303	8991.5
4 pm- 6pm ($P_{load} > P_{DG}$)	70	2.618	1.000 0.400 0.200 0.200 0.200	0.47467	0.72621	2.74259	0.10809	0.04790	10537.5
6 pm-8 pm ($P_{load} > P_{DG}$)	90	3.366	1.000 0.400 0.200 0.200 0.200	0.42280	1.50208	2.75413	0.13593	0.05943	7433.9
8 pm-10 pm ($P_{load} > P_{DG}$)	100	3.740	1.000 0.400 0.200 0.200 0.200	0.38872	1.89449	2.76186	0.15432	0.06717	5864.3
10 pm- 12 ($P_{load} > P_{DG}$)	60	2.244	1.000 0.400 0.200 0.200 0.200	0.49332	0.34251	2.73870	0.09840	0.04401	12072.3
12- 2 am ($P_{load} < P_{DG}$)	50	1.870	0.935 0.374 0.187 0.187 0.187	0.51077	0.08932	2.73488	0.08922	0.04018	13250.8
2 am-4 am ($P_{load} < P_{DG}$)	10	0.374	0.188 0.075 0.037 0.037 0.037	0.56387	0.06050	2.72208	0.06048	0.02738	15274.3
4 am- 6 am ($P_{load} < P_{DG}$)	20	0.748	0.373 0.150 0.075 0.075 0.075	0.55711	0.06413	2.72368	0.06409	0.02898	14781.5

69 bus system: Total DG capacity = 3 MW (Bus no: 4, 62, 2, 11 and 21)

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am ($P_{load} < P_{DG}$)	30	1.122	0.337 0.337 0.224 0.112 0.112	0.54944	0.06811	2.72529	0.06805	0.03060	14205.6
8 am-10 am ($P_{load} < P_{DG}$)	40	1.496	0.449 0.449 0.298 0.150 0.150	0.53699	0.07474	2.72812	0.07466	0.03342	13673.6
10 am-12 ($P_{load} < P_{DG}$)	70	2.618	0.785 0.785 0.524 0.262 0.262	0.47816	0.10625	2.74155	0.10611	0.04686	12032.6
12 -2 pm ($P_{load} > P_{DG}$)	100	3.740	0.900 0.900 0.600 0.300 0.300	0.38834	0.89471	2.76194	0.15454	0.06725	8363.5
2 pm- 4 pm ($P_{load} < P_{DG}$)	80	2.992	0.898 0.898 0.598 0.299 0.299	0.45106	0.12082	2.74776	0.12066	0.05307	11470.3
4 pm- 6pm ($P_{load} < P_{DG}$)	70	2.618	0.785 0.785 0.524 0.262 0.262	0.47816	0.10625	2.74155	0.10611	0.04686	12032.6
6 pm-8 pm ($P_{load} > P_{DG}$)	90	3.366	0.900 0.900 0.600 0.300 0.300	0.42250	0.50226	2.75419	0.13610	0.05950	9933.3
8 pm-10 pm ($P_{load} > P_{DG}$)	100	3.740	0.900 0.900 0.600 0.300 0.300	0.38834	0.89471	2.76194	0.15454	0.06725	8363.5
10 pm- 12 ($P_{load} < P_{DG}$)	60	2.244	0.673 0.673 0.448 0.224 0.224	0.50146	0.09574	2.73622	0.09362	0.04153	12583.1
12- 2 am ($P_{load} < P_{DG}$)	50	1.870	0.561 0.561 0.374 0.187 0.187	0.52103	0.08326	2.73175	0.08316	0.03706	13134.8
2 am-4 am ($P_{load} < P_{DG}$)	10	0.374	0.112 0.112 0.076 0.037 0.037	0.56412	0.06039	2.72202	0.06037	0.02732	15245.9
4 am- 6 am ($P_{load} < P_{DG}$)	20	0.748	0.224 0.224 0.150 0.075 0.075	0.55846	0.06335	2.72327	0.06331	0.02857	14728.7

4.9.6 90 Bus Test System

The third test system contains 90 buses and 89 branches. It is a radial system with the total load of 19.45 MW and 9.72 MVAR [5]. Three different cases are considered wherein the total DG capacities are 5 MW, 10 MW and 15 MW. The single line diagram is as shown in Figure 4.20

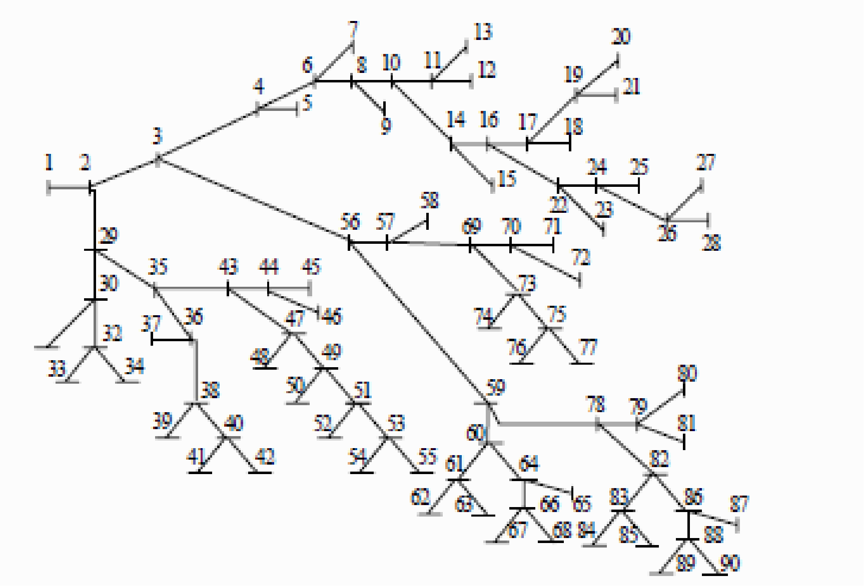


Figure 4.20 90 Bus Test System

The results obtained are tabulated below in similar lines as previous sections.

<u>Base case</u>

<u>Without DG</u>

P_{load} (MW)	Q_{load} (MVar)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)	P_{loss} (MW)	Q_{loss} (MVar)	VSI	Cost (Rs/hr)
19.45	9.72	20.2242	12.7205	0.77420	3.00048	0.19166	80896.8

With DG : 3 DG case

Total DG size = 5 MW : (in the decreasing order of NPEI)

P_{DG} total (MW)	DG Sizes (MW)	Bus No	NPEI	P_{loss} (MW)	Q_{loss} (MW)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)
5	1.875	15	0.5589874	0.20981	1.12971	15.10481	11.2347
	1.875	44					
	1.250	5					
5	0.625	44	0.5553468	0.21683	1.15273	15.11183	11.2577
	2.500	6					
	1.875	23					
5	0.625	9	0.5514035	0.22771	1.19584	15.12271	11.3008
	0.625	7					
	3.750	37					
5	0.625	46	0.5510371	0.22406	1.16682	15.11906	11.2718
	1.250	63					
	3.125	6					
5	1.250	67	0.5505933	0.22925	1.19922	15.12424	11.3042
	1.250	6					
	2.500	28					

With DG : 3 DG case

Total DG size = 5 MW : (in the decreasing order of savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	5	1.875	15	7187.5	60419.24	13290.06	1
		1.875	44				
		1.250	5				
2	5	0.625	44	8125.0	60447.32	12324.48	2
		2.500	6				
		1.875	23				
3	5	1.250	67	8125.0	60496.96	12274.84	5
		1.250	6				
		2.500	28				
4	5	0.625	46	8750.0	60476.24	11670.56	4
		1.250	63				
		3.125	6				
5	5	1.250	67	9062.5	60490.84	11343.46	3
		1.250	6				
		2.500	28				

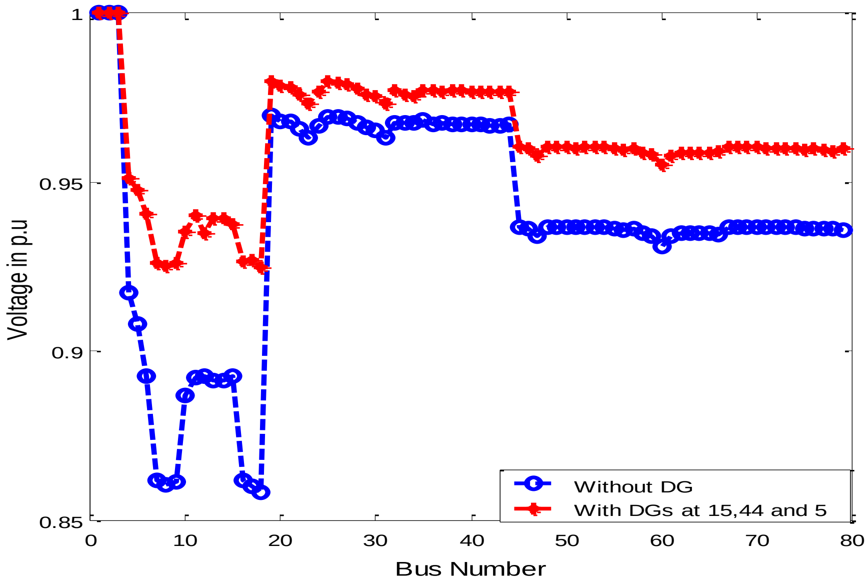


Figure 4.21 Voltage plot with DGs at 15, 44 and 5

With DG : 3 DG case

Total DG size = 10 MW : (in the decreasing order of NPEI)

P_{DG} total (MW)	DG Sizes (MW)	Bus No	NPEI	P_{loss} (MW)	Q_{loss} (MW)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)
10	2.500	38	0.5920634	0.16171	0.80808	10.05671	10.9131
	2.500	4					
	5.000	71					
10	1.250	22	0.5911155	0.16389	0.82757	10.05889	10.9326
	2.500	41					
	6.250	12					
10	1.250	57	0.5899835	0.16708	0.82616	10.06208	10.9312
	5.000	6					
	3.750	36					
10	3.750	51	0.5890508	0.16838	0.83511	10.06338	10.9401
	3.750	5					
	2.500	6					
10	1.250	40	0.5863184	0.16810	0.84749	10.06310	10.9525
	1.250	15					
	7.500	70					

WITH DG : 3 DG CASE

TOTAL DG SIZE = 10 MW: (in the decreasing order of Savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	10	3.750	51	14375	40253.52	26268.28	4
		3.750	5				
		2.500	6				
2	10	2.500	38	16250	40226.84	24419.96	1
		2.500	4				
		5.000	71				
3	10	1.250	57	16250	40248.32	24398.48	3
		5.000	6				
		3.750	36				
4	10	1.250	22	17500	40235.56	23161.24	2
		2.500	41				
		6.250	12				
5	10	1.250	40	18125	40252.40	22519.4	5
		1.250	15				
		7.500	70				

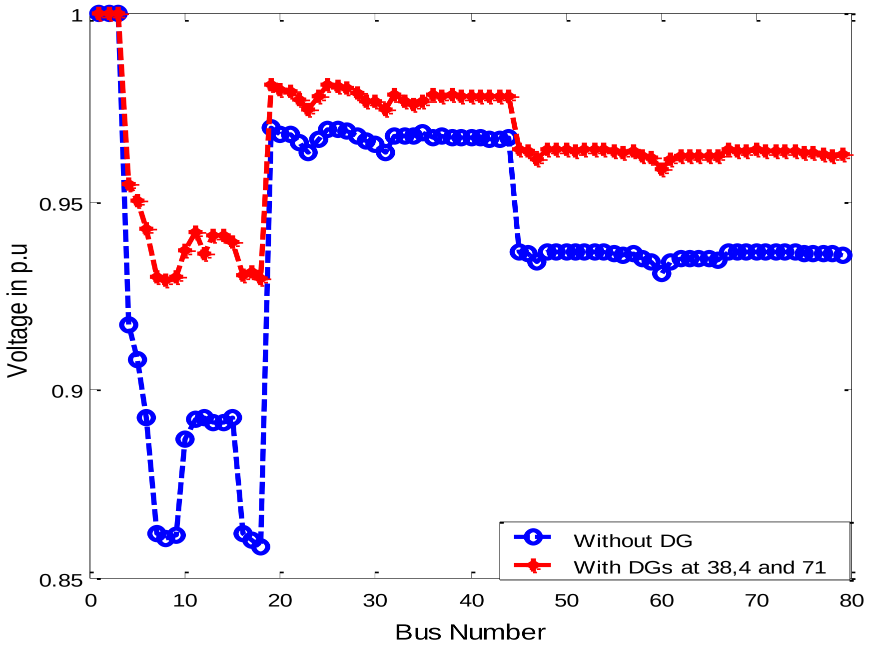


Figure 4.22 Voltage plot with DGs at 38,4 and 71

With DG : 3 DG case

Total DG size = 15 MW : (in the decreasing order of NPEI)

P_{DG} total (MW)	DG Sizes (MW)	Bus No	NPEI	P_{loss} (MW)	Q_{loss} (MW)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)
15	5.625	61	0.7970713	1.27646	3.92608	6.17146	14.0311
	5.625	27					
	3.750	26					
15	3.750	9	0.6079131	0.13675	0.64804	5.03175	10.7530
	3.750	62					
	7.500	70					
15	1.875	24	0.6005465	0.14966	0.69419	5.04466	10.7992
	7.500	6					
	5.625	2					
15	1.875	12	0.6002422	0.14663	0.72303	5.04163	10.8280
	1.875	52					
	11.25	6					
15	1.875	38	0.5967233	0.15335	0.74399	5.04835	10.8490
	3.750	6					
	9.375	5					

With DG : 3 DG case

Total DG size = 15 MW: (in the decreasing order of savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	15	3.750	9	24375.0	20127.00	36394.80	2
		3.750	62				
		7.500	70				
2	15	1.875	24	24375.0	20178.64	36343.16	3
		7.500	6				
		5.625	2				
3	15	5.625	61	21562.5	24685.84	34648.46	1
		5.625	27				
		3.750	26				
4	15	1.875	38	26250.0	20193.40	34453.40	5
		3.750	6				
		9.375	5				
5	15	1.875	12	27187.5	20166.52	33542.78	4
		1.875	52				
		11.25	6				

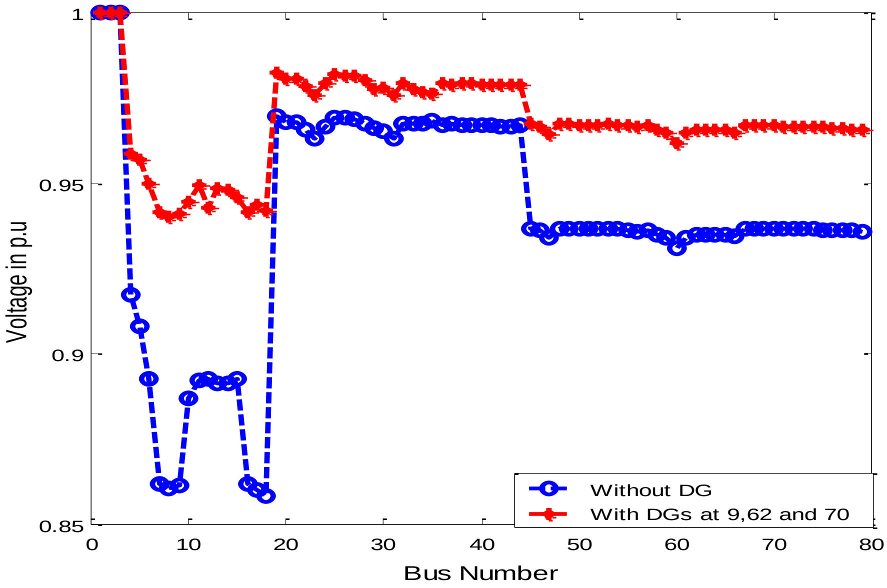


Figure 4.23 Voltage plot with DGs at 9, 62 and 70

With DG: 5 DG case

Total DG size: 5 MW: (in the decreasing order of NPEI)

P_{DG} total (MW)	DG Sizes (MW)	Bus No	NPEI	P_{loss} (MW)	Q_{loss} (MW)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)
5	1.500	16	0.56099	0.20843	1.12916	15.1034	11.2342
	1.500	47					
	1.000	15					
	0.500	59					
	0.500	49					
5	1.500	35	0.55918	0.21378	1.14763	15.1088	11.2526
	2.000	14					
	0.500	45					
	0.500	27					
	0.500	58					
5	2.000	61	0.55477	0.21817	1.16883	15.1132	11.2738
	1.000	12					
	1.000	57					
	0.500	22					
	0.500	34					
5	1.000	37	0.55358	0.22053	1.17479	15.1155	11.2798
	1.000	24					
	1.000	48					
	1.000	12					
	1.000	56					
5	2.500	66	0.55227	0.22603	1.18738	15.1210	11.2924
	1.000	5					
	0.500	6					
	0.500	24					
	0.500	28					

With DG : 5 DG case

Total DG size = 5 MW: (in the decreasing order of savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	5	2.500	66	6375	60484.12	14037.68	5
		1.000	5				
		0.500	6				
		0.500	24				
		0.500	28				
2	5	1.500	35	6625	60435.12	13836.68	2
		2.000	14				
		0.500	45				
		0.500	27				
		0.500	58				
3	5	2.000	61	6625	60452.68	13819.12	3
		1.000	12				
		1.000	57				
		0.500	22				
		0.500	34				
4	5	1.500	16	6750	60413.72	13733.08	1
		1.500	47				
		1.000	15				
		0.500	59				
		0.500	49				
5	5	1.000	37	7500	60462.12	12934.68	4
		1.000	24				
		1.000	48				
		1.000	12				
		1.000	56				

With DG: 5 DG case

Total DG size: 10 MW: (in the decreasing order of NPEI)

P_{DG} total (MW)	DG Sizes (MW)	Bus No	NPEI	P_{loss} (MW)	Q_{loss} (MW)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)
10	3.000	5	0.59816	0.15141	0.77373	10.0464	10.8787
	4.000	9					
	1.000	52					
	1.000	10					
	1.000	61					
10	4.000	9	0.59626	0.15487	0.79343	10.0499	10.8984
	2.000	13					
	2.000	4					
	1.000	5					
	1.000	24					
10	5.000	6	0.59592	0.15528	0.78545	10.0503	10.8905
	2.000	3					
	1.000	38					
	1.000	21					
	1.000	22					
10	3.000	38	0.58999	0.16709	0.83739	10.0621	10.9424
	3.000	70					
	2.000	7					
	1.000	3					
	1.000	29					
10	2.000	25	0.57837	0.18686	0.92397	10.0819	11.0290
	2.000	33					
	2.000	71					
	2.000	3					
	2.000	68					

With DG : 5 DG case

Total DG size = 10 MW: (in the decreasing order of savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	10	5.000	6	12125	40201.12	28570.68	3
		2.000	3				
		1.000	38				
		1.000	21				
		1.000	22				
2	10	3.000	5	13250	40185.64	27461.16	1
		4.000	9				
		1.000	52				
		1.000	10				
		1.000	61				
3	10	4.000	9	13250	40199.48	27447.32	2
		2.000	13				
		2.000	4				
		1.000	5				
		1.000	24				
4	10	3.000	38	13500	40248.36	27148.44	4
		3.000	70				
		2.000	7				
		1.000	3				
		1.000	29				
5	10	2.000	25	15000	40327.44	25569.36	5
		2.000	33				
		2.000	71				
		2.000	3				
		2.000	68				

With DG: 5 DG case

Total DG size: 15 MW: (in the decreasing order of NPEI)

P_{DG} total (MW)	DG Sizes (MW)	Bus No	NPEI	P_{loss} (MW)	Q_{loss} (MW)	$P_{utility}$ (MW)	$Q_{utility}$ (MW)
15	4.500	6	0.61185	0.12961	0.62262	5.02461	10.7276
	6.000	56					
	1.500	9					
	1.500	46					
	1.500	59					
15	4.500	4	0.60859	0.13627	0.62941	5.03127	10.7344
	4.500	70					
	3.000	33					
	1.500	12					
	1.500	49					
15	6.000	29	0.60516	0.14099	0.67882	5.03599	10.7838
	3.000	48					
	3.000	10					
	1.500	71					
	1.500	4					
15	7.500	2	0.60033	0.14974	0.72086	5.04474	10.8259
	3.000	10					
	1.500	68					
	1.500	6					
	1.500	53					
15	3.000	70	0.58727	0.17109	0.74660	5.06609	10.8516
	3.000	2					
	3.000	56					
	3.000	12					
	3.000	3					

With DG : 5 DG case

Total DG size = 15 MW: (in the decreasing order of savings)

Savings Choice no:	P_{DG} Total (MW)	DG size (MW)	Bus no	DG cost (Rs/hr)	$P_{utility}$ cost (Rs/hr)	Savings (Rs/hr)	NPEI choice no:
1	15	6.000	29	18000	20143.96	42752.84	3
		3.000	48				
		3.000	10				
		1.500	71				
		1.500	4				
2	15	7.500	2	19125	20178.96	41592.84	4
		3.000	10				
		1.500	68				
		1.500	6				
		1.500	53				
3	15	4.500	6	19875	20098.44	40923.36	1
		6.000	56				
		1.500	9				
		1.500	46				
		1.500	59				
4	15	4.500	4	20250	20125.08	40521.72	2
		4.500	70				
		3.000	33				
		1.500	12				
		1.500	49				
5	15	3.000	70	22500	20264.36	38132.44	5
		3.000	2				
		3.000	56				
		3.000	12				
		3.000	3				

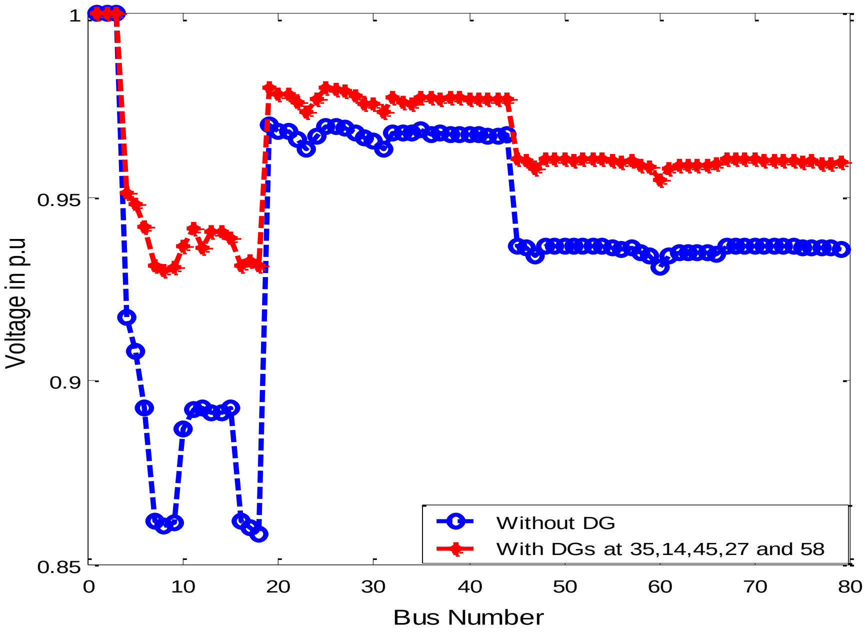


Figure 4.24 Voltage plot with DGs at 35, 14, 45, 27 and 58

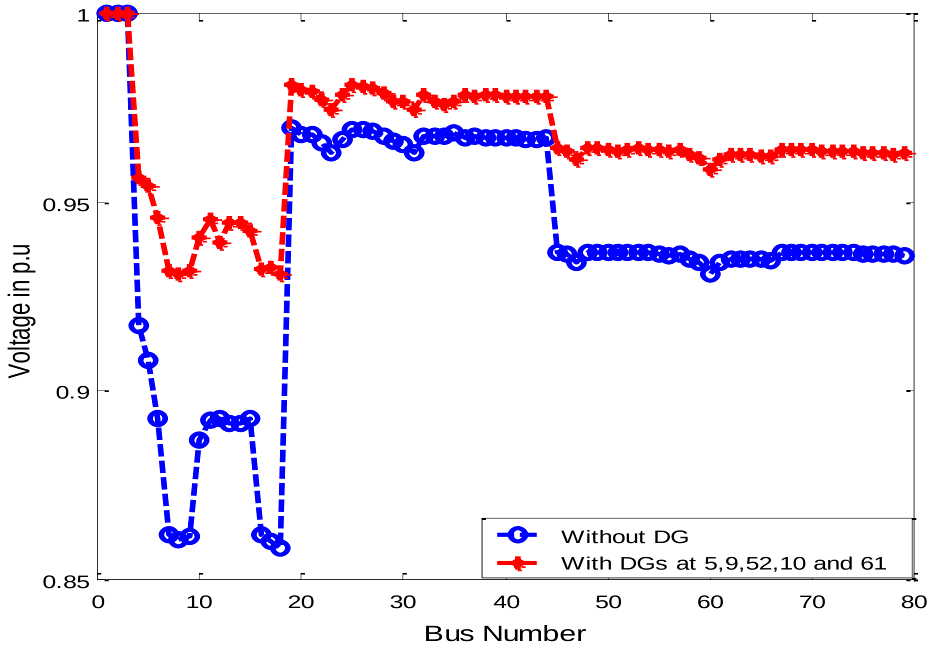


Figure 4.25 Voltage plot with DGs at 5, 9, 52, 10 and 61

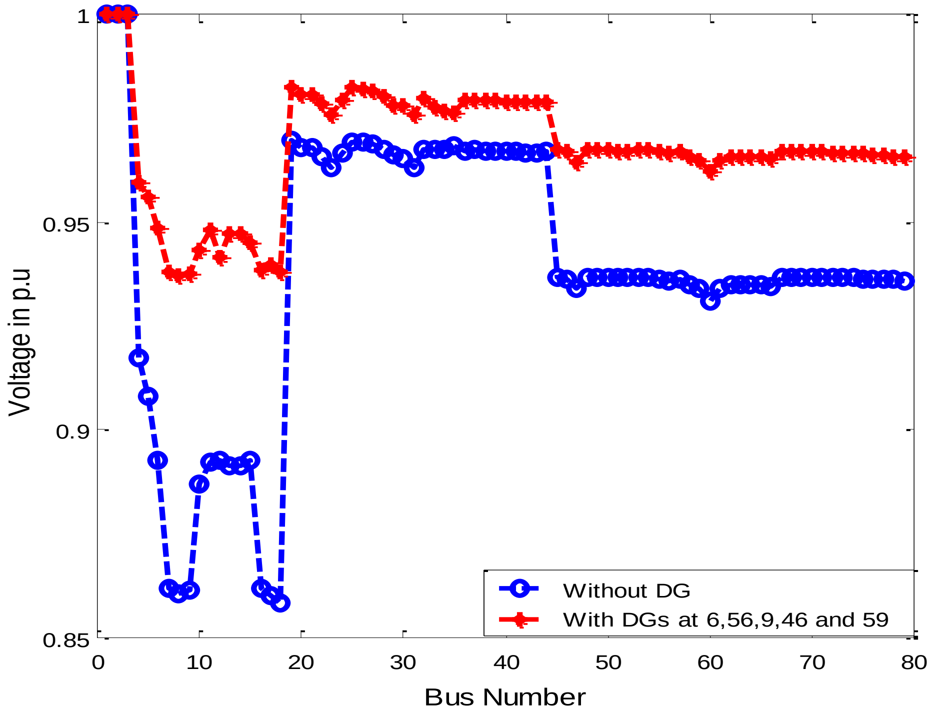


Figure 4.26 Voltage plot with DGs at 6, 56, 9, 46 and 59

4.9.7 Load variation

In 90 bus system when the total DG capacity is 1 MW, it can meet only 10% and 20% of the total system load. When total DG capacity is 2 MW, it can meet 10%, 20%, 30%, 40% and 50% of the total system load. When the total DG capacity is 3 MW, it can meet 10%, 20%, 30%, 40%, 50%, 60%, and 70% of the total system load. When load demand exceeds the total DG capacities remaining load demand has to be supplied by the utility. Between zero and the maximum capacity the DG can be tuned to any capacity.

90 bus system: Total DG capacity = 5 MW (Bus no: 15, 44 and 5)

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am $(P_{load} > P_{DG})$	30	5.835	1.875 1.875 1.250	0.62961	1.06620	10.5703	0.09770	0.46532	69444.5
8 am-10 am $(P_{load} > P_{DG})$	40	7.780	1.875 1.875 1.250	0.63122	3.05415	10.5741	0.09615	0.46914	61492.7
10 am-12 $(P_{load} > P_{DG})$	70	13.62	1.875 1.875 1.250	0.61290	9.05273	10.7659	0.12623	0.66088	37498.4
12 -2 pm $(P_{load} > P_{DG})$	100	19.45	1.875 1.875 1.250	0.55899	15.1048	11.2347	0.20981	1.12971	13290.1
2 pm- 4 pm $(P_{load} > P_{DG})$	80	15.56	1.875 1.875 1.250	0.59913	11.0641	10.8909	0.14805	0.78590	29452.9
4 pm- 6pm $(P_{load} > P_{DG})$	70	13.62	1.875 1.875 1.250	0.61290	9.05273	10.7659	0.12623	0.66088	37498.4
6 pm-8 pm $(P_{load} > P_{DG})$	90	17.51	1.875 1.875 1.250	0.58106	13.0814	11.0471	0.17588	0.94205	21383.7
8 pm-10 pm $(P_{load} > P_{DG})$	100	19.45	1.875 1.875 1.250	0.55899	15.1048	11.2347	0.20981	1.12971	13290.1
10 pm- 12 $(P_{load} > P_{DG})$	60	11.67	1.875 1.875 1.250	0.62305	7.04735	10.6716	0.11035	0.56663	45519.9
12- 2 am $(P_{load} > P_{DG})$	50	9.725	1.875 1.875 1.250	0.62906	5.04784	10.6078	0.10034	0.50282	53517.9
2 am-4 am $(P_{load} < P_{DG})$	10	1.945	0.729 0.729 0.487	0.63932	0.12510	10.5092	0.08060	0.40420	77599.9
4 am- 6 am $(P_{load} < P_{DG})$	20	3.890	1.459 1.459 0.972	0.63311	0.18006	10.5459	0.09106	0.44093	74585.1

90 bus system: Total DG capacity = 10 MW (Bus no: 38, 4 and 71)

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am $(P_{load}<P_{DG})$	30	5.835	1.459 1.459 2.917	0.63647	0.21892	10.5290	0.08542	0.42400	70539.6
8 am-10 am $(P_{load}< P_{DG})$	40	7.780	1.945 1.945 3.890	0.63266	0.26983	10.5538	0.09183	0.44885	67174.9
10 am-12 $(P_{load}> P_{DG})$	70	13.62	2.500 2.500 5.000	0.62459	4.03458	10.6294	0.10808	0.52440	48508.5
12 -2 pm $(P_{load}> P_{DG})$	100	19.45	2.500 2.500 5.000	0.59206	10.0567	10.9131	0.16171	0.80808	24420.0
2 pm- 4 pm $(P_{load}> P_{DG})$	80	15.56	2.500 2.500 5.000	0.61777	6.03602	10.6933	0.12002	0.58828	40502.7
4 pm- 6pm $(P_{load}> P_{DG})$	70	13.62	2.500 2.500 5.000	0.62459	4.03458	10.6294	0.10808	0.52440	48508.5
6 pm-8 pm $(P_{load}> P_{DG})$	90	17.51	2.500 2.500 5.000	0.60695	8.04337	10.7878	0.13787	0.68272	32473.3
8 pm-10 pm $(P_{load}> P_{DG})$	100	19.45	2.500 2.500 5.000	0.59206	10.0567	10.9131	0.16171	0.80808	24420.0
10 pm- 12 $(P_{load}> P_{DG})$	60	11.67	2.500 2.500 5.000	0.62753	2.03899	10.5958	0.10199	0.49078	56490.8
12- 2 am $(P_{load}< P_{DG})$	50	9.725	2.431 2.431 4.863	0.62780	0.32257	10.5857	0.10007	0.48074	63803.0
2 am-4 am $(P_{load}< P_{DG})$	10	1.945	0.486 0.486 0.973	0.64088	0.12258	10.5006	0.07808	0.39564	77245.5
4 am- 6 am $(P_{load}< P_{DG})$	20	3.890	0.973 0.973 1.944	0.63921	0.16983	10.5113	0.08083	0.40626	80211.2

90 bus system: Total DG capacity = 15 MW (Bus no: 61, 27, and 26)

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am ($P_{load}<P_{DG}$)	30	5.835	2.188 2.188 1.459	0.54134	0.40502	11.0611	0.27152	0.95612	79268.3
8 am-10 am ($P_{load}< P_{DG}$)	40	7.780	2.918 2.918 1.944	0.46896	0.59710	11.4903	0.41910	1.38528	67325.4
10 am-12 ($P_{load}<P_{DG}$)	70	13.62	5.106 5.106 3.403	0.13385	1.42753	13.5269	1.11603	3.42194	55615.7
12 -2 pm ($P_{load}> P_{DG}$)	100	19.45	5.625 5.625 3.750	0.79707	6.17146	14.0311	1.27646	3.92608	34648.4
2 pm- 4 pm ($P_{load}< P_{DG}$)	80	15.56	5.625 5.625 3.750	0.07787	2.24894	14.1646	1.33294	4.05968	50338.5
4 pm- 6pm ($P_{load}< P_{DG}$)	70	13.62	5.106 5.106 3.403	0.13385	1.42753	13.5269	1.11603	3.42194	55615.7
6 pm-8 pm ($P_{load}> P_{DG}$)	90	17.51	5.625 5.625 3.750	0.07763	4.20734	14.0830	1.30184	3.97802	42504.9
8 pm-10 pm ($P_{load}> P_{DG}$)	100	19.45	5.625 5.625 3.750	0.07971	6.17146	14.0311	1.27646	3.92608	34648.4
10 pm- 12 ($P_{load}< P_{DG}$)	60	11.67	4.376 4.376 2.918	0.26202	1.10632	12.7163	0.83932	2.61129	59695.5
12- 2 am ($P_{load}< P_{DG}$)	50	9.725	3.647 3.647 2.431	0.37571	0.83039	12.0403	0.60789	1.93534	63595.7
2 am-4 am ($P_{load}< P_{DG}$)	10	1.945	0.729 0.729 0.487	0.62917	0.14390	10.5616	0.09940	0.45655	77524.7
4 am- 6 am ($P_{load}< P_{DG}$)	20	3.890	1.459 1.459 0.972	0.59350	0.25374	10.7511	0.16474	0.64608	74290.3

90 bus system: Total DG capacity = 5 MW (Bus no: 16, 47, 15, 59 and 49

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am (P_{load}> P_{DG})	30	5.835	1.500 1.500 1.000 0.500 0.500	0.61494	1.09445	10.6397	0.12595	0.53468	69769.0
8 am-10 am (P_{load}> P_{DG})	40	7.780	1.500 1.500 1.000 0.500 0.500	0.61870	3.07838	10.6343	012038	0.52927	61833.3
10 am-12 (P_{load}> P_{DG})	70	13.62	1.500 1.500 1.000 0.500 0.500	0.60748	9.06450	10.7969	0.13802	0.69191	37888.8
12 -2 pm (P_{load}> P_{DG})	100	19.45	1.500 1.500 1.000 0.500 0.500	0.56099	15.1034	11.2342	0.20843	1.12916	13733.2
2 pm- 4 pm (P_{load}> P_{DG})	80	15.56	1.500 1.500 1.000 0.500 0.500	0.59732	11.0715	10.9117	0.15554	0.80671	29860.8
4 pm- 6pm (P_{load}> P_{DG})	70	13.62	1.500 1.500 1.000 0.500 0.500	0.60748	9.06450	10.7969	0.13802	0.69191	37888.8
6 pm-8 pm (P_{load}> P_{DG})	90	17.51	1.500 1.500 1.000 0.500 0.500	0.58194	13.0845	11.0573	0.17898	0.95234	21808.8
8 pm-10 pm (P_{load}> P_{DG})	100	19.45	1.500 1.500 1.000 0.500 0.500	0.56099	15.1034	11.2342	0.20843	1.12916	13733.2
10 pm- 12 (P_{load}> P_{DG})	60	11.67	1.500 1.500 1.000 0.500 0.500	0.61505	7.06336	10.7126	0.12636	0.06076	45893.4
12- 2 am (P_{load}> P_{DG})	50	9.725	1.500 1.500 1.000 0.500 0.500	0.61876	5.06799	10.6585	0.12049	0.55349	53874.8
2 am-4 am (P_{load}< P_{DG})	10	1.945	0.583 0.583 0.389 0.195 0.195	0.63694	0.12970	10.5205	0.08520	0.41548	77751.5
4 am- 6 am (P_{load}< P_{DG})	20	3.890	1.167 1.167 0.778 0.389 0.389	0.62362	0.19829	10.5906	0.10929	0.48556	74852.1

90 bus system: Total DG capacity = 10 MW (Bus no: 5, 9, 52, 10 and 61)

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am ($P_{load} < P_{DG}$)	30	5.835	1.751 2.334 0.584 0.583 0.583	0.63357	0.22263	10.5527	0.08913	0.44765	72275.5
8 am-10 am ($P_{load} < P_{DG}$)	40	7.780	2.334 3.112 0.778 0.778 0.778	0.62762	0.27650	0.10596	0.09850	0.49109	69482.3
10 am-12 ($P_{load} > P_{DG}$)	70	13.62	3.000 4.000 1.000 1.000 1.000	0.62157	0.40376	10.6603	0.11112	0.55526	66031.8
12 -2 pm ($P_{load} > P_{DG}$)	100	19.45	3.000 4.000 1.000 1.000 1.000	0.59816	10.0464	10.8787	0.15141	0.77373	27461.2
2 pm- 4 pm ($P_{load} > P_{DG}$)	80	15.56	3.000 4.000 1.000 1.000 1.000	0.61767	6.03467	10.7027	0.11867	0.59771	43508.1
4 pm- 6pm ($P_{load} > P_{DG}$)	70	13.62	3.000 4.000 1.000 1.000 1.000	0.62157	0.40376	10.6603	0.11112	0.55526	66031.8
6 pm-8 pm ($P_{load} > P_{DG}$)	90	17.51	3.000 4.000 1.000 1.000 1.000	0.60968	8.03758	10.7755	0.13208	0.67043	35496.5
8 pm-10 pm ($P_{load} > P_{DG}$)	100	19.45	3.000 4.000 1.000 1.000 1.000	0.59816	10.0464	10.8787	0.15141	0.77373	27461.2
10 pm- 12 ($P_{load} > P_{DG}$)	60	11.67	3.000 4.000 1.000 1.000 1.000	0.62169	2.04637	10.6478	0.10937	0.54279	59461.3
12- 2 am ($P_{load} < P_{DG}$)	50	9.725	2.918 3.890 0.973 0.972 0.972	0.62003	0.33304	10.6519	0.11054	0.54691	66679.6
2 am-4 am ($P_{load} < P_{DG}$)	10	1.945	0.584 0.778 0.195 0.194 0.194	0.64051	0.12296	10.5031	0.07846	0.39815	77828.5
4 am- 6 am ($P_{load} < P_{DG}$)	20	3.890	1.167 1.556 0.389 0.389 0.389	0.63787	0.17144	10.5216	0.08244	0.41665	75056.8

90 bus system: Total DG capacity = 15 MW (Bus no: 6, 56, 9, 46 and 59)

Duration	% load	DG total	DG sizes	NPEI	P utility	Q utility	P loss	Q loss	Savings
6 am- 8 am (P_{load}< P_{DG})	30	5.835	1.751 2.334 0.584 0.583 0.583	0.63740	0.21705	10.5242	0.08355	0.41928	72297.9
8 am-10 am (P_{load}< P_{DG})	40	7.780	2.334 3.112 0.778 0.778 0.778	0.63433	0.26654	10.5455	0.08854	0.44056	69522.1
10 am-12 (P_{load}< P_{DG})	70	13.62	4.085 5.446 1.362 1.361 1.361	0.62004	0.42357	10.6458	0.11207	0.05408	61163.3
12 -2 pm (P_{load}> P_{DG})	100	19.45	4.500 6.000 1.500 1.500 1.500	0.61185	5.02461	10.7276	0.12961	0.62262	40923.4
2 pm- 4 pm (P_{load}< P_{DG})	80	15.56	4.500 6.000 1.500 1.500 1.500	0.61614	1.03515	10.6753	0.11915	0.57033	56881.2
4 pm- 6pm (P_{load}< P_{DG})	70	13.62	4.085 5.446 1.362 1.361 1.361	0.62004	0.42357	10.6458	0.11207	0.05408	61163.3
6 pm-8 pm (P_{load}> P_{DG})	90	17.51	4.500 6.000 1.500 1.500 1.500	0.61589	3.02697	10.6864	0.12147	0.58147	48913.9
8 pm-10 pm (P_{load}> P_{DG})	100	19.45	4.500 6.000 1.500 1.500 1.500	0.61185	5.02461	10.7276	0.12961	0.62262	40923.4
10 pm- 12 (P_{load}< P_{DG})	60	11.67	3.501 4.668 1.167 1.167 1.167	0.62564	0.36981	10.6063	0.10281	0.50134	63954.8
12- 2 am (P_{load}< P_{DG})	50	9.725	2.918 3.890 0.973 0.972 0.972	0.63041	0.31746	10.57289	0.09496	0.46788	66741.9
2 am-4 am (P_{load}< P_{DG})	10	1.945	0.584 0.778 0.195 0.194 0.194	0.64097	0.12237	10.5001	0.07787	0.39509	78811.4
4 am- 6 am (P_{load}< P_{DG})	20	3.890	1.167 1.556 0.389 0.389 0.389	0.63961	0.16899	10.5091	0.07999	0.40414	75066.6

4.8 Conclusive Remarks

- The criteria for multiple DG source insertions for distribution system developed with the help of proposed network performance enhancement index. This index is a combination of indices for technical parameters of system and will help in judgement of location of the multiple DG sources. The priority list of the optimal locations and size of DG sources is prepared to help the system designer to choose most feasible locations.
- Economic analysis of multiple DG sources insertion has been carried out. This analysis helps the designer to estimate the amount of savings in operational costs in integrated operation of utility and DG sources. Based on this analysis the designer can apply trade-off between best technical choice based on NPEI and best economical choice. The priority list generated helps to decide on most realistic solution
- As the load demand on distribution system is varying in different durations of the day, it is very crucial to decide the generation through DG sources meeting this varying load demand. To facilitate this process of DG capacity allocation, a load curve is considered as a percentage of peak system load. The amount of DG power generation in different durations have been arrived at. As long as total DG capacity is sufficient to meet the system load in any duration of the day, power drawn from the utility is less. Once the load demand exceeds the total DG capacities, then share of utility increases to address the increased load. The analysis reveals the system conditions in such scenario.
- The technical analysis gives the technically feasible solution based on potential as well as type of DG sources and economic analysis improves the solution by arriving at more economical solution. Hence both technically and economically feasible can be obtained in tandem manner.

To validate the analysis and proposals made in this work, three systems with different load demand are considered. The data for 33 bus, 69 bus and 90 bus system are taken from reported literature. The criteria proposed has demonstrated the flexibility for the designer in choosing the most feasible locations and corresponding size of DG sources.

CHAPTER 5

ROLE OF DG SOURCES IN POST FAULT NETWORK RECONFIGURATION

5.1. Introduction

The role of DG is much crucial when distribution system is subjected to fault. The process of isolation of fault will lead to disconnection of certain portion of the network from supply. By means of switching alternate paths, the power supply in those disconnected areas can be restored. However this will change the network topology and system operating conditions. The DG sources placed at some previously selected locations play a role in deciding the best route for reconfiguration.

In the areas of loss reduction with DG, the methods for determining optimal sizes and capacities of DG units in HV and LV systems were proposed from the view point of planning states [93]. A technique for loss reduction and load balancing using network reconfiguration in distribution system was developed by changing the status of sectionalizing switches and implemented for loss reduction or load balancing due to branch exchange in the system [37].

An algorithm for determining the minimum loss configuration of radial distribution network based on the concept of optimum power flow pattern by solving the KVL and KCL equation of the network was developed [94]. An approach to solve the distribution feeder reconfiguration problem for loss reduction and service restoration was proposed with an efficient algorithm. By using that algorithm, a more effective network reconfiguration had been carried out with reduction in power loss. Branch voltage-drops and line constants were used with all electrical constraints. Meshed networks were considered instead of tie radial topology by closing all the tie switches. By considering only the largest switching index in each loop, the algorithm adopted reduced the number of feasible states drastically. Tie switching index was also be used for service restoration [95].

Another technique had been proposed focussing on determination of network reconfiguration strategies at power distribution system with dispersed generators for loss reduction by using genetic algorithm approach [97]-[98]. The network reconfiguration at the power distribution systems with dispersed generations (DG) putting emphasis on loss reduction was discussed and recommendations for the reconfiguration process were devised [99]. Conventional power distribution systems have a radial network and unidirectional power flows. With the advent of dispersed generations, the power distribution system have a locally looped network and bidirectional power flows Therefore insertion of DG into the power distribution system can cause operational problems and impact on existing operational schemes. There are several operational schemes in power distribution systems [85].

The operation strategies for network reconfiguration in the automated Distribution systems were developed in recent past. In this approach, DG is considered as a real-time operation tool and loss reduction and service restoration is attempted from the point of view of distribution operation and control [17]. The allocation of power losses to consumers connected to radial distribution networks before and after network reconfiguration in a deregulated environment was proposed to address the market economy .The loss allocation is made in a quadratic way and it is based on identifying the real and imaginary parts of current in each branch, and losses are allocated to consumers [18].The network reconfiguration algorithm is based on the fuzzy multi-objective approach and the max–min principle is adopted for the optimization in a fuzzy frame work.

The approach on the basis handling insufficiency of genetic algorithm in the solution of distribution network reconfiguration was developed, and an improved immune genetic algorithm (IIGA) was proposed. The artificial intelligence techniques were applied for network reconfiguration. The strategies developed aim at altering power flow through the lines, leading to power loss reduction and voltage improvement in radial distribution systems. [100-103].

A reconfiguration methodology based on an Ant Colony Algorithm (ACA) which aims at achieving the minimum power loss and increment load balance factor of radial distribution networks with distributed generators was developed [11].

The problem of service restoration with distributed generation sources, in situations wherein enough capacity is not available to restore the entire out of service area was addressed in recent literature. In the reported work it was suggested that the network operator can implement intentional island operation with the support of black-start DG [22].

The network reconfiguration with DG sources is very crucial in distribution system operation and control. The strategies to be adopted need to include the prevailing load demand on the system, availability of DG capacities, location of fault and fault isolation and closing of tie switches. The network reconfiguration made should result in efficient performance of the network in terms of power loss and voltage profile. In this context, the work carried out to develop to investigate the role of DG sources in post fault reconfiguration with the following objectives is given in this chapter.

1. To identify possible schemes for network reconfiguration.
2. To recommend the most efficient scheme for reconfiguration in the event of fault in any location. The reconfiguration is done with an effort to minimise service discontinuity.
3. To suggest alternative reconfiguration schemes in order to enable the system operator to select the most feasible configuration depending on the circumstances.
4. To determine the DG islanding operation scenarios in the simultaneous multiple fault scenarios.

5.2. Network Reconfiguration with DG Sources

Feeder reconfiguration is a necessary process in automated distribution systems to reduce distribution feeder losses and improve system operation. Load transfer can be achieved by transferring loads from one feeder to another by altering the open/close status of the feeder switches. There are a number of closed and normally opened switches in a distribution system, and the combinations of possible switching operations are tremendous. Thus feeder reconfiguration becomes a complex decision-making and time-consuming process for system operators. The distribution network reconfiguration helps in maintaining service continuity and the objective will be to get efficient operation of the system in the reconfigured structure of the network. This is achieved by changing the status of numerous normally closed and normally open switches existing in the initial configuration of distribution system [16].

5.2.1 Importance of DG sources in loss reduction

There are several operational procedures in power distribution systems, one of which is network reconfiguration. This is one of the most important functions of the automated distribution system in a normal operation state. The presence of DG sources will give benefit of loss reduction. However, the process of network reconfiguration will be difficult with DG sources. This is due to the fact that, with DGs, more than one source exists in network and system architecture is more complex. In recent literature, the researchers have attempted to device techniques to handle DGs in network reconfiguration. The network reconfiguration approach for loss minimization which was reported in [16] [17] is adopted in this work and its formulation is as follows:

$$\text{Minimize } L = \sum_{i=1}^{n} loss_i$$

Where, n is the number of branch and, $loss_i$: loss at branch i

The constraints set are as below: .

1. Radial structure for distribution network is considered.
2. All buses in the network are energised
3. Each bus is having good voltage profile within acceptable limits
4. The network components like feeders, switches carry current within their ratings.

5.2.2 Strategies for Loss Reduction

In case the DG locations and their sizes in the system are known, then the network reconfiguration problem can be addressed with the objective of loss reduction. As conceived in past literature, the treatment of DG is done by representing it as negative load, that is constant power sink. This amounts to taking current flowing reverse to load. The modern instrumentation is employed in automation systems and all the measurement parameters like bus voltages and currents can be recorded. The status of each load can be computed with state estimating techniques. That is the DG sources are embedded into the distribution network. Due to this process, another constraint pertaining to reverse power of DG which should be within acceptable limits is to be introduced.

While designing the distribution network, the installation node and capacity of DG units may not be optimally selected. The governing factors for this situation could be availability of resource for power generation, the economics of operation and environmental policies. The independent power producers are responsible for installation and operation of DG sources in such locations. Controlling such multiple generation sources is extremely difficult in the absence of coordination between all agencies involved. The location and capacities of DGs will play crucial role in the power losses in the system. Any non optimal solution will deteriorate the network operation. Hence it is always beneficial to reconfigure the initial network without DG sources to an optimal network with DG sources. This step is necessary to get the healthy status for the network. The series of operations of closing the normally open switches and opening the normally closed switches is carried out to get optimum network with DGs. This optimal network with DGs become the best configuration and used subsequently as base configuration for network reconfiguration under fault conditions. It is evident that, the restructures network after fault isolation will not be the optimal network. However the possible best configuration close to the optimal configuration with DG sources has to be found out to improve the performance of the system. The flow chart for implementation of the network reconfiguration strategy is given in Figure 5.1

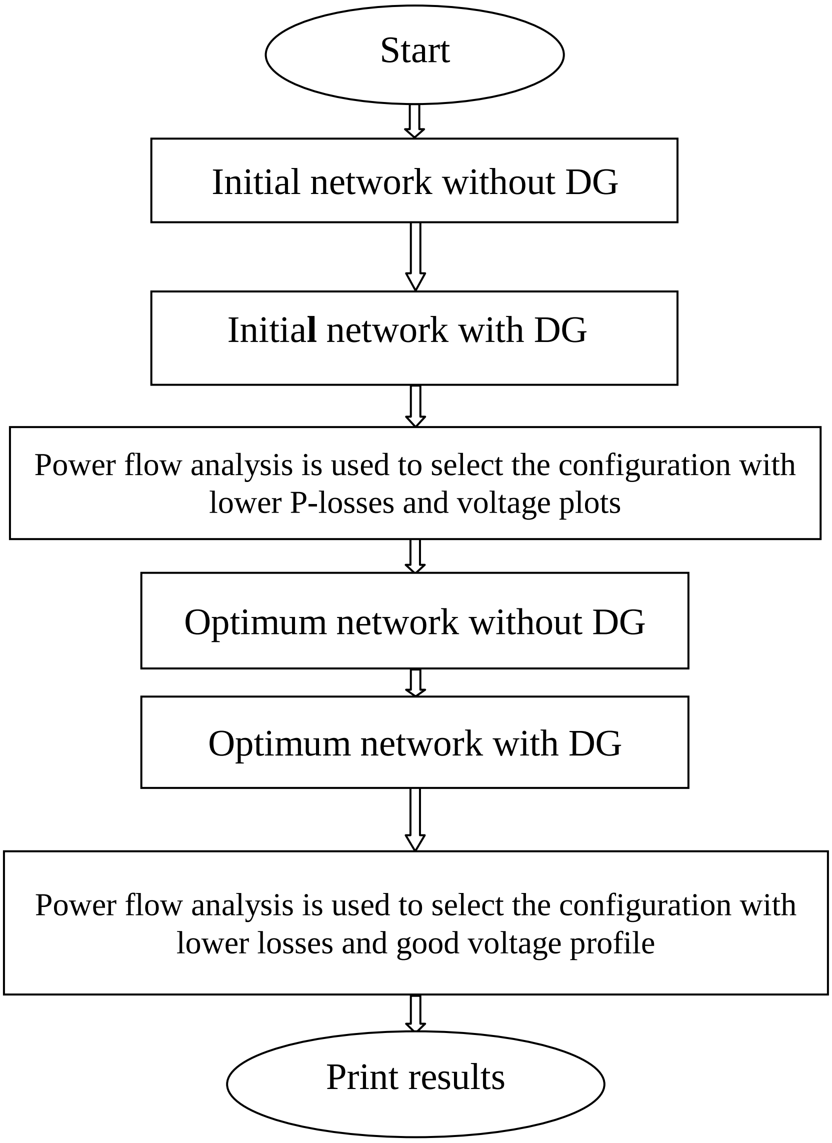


Figure 5.1 Flow chart for network reconfiguration

5.3 Service Restoration with DG sources

The reliability of service will be enhanced substantially with presence of DG sources. This is due to the fact that, in the event of acute shortage of power supply from utility, the DGs can operate in island mode and serve the consumers. However to achieve this, interaction between all independent power producers operating DG sources is very crucial. The protective devices should operate in proper coordination to prevent any damage due to maloperation. In a nutshell careful planning is necessary and operational strategies to be devised when DGs are working in distribution system.

Keeping track of the load variations is very much essential during islanding operation of DG unit. The occurrence of the fault has to be detected appropriately and decision to stop DG operation has to be taken by sensing appropriate signals of fault occurring within islanding region. Once DG source is blocked from generation, bringing it back to the network demands synchronisation with utility source again. Hence the instrumentation play key role in this process and automated scheme has to be put in place to re-integrate the utility and DG sources. It has to be ensured that all parameters for synchronisation must be met as quickly as possible with the help of control circuitry.

As discussed above the DGs contribute for efficient operation of the network during reconfiguration. In addition, they help to maintain service continuity in intentional islanding mode. The suitable control strategies have to be devised to handle this complex operation. The latest control technologies should be used in implementation of developed strategies. The service restoration strategy reported in [17] is employed in this work for building approach to service restoration with DG sources.

5.3.1 Strategies for Service Restoration

In order to consider DGs in network reconfiguration process, few aspects needs to be accounted. These aspects are grouped into three classifications as recommended in the literature [17].

1. The start-up and intentional isolation capability of DG
2. The extent of Controllability of DG in distribution automation
3. The post fault status of DG after isolation of fault. This pertains to interconnection condition of DG.

The first aspect of start-up and intentional isolation capability of DG is the most important factor in network reconfiguration. This factor decides the possibility if service restoration after isolation of fault. There can be two varieties of DGs based on start-up capability as below:

1. BDG (Black-start DG): These types of DGs are having intentional islanding capability. The type of DG could be cogeneration, separated excited power converter and Separate-excited machine etc. The energy source availability is not a constraint for this type of DG.

2. NBDG (Non Black-start DG): These types of DGs are having uncertainty of source availability. Hence they cannot be considered for intentional islanding operation. The examples are Wind generation, photovoltaic, etc.

As discussed earlier, the controlling actions play key role in network reconfiguration process and achieved successfully through distribution automation schemes. According to controllability features, the facilities for communication between independent power producers and the utility, further classification can be done as below:

1. CDG (Controllable DG): The independent power producer has all necessary control and communication devices and operates coherently with Master Control Station.

2. NCDG (Non-controllable DG): In this type, there are no possibilities of coordinated operation with utility, as the DGs are not provided with the necessary hardware and software for control and communication.

The fault in a distribution network has to be isolated by opening of the nearby switches. This process alters the interconnection status of DGs and they are categorises as follows:

1. SDG (Survived DG): These DG sources remain interconnected with utility after fault isolation.

2. NSDG (Non-Survived DG): These type of DG sources get disconnected from utility, that is go out of integrated operation due to fault isolation.

With the help of above classifications, the strategy for service restoration is formed as below:

1. Fault location in the network is identified.
2. The fault section is isolated.
3. The DG inter-connection status as survived (SDG) or non survived (NSDG) is determined.

4. The optimal configuration with objective of minimizing service discontinuity area is attempted as option-1. This is subjected to the satisfying following criteria.

   a. Voltage and Currents in the network are within limits.

   b. The network restoration will not include NSDG sources.

   c. SDG units are considered as negative load and continue to be interconnected with utility grid.

5. If any area remain un-restored, then step 6 is executed, else step 7 can be performed.

6. The DG capability as BDG or NBDG or CDG or NCDG is identified. This is required to evaluate possibility of intentional island operation. This process called as option -2

   Intentional Island Operation Mode :

   All DG units with B.D.G and C.D.G are considered for finding new routes. By identifying the existence of such paths, the service discontinuity can be minimised with the help of these DGs.

7. NSDG units brought back to the network by the synchronous operation if their interconnected buses are strong enough.

8. All NSDG units are re- integrated to the network.

   a. If there is no better choice, the current status is maintained. Otherwise step 6 is executed.

   b. If the fault is completely cleared, then system will return to normal operation configuration.

5.4 Case Studies and Results

To verify the effectiveness of proposed approach, the power flow algorithm described in the chapter 4 is employed, the studies on performance of distribution system with DGs for network reconfiguration configuration have been undertaken. The methodology has been implemented in the MATLAB® environment.

5.4.1 Optimum Configuration of 33 Bus Test System

The radial system with 33 buses and 32 branches with the total load of 3.715 MW and 2.28 MVAR, is considered for analysis [17]. The initial network without DG sources is shown in Figure 5.2 The initial network with insertion of DGs at bus numbers 4,7, 25, 30 is shown in Figure 5.3

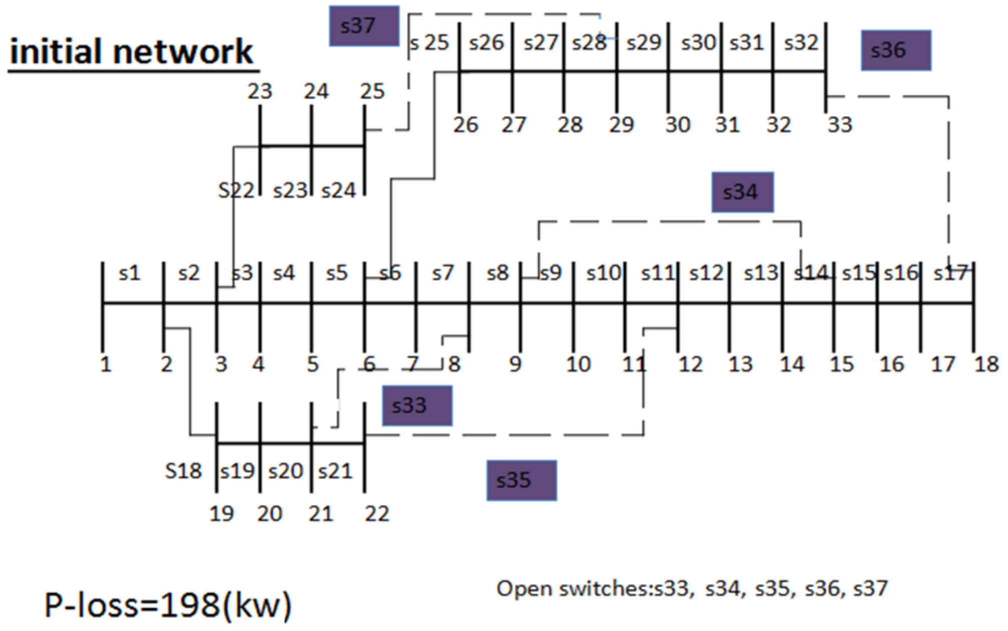


Figure 5.2 Initial network without DG

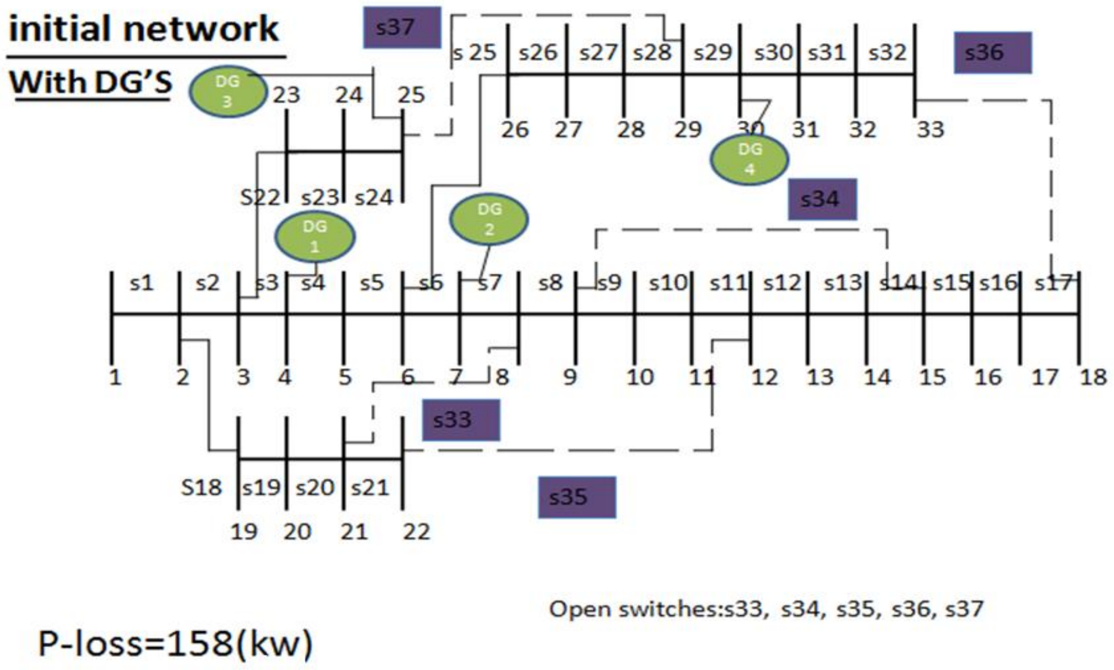


Figure 5.3 Initial network with DGs at 4, 7, 25, 30

The capacities of the DG sources at different buses is given in Table 5.1. These capacities are generally depend on potential of DG sources and independent power producer . Hence these capacities may not be optimal sizes of DGs [17].

Table 5.1 Capacities of DG sources

Bus number	DG capacity(kw)
4	50
7	100
25	200
30	100

The voltage profile plots for initial network without DGs and initial network with DGs are given in Figure 5.4 and 5.5 respectively.

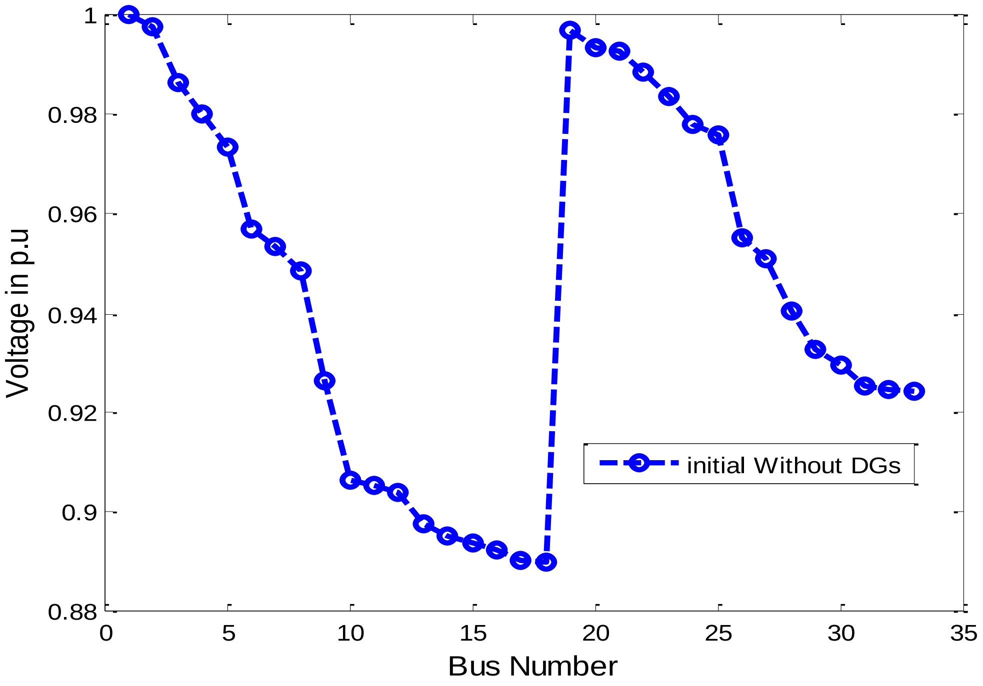


Figure 5.4 Voltage Profile Plot without DGs

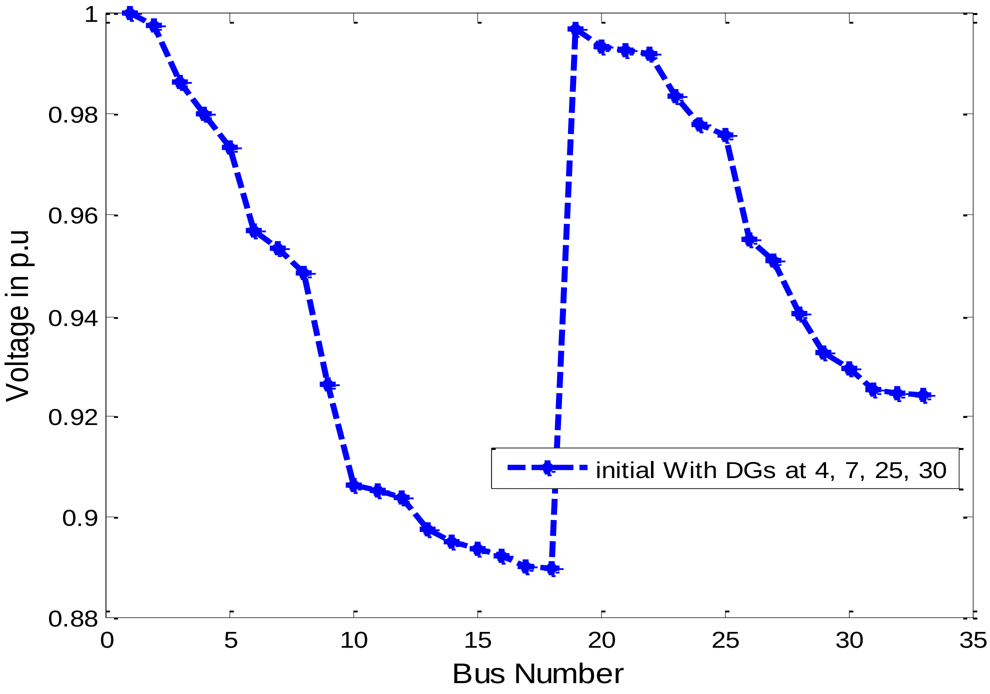


Figure 5.5 Voltage Profile Plot with DGs at 4, 7, 25 and 30

As a first step in the study, the reconfiguration of the initial network without DGs to get optimum network without DGs is attempted. Table 5.2 gives four possible reconfiguration schemes. The first scheme with power losses of 136 kW is the most optimum network without DGs. By choosing this configuration the losses will reduce from 198 kW to 136 kW. This optimal configuration is shown in Figure 5.6.

Table 5.2 Reconfiguration Schemes network without DG's

Open switches	Power Loss (kW)
S7, S9, S14, S32, S37	136
S7, S14, S35, S28, S32	174
S33, S34, S35, S36, S37	198
S33, S35, S17, S34, S24	225

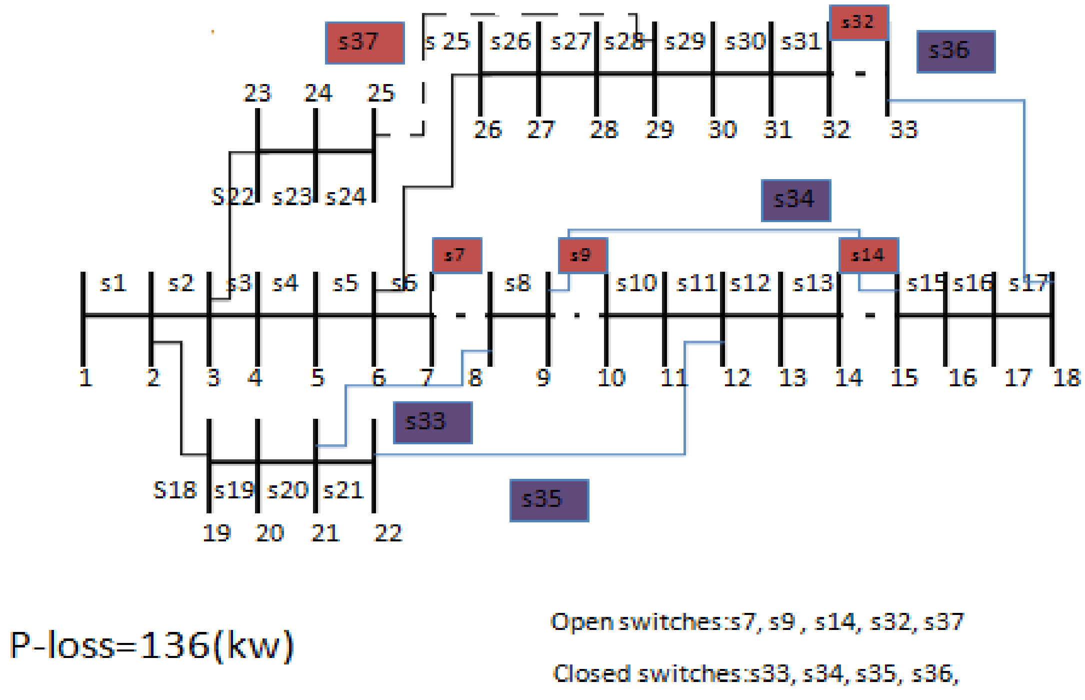
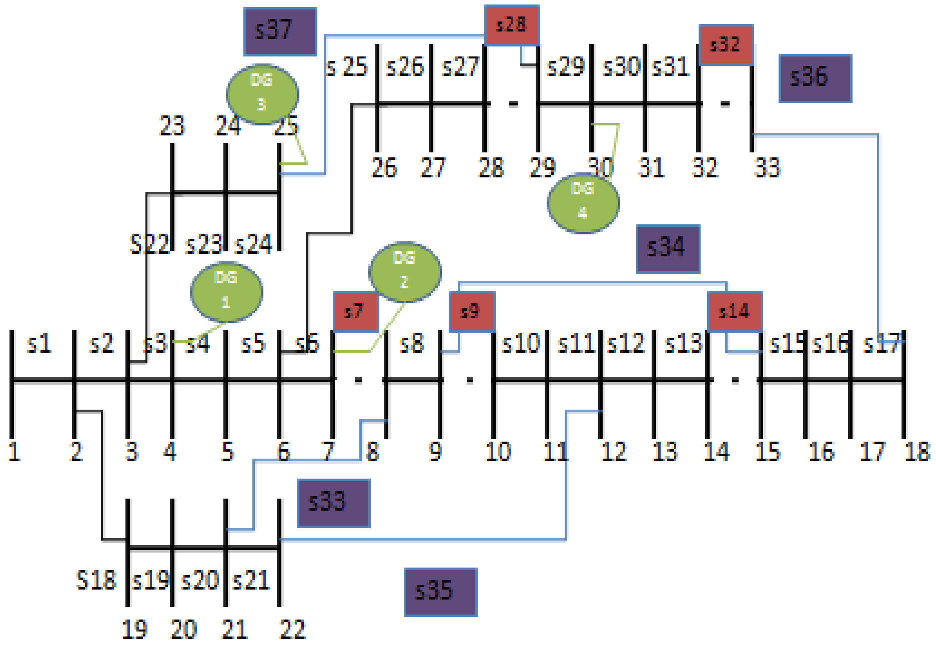


Figure 5.6 Optimum Network without DG

In the next step, reconfiguration scheme is arrived at to find the optimum network in presence of DGs. As given in Table 5.3, the insertion of DGs will bring down the system losses to 108 kW. The reconfiguration scheme is given in Figure 5.7. The voltage profile plots for optimum network without DGs and optimum network with DGs are given in Figures 5.8 and 5.9 respectively.

Table 5.3 Reconfiguration Schemes for optimum network with DG's

Open switches	Power Loss (kW)
S7, S9, S14, S32, S28	108
S33, S34, S35, S36, S37	158
S33, S35, S17, S34, S37	199



P-loss=108(kw)

Open switches:s7, s9 , s14, s32, s28

Closed switches:s33, s34, s35, s36, s37

Figure 5.7 Optimum Network with DGs at 4, 7, 25 and 30

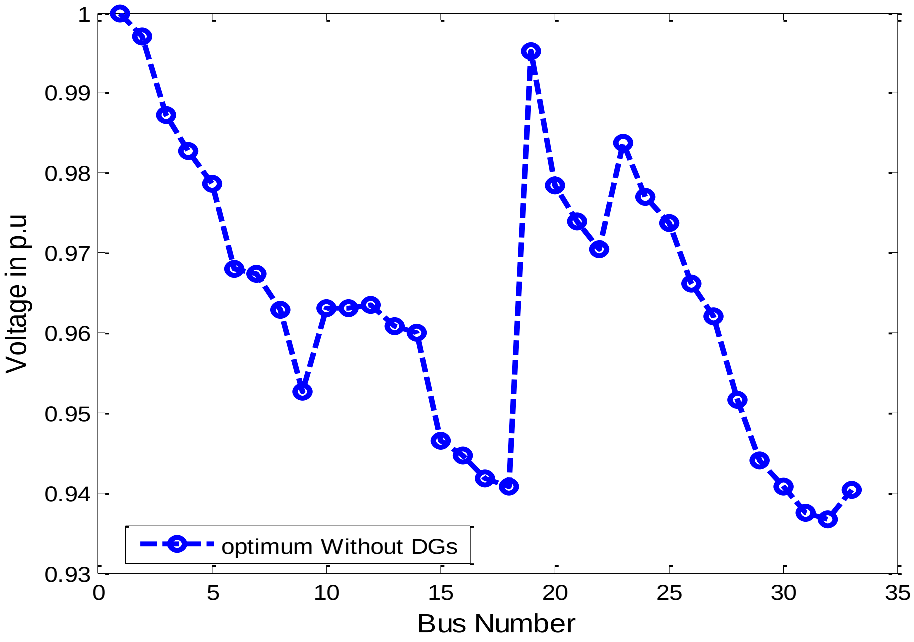


Figure 5.8 Voltage Profile Plot of Optimum Network without DGs

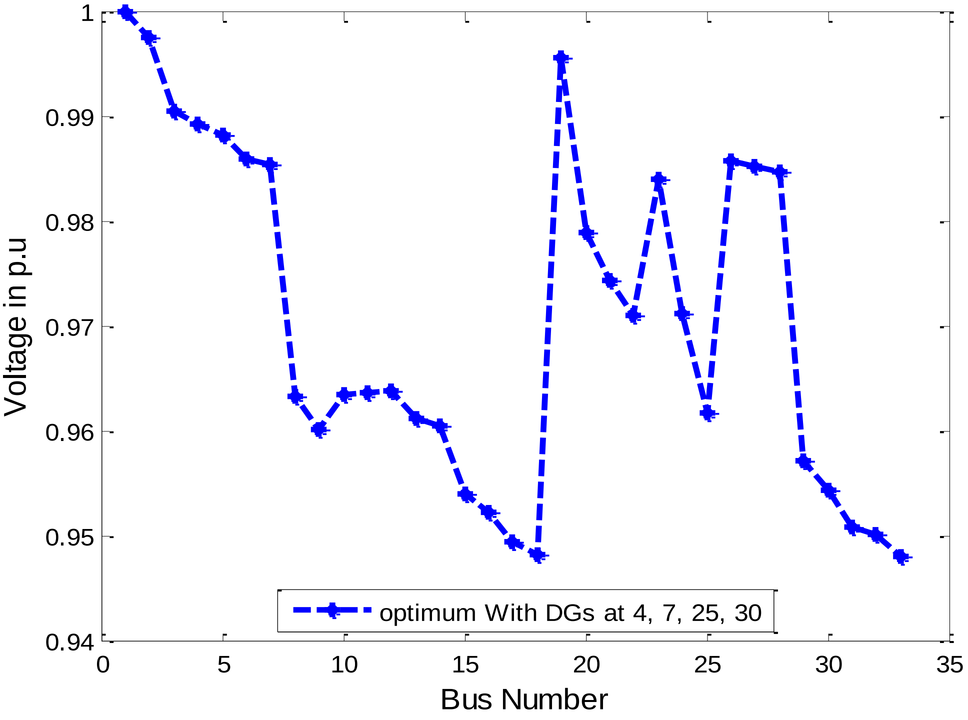


Figure 5.9 Voltage Profile Plot of Optimum Network with DGs at 4, 7, 25 and 30

Table 5.4 summarises the cases considered above without DG sources and with DG sources.

Table 5.4 Summary of Cases considered for Reconfiguration

case	P- losses(kw)
Initial network without DG	198
Initial network with DG	158
optimum network without DG	136
optimum network with DG	108

From the results of the case study, the loss reduction effects of DG units are summarized as follows:

1. It can be seen that DG units have the effects of loss reduction and voltage profile improvement over feeders. The additional loss reduction is about 12.2% through the network reconfiguration with DG units. This result verifies the loss reduction support of DG in the distribution networks.
2. The topological structures of the optimum network without DG units are different from those with DG units. The optimization is required to maximize the loss reduction effects of DG units. Therefore, DG should be integrated into the distribution automation centre and results are taken as optimal configuration and voltage profile also improved.

5.4.2 Service Restoration of 33 Bus Test System

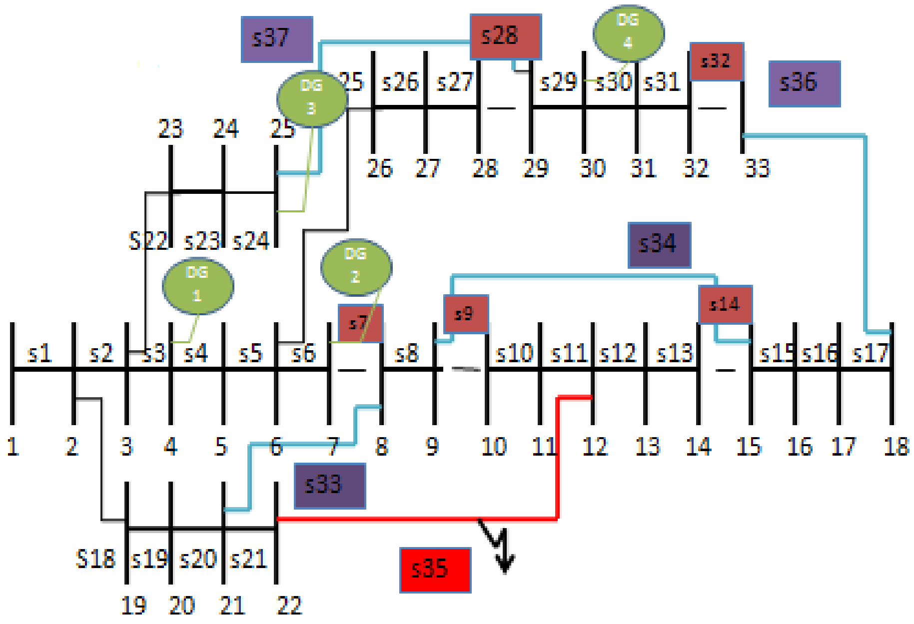
The various fault situations are considered for reconfiguration studies. The optimum network with DG sources is considered as pre-fault system.

At the first instances, individual fault on lines S35 and S24 is considered. Table 5.5 shows survival status of the DGs in the event of such faults.

Table 5.5 DG Survival status during fault at S35 and S24

Line opened by fault	S35	S24
DG-1	SDG	SDG
DG-2	SDG	SDG
DG-3	SDG	NSDG
DG4	SDG	NSDG

The Network during fault at S35 is shown in Figure 5.10.



Open switches: s7, s9 , s14, s28, s32

Closed switches: s33, s34, s36,s37

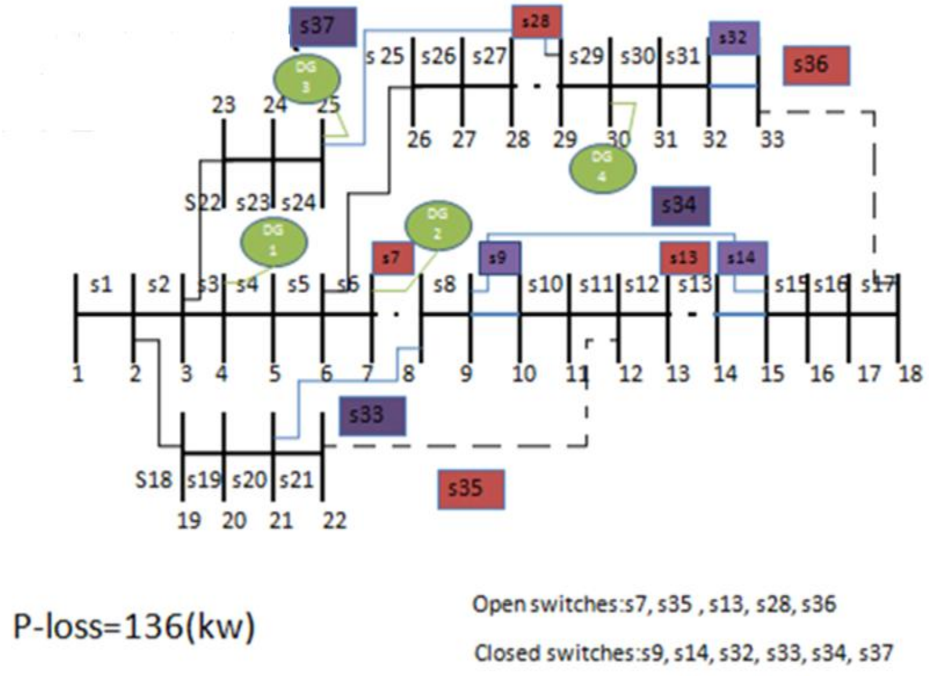
Faults: S35

Figure 5.10 Network during fault at S35

The reconfiguration for this network under fault is attempted and the service restoration scenario is given in Table 5.6. The reconfigured network after fault isolation is given in Figure 5.11. The system losses will be 136 kW for the best reconfiguration scheme.

Table 5.6 Service restoration of network during post fault at S35

	Open switches	Un-restored area	NSDG
Prefault network	S7, S9, S14, S28, S32	None	None
Reconfigured network after fault is isolated	S7, S35, S13, S28,S36	None	None



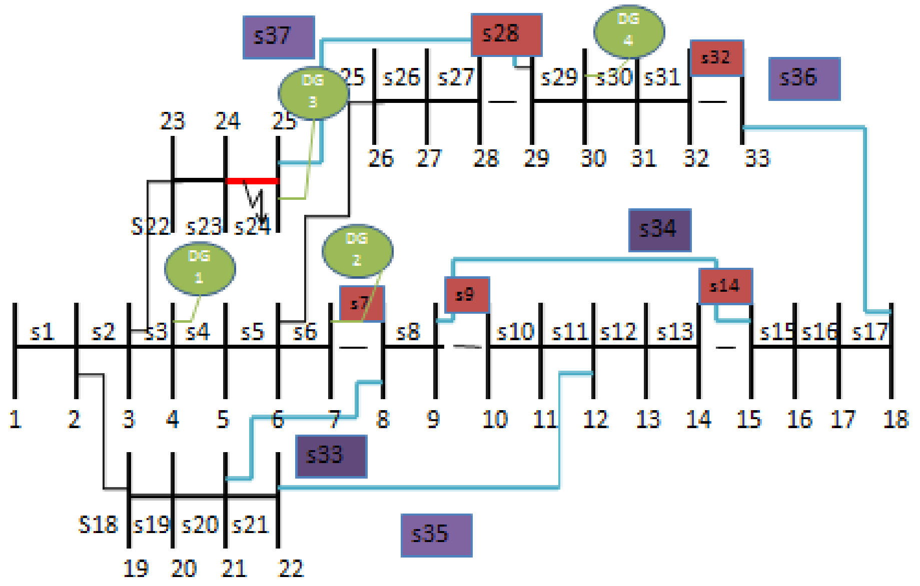
P-loss=136(kw)

Open switches:s7, s35 , s13, s28, s36

Closed switches:s9, s14, s32, s33, s34, s37

Figure 5.11 Reconfigured network after fault is isolated

The Network during fault at S24 is shown in Figure 5.12.



Open switches: s7, s9 , s14, s28, s32

Closed switches: s33, s34, s36,s37

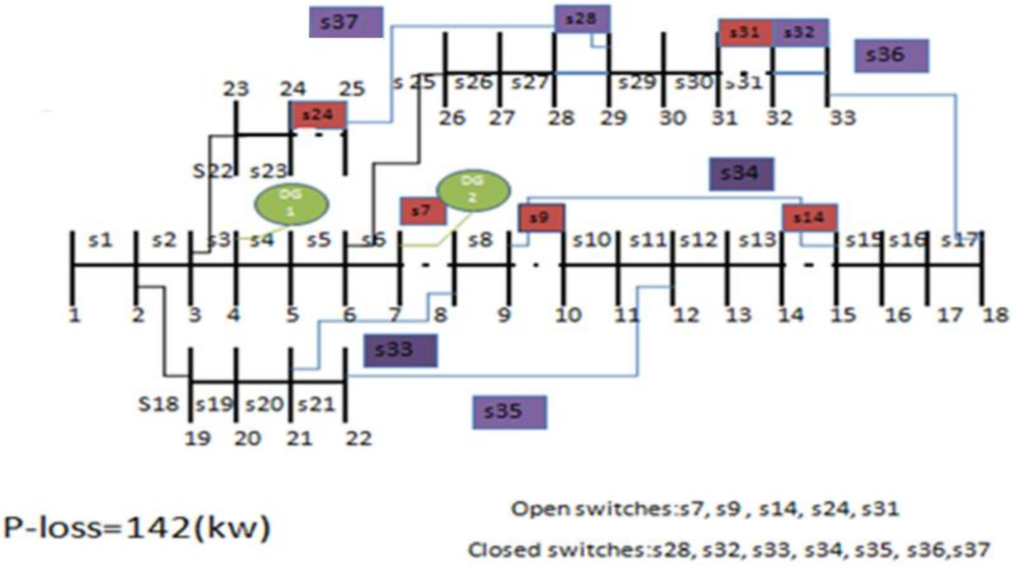
Faults: S24

Figure 5.12 Network during fault at S24

The reconfiguration for this network under fault is attempted and the service restoration scenario is given in Table 5.7. The reconfigured network after fault isolation is given in Figure 5.13. The system losses will be 142 kW for the best reconfiguration scheme. When all NSDGs are brought back to service ths system losses further reduces to 119 kW and scheme is shown on Figure 5.14.

Table 5.7 Service restoration of network during post fault at S24

	Open switches	Un-restored area	NSDG
Prefault network	S7, S9, S14, S28, S32	None	None
Reconfigured network after fault is isolated	S7, S9, S14, S24, S31	None	DG3 DG4
Reconfigured network after all NSDG's are interconnected	S7, S9, S14, S24, S32	None	None

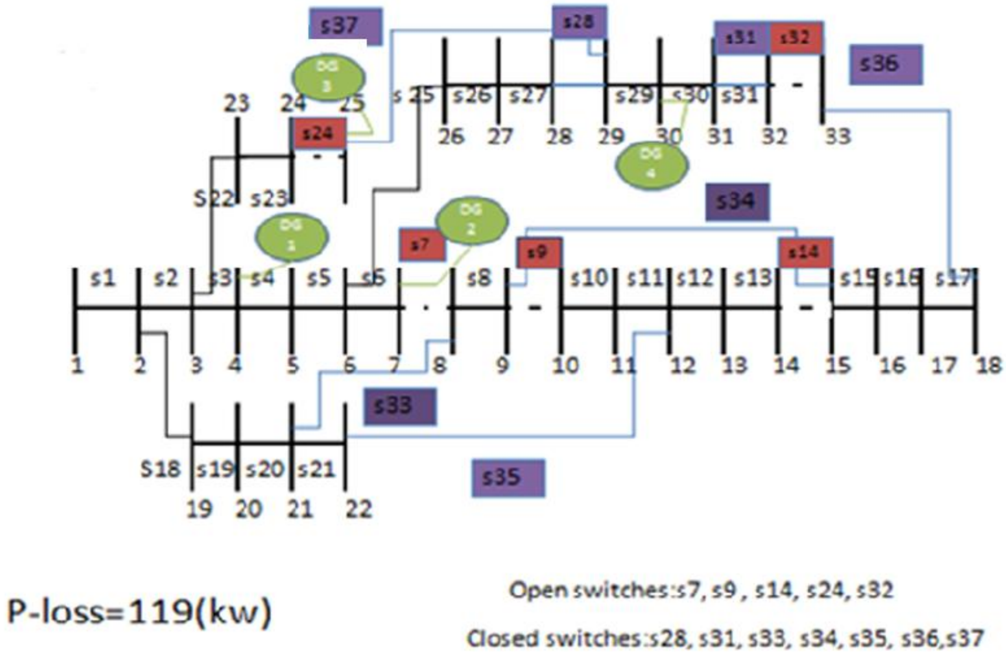


P-loss=142(kw)

Open switches:s7, s9 , s14, s24, s31

Closed switches:s28, s32, s33, s34, s35, s36,s37

Figure 5.13 Reconfigured network after fault is isolated



P-loss=119(kw)

Open switches:s7, s9 , s14, s24, s32

Closed switches:s28, s31, s33, s34, s35, s36,s37

Figure 5.14 Reconfigured network after all NSDG's are interconnected

The summary of the above analysis is as follows :

The optimum network with DG is the results of the above section considered as initial network for this case. In Table 4, all of the DG units are assumed to be SDG during a fault S35 .Hence, the network restoration problems could be solved by option-1 with SDG units. From Table 4 at fault S24 DG-l and DG-2 survived during a fault (that is SDG). Therefore, first the network restoration problems could be solved by option-1 by excluding NSDG. And then it could be solved again after all NDSG are interconnected to the network unless there is an un-restored area. If there is an un-restored area, it should be solved again by option-2. In these there is no un-restored area.

5.4.3 Service Restoration for Simultaneous Multiple Faults

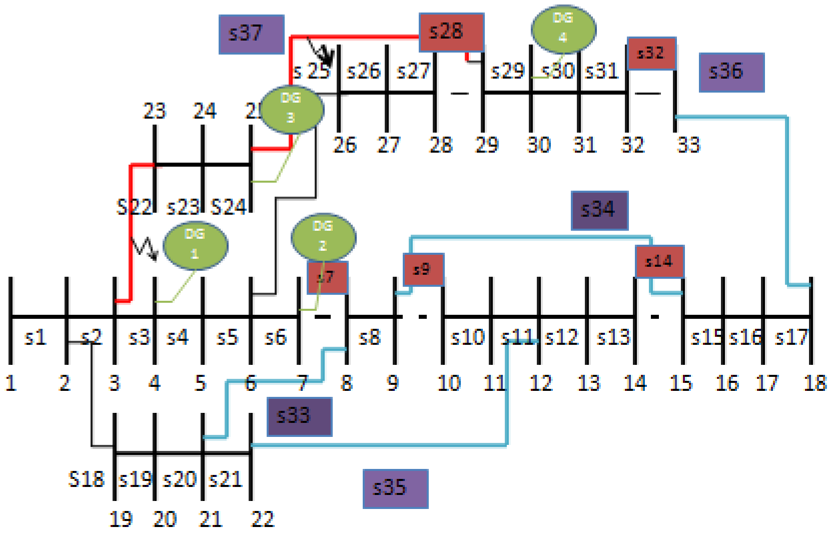
The analysis carried out in previous sections incorporates the approach of finding the optimum network with DGs with emphasis on loss reduction, made by the earlier literature [17]. However the important scenario of multiple faults occurring simultaneously in a system has to be addressed appropriately. These multiple faults lead to discontinuity of service of utility to certain sections in the system. In such circumstances, the DGs have to be operated in islanding mode to restore power supply to affected areas, till fault is cleared. The analysis given below illustrates such situations.

Case 1: The simultaneous fault on S22 and S37

The Table 5.8 gives the DG survival status in the network in these multiple fault case. The network configuration during fault is given in Figure 5.15.

Table 5.8 DG Survival Status during service restoration at faults S22 and S37

Line opened by fault	S22 & S37
DG-1	SDG
DG-2	SDG
DG-3	NSDG
DG-4	NSDG



Open switches: s7, s9 , s14, s28, s32

Closed switches: s33, s34, S35, s36,s37

Faults: S22, S37

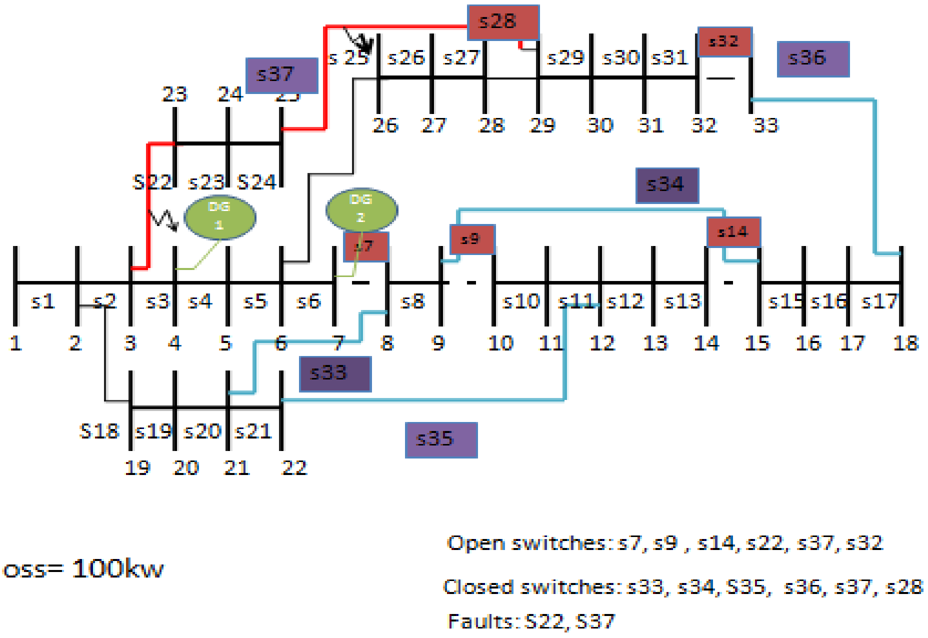
Figure 5.15 Network during fault at S22 & S37

Table 5.9 gives the service restoration process for reconfirmation schemes.

Table 5.9 Service restoration of network during post fault at S22 & S37

	Open switches	Un-restored area	NSDG
Prefault network	S7, S9, S14, S28, S32	None	None
Reconfigured network after fault is isolated	S7, S9, S14, S22, S37, S32	23, 24, 25 Bus	DG3 DG4
Reconfigured network after all NSDG’s are interconnected	S7, S9, S14, S22, S37, S32	23, 24, 25 Bus	DG3

The Figure 5.16 shows the Reconfigured network after fault is isolated. Since few loads are disconnected, the system losses are 100 kW in this case.



P-loss= 100kw

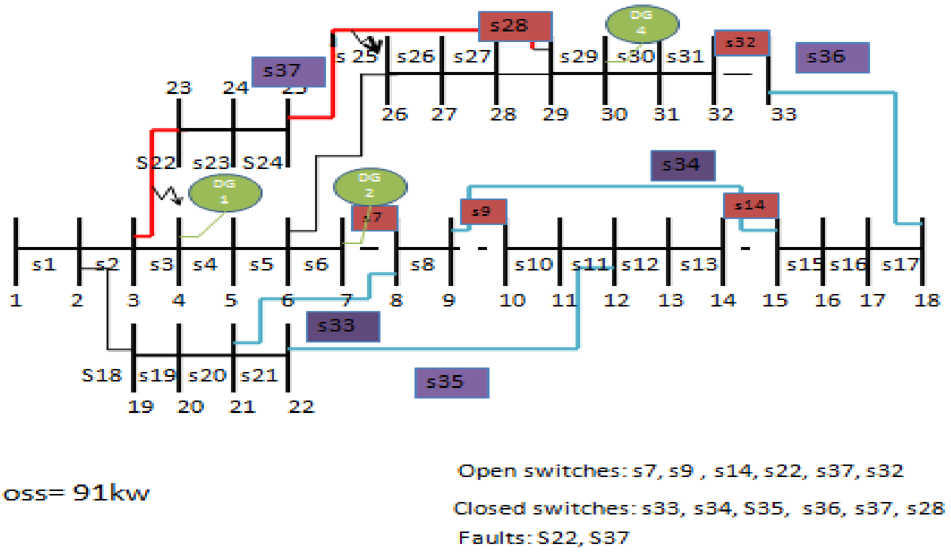
Open switches: s7, s9 , s14, s22, s37, s32

Closed switches: s33, s34, S35, s36, s37, s28

Faults: S22, S37

Figure 5.16 Reconfigured network after fault is isolated

The process of bringing the Non Servicing DGs (NSDG) back to service (SDG) has lead to new configuration given in Figure 5.17. The system losses are now reduced to 91 kW.



P-loss= 91kw

Open switches: s7, s9 , s14, s22, s37, s32

Closed switches: s33, s34, S35, s36, s37, s28

Faults: S22, S37

Figure 5.17 Reconfigured network after all NSDG's are interconnected

This reconfiguration has resulted in Islanding areas comprising of branches 23,24,25. The total load on this segment is 160 kW, which can be served by DG3 with capacity of 200 kW. The Islanding scenario is given in Table 5.10. The decision making for intentional islanding operation to reduce the power outage area has to be taken with coordination with all stake holders like utility, independent power producers and distribution companies. The implementation of distribution automation systems will be very much helpful for effective interaction and management.

Table 5.10 Islanding Scenario resulting from fault at S22 & S37

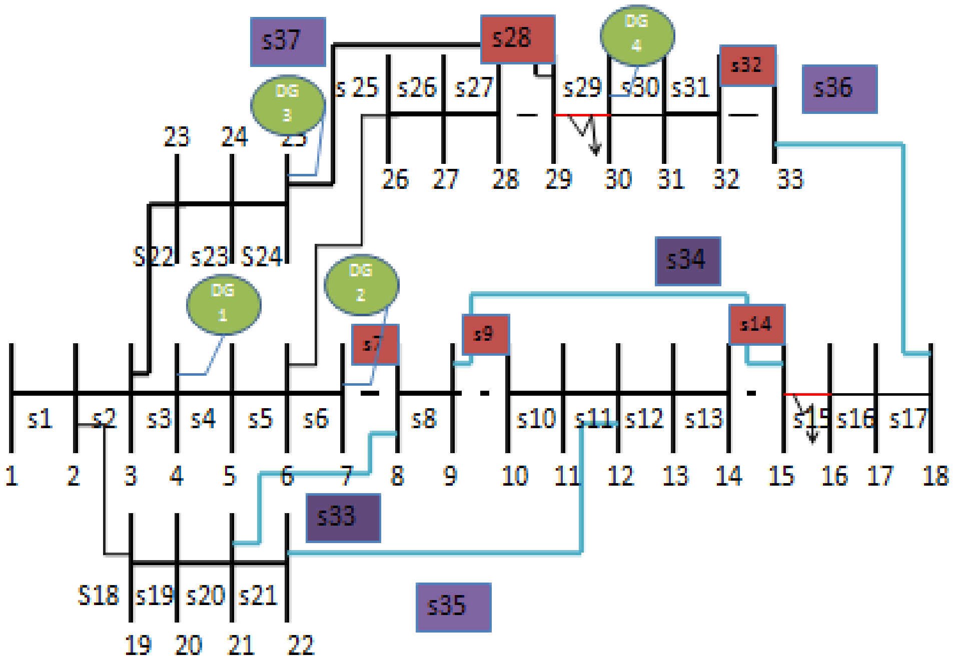
Islanding area	DG3- capacity (kW)	Load Demand (kW)
23, 24, 25	200	160

Case 2: The simultaneous fault on S15 and S29

The Table 5.11 gives the DG survival status in the network in these multiple fault case. The network configuration during fault is given in Figure 5.18.

Table 5.11 DG Survival Status during service restoration at faults S15 and S29

Line opened by fault	S15 & S29
DG-1	SDG
DG-2	SDG
DG-3	SDG
DG-4	NSDG



Open switches: s7, s9 , s14, s28, s32

Closed switches: s33, s34, S35, s36,s37

Faults: S15, S29

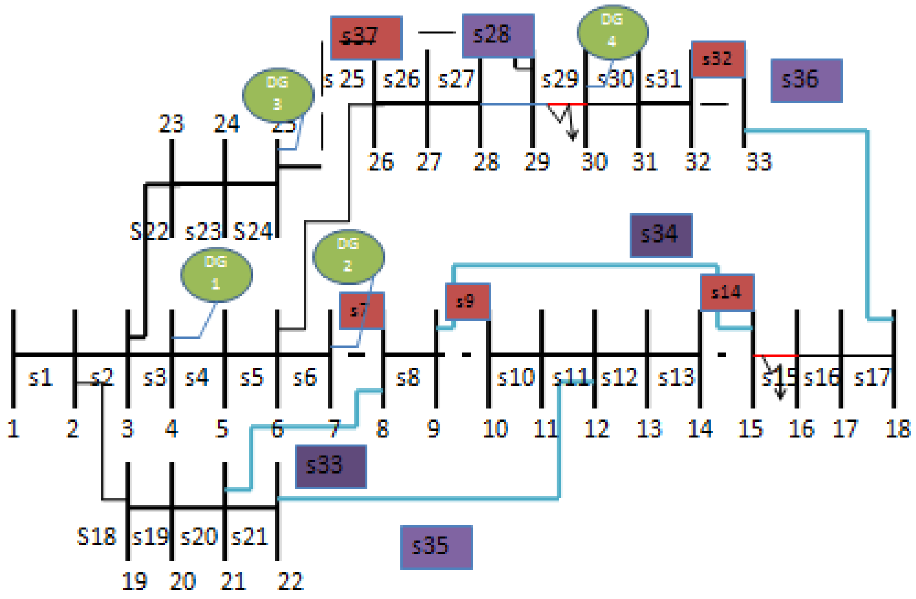
Figure 5.18: Network during fault at S15 & S29

Table 5.12 gives the service restoration process for reconfirmation schemes.

Table 5.12 Service restoration of network during post fault at S15 & S29

	Open switches	Un-restored area	NSDG
Prefault network	S7, S9, S14, S28, S32	None	None
Reconfigured network after fault is isolated	S7, S9, S14, S15, S29, S37	16, 17 , 18, 33, 32, 31, 30 Bus	DG4

The Figure 5.19 shows the reconfigured network after fault is isolated. Since few loads are disconnected, the system losses are 99 kW in this case.



Ploss- 99 kW

Open switches: s7, s9 , s14, s15, s29, s37

Closed switches: s33, s34, S35, s36,s28

Faults: S15, S29

Figure 5.19 Reconfigured network after fault is isolated

This reconfiguration has resulted in Islanding areas comprising of branches 16,17,18,30,31,32,33. The total load on this segment is 100 kW, which can be served by DG4 with capacity of 100 kW. The Islanding scenario is given in Table 5.13.

Table 5.13 Islanding Scenario resulting from fault at S15 & S29

Islanding area	DG3- capacity (kW)	Load Demand (kW)
16, 17, 18, 33, 32, 31, 30	100	70

5.5 Conclusive Remarks

- The analysis for obtaining optimal configuration from the given initial network without DGs has been carried out. The optimal configuration without DGs calls for network reconfiguration with the criteria of reduction in power loss. The presence of DGs will further alter the optimal configuration without DGs to achieve lowest possible power loss in the system. The studies conducted have illustrated the process of reconfiguration in presence of DG sources. The post fault network reconfiguration can be carried out effectively with smart grids having ICT features communicating with all operators.
- The presence of DG sources becomes very much important for service restoration after occurrence of fault in the system. The fault section has to be isolated which results in service discontinuity to certain areas of the network. In such circumstances the DGs will play effective role in ensuring service continuity to all healthy part of the network by way of network reconfiguration. The study has demonstrated the possibilities of post fault configuration for selected fault locations.
- The most severe condition in operation of the distribution network is simultaneous faults occurring in different parts of the network. The process of fault isolation will eventually lead to discontinuity of service to some areas. That is those areas will not be connected to utility. Then to restore power supply to such areas, possibility of DG connectivity operating in Islanding mode has been explored. The sample cases of multiple faults have been considered, and the scheme for configuration for maintaining service continuity for majority areas of the network by utility and DG sources has been worked out. The possibility of Islanding operation of a DG source to serve a local area has been presented in this work.

To validate the analysis and proposals made in this work, a 33 bus test system reported in literature is considered. The strategies proposed for network reconfiguration will be very much helpful for system operator to deal with fault scenarios and aid the decision making process to achieve better performance of the system.

CHAPTER 6

CONCLUSIONS AND FURTHER SCOPE

6.1 Conclusions

Following are the summary of conclusions drawn from the research work presented in this thesis.

The analysis carried out evaluates (a) Industrial captive power plant working as DG Source (b) factors related to Single DG source insertion for distribution system (c) complex issues associated with multiple DG sources insertion to distribution system (d) relevance of DG sources in network reconfiguration.

- A visual tool to simulate Industrial captive power plant operation and explore the possibility of functioning as distributed generation source has been developed. The developed tool facilitates decision on power export based on existing load and generation scenario of the industrial unit and also considering utility requirement of energy.

- An analytical technique for single distributed generation source allocation for a large distribution network has been developed. The proposed approach emphasises on improvement on any specific parameter based on choice of system designer from either technical or economical perspective.

- A strategic approach for multiple distributed generation source allocation for large distribution network has been devised. A comprehensive index termed as Network Performance Enhancement Index (NPEI) is proposed which is a combination of indices related to loss reduction, voltage profile improvement, voltage regulation, voltage stability. The selection based on NPEI ensures overall improvement on all these parameters. The methodology developed provides enough alternatives from both technical and economical perspectives to the designer to enable him to decide on most feasible solution. The salient feature of the present work is to provide the flexibility to the designer to choose most feasible sizes of DG in appropriate locations based on priority. The random search limitation can be circumvented by way of priority list and selecting the most technical and economical feasible solution.

- The scope of DGs for service restoration has been accounted in arriving at optimal configuration with DG sources for post fault conditions. The technique designed enumerates the situations of islanding of DGS due to fault in any part of network and guides the operator for supply of local loads in such a situation.

6.2. Scope for further investigations

The development in Information and Communication Technology (ICT) domain has made greater impact in implementation of modern schemes in all engineering applications. The real time operation of distribution system is a perfect candidate for implementation of ICT for improving its management. The incorporation of DG sources into the distribution network further demands exploration of ICT for successful integration. In this regard further investigation can be contemplated in the following areas:

- Design and Management of Smart Grid applications with DG sources will facilitate better interaction between DG operators and utility. The service continuity, safety, reliability can be enhanced with smart grids. Since ICT is extensively used in this scheme, the system parameters can be controlled effectively
- The main characteristic of the distribution system is its varying load over large area. Since the independent power producers are interested in most economical operation of DG sources and higher profit margin, a power trade model can be built. This model guides the power generation scheduling from DG sources according to the load demand, and also power availability from

the utility. The Time-of-day (ToD) tariff will be very much helpful in building the trade model and will lead to win-win situation for utilities and DG operators.

- Use of Smart Grid ICT in distribution DSM and reconfiguration
- DG-Distributed Generation hybrid integration (DC-AC) interfacing schemes
- Use of SC-AI soft computing search techniques in simultaneous DG sizing and siting.

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APPENDIX A

FEATURES OF SKM POWER TOOLS AND MRPL PLANT DATA

Power Flow Solution in SKM Power Tools for Windows (PTW)

PTW's solution depends on the system topology, combined with knowledge of associated branch impedances and load data. PTW forms the appropriate matrixes and, through optimal ordering and standard matrix algebra techniques, solves for the dependent variables. One power flow solution technique is known as the double current injection method (PTW's Load Flow Study uses this method). In this method, the first estimate assumes no losses and calculates the current flows in each branch, given the load values and system nominal voltages. Then the losses across the system are calculated, and the voltage drop is determined for each branch and bus. Given this new voltage at each bus, the load currents are re-calculated, and the iterative process begins. The new currents develop new losses in the branches and thus new voltage drops in each branch and bus. The iterative process continues until there is little change in the voltage at each bus between estimates, and convergence is achieved.

Modeling of Transformers

Transformer primary and secondary tap settings and transformer off-nominal voltages are considered in the steady-state load flow solution. A negative primary tap setting raises the secondary bus voltage. Similarly, a positive secondary tap setting raises the secondary bus voltage.

Utility System Representation

The utility system voltage drop is modelled as impedance between the swing bus and swing bus (ideal) voltage source. The utility system three-phase short circuit capacity is used to determine the positive sequence impedance for this calculation.

Load Characteristics

The load flow solution takes into account load characteristics to calculate the load flow conditions in the power system. The load flow conditions are solved in conjunction with solution of the voltage conditions at each load bus, as described in the previous section.

The type of loads and the system losses significantly influence the results of the load flow and voltage drop calculations. Constant impedance type loads are loads that vary as the square of the applied voltage. Examples of this type of load include incandescent lighting and resistance heating elements. Constant kVA loads are loads that remain (or attempt to remain) constant within boundary limitations regardless of the applied voltage. Illustrations of this type of load include motor loads and some types of lighting, which utilize an inductive ballast to establish constant wattage to the lamp.

It is clear that with constant kVA type loads, the actual load currents increase with decreasing voltage. With constant impedance loads, line currents decrease as the voltage is lowered. If both KVA loads and constant impedance loads are present, then the resulting voltage effects may be partially or totally cancelled.

Constant current type loads hold their current constant under varying voltage conditions. Like constant impedance type loads, as the voltage drops at the bus the amount of apparent power consumed by the constant current type load decreases. Constant current type loads are affected by the fluctuations in the bus voltage angle.

Voltage Drop Calculations

The total voltage drop in any one branch or the total bus voltage drop in SKM Power Tools is calculated as per NEC standards, USA. Thus, it is critical to know the voltage drop in each branch of the power system, and the total voltage drop from the source of supply to the bus in the branch circuit. The voltage drop calculations are incorporated directly into the calculation of the steady-state load flows.

Simulation of Load Flow in SKM Tools

Before carrying out the Load Flow Study the following requirements are defined.

- Power system topology and connections.
- Utility connection (swing bus)
- Individual loads characteristics
- Feeder and transformer capacities
- Generator capacities

System Modeling

PTW uses the three-phase short circuit capacity to calculate equivalent positive sequence impedance in case Utility impedance connection is selected. The voltage drop at the swing bus is calculated, given the total power supplied by the swing bus generator and this positive sequence impedance. It is reported separately in the Load Flow Report. Upon opening a new Project, the PTW does not model the system equivalent impedance by default. This means the voltage at the swing bus is equal to the voltage of the swing bus generator, which is set by default to 1 pu voltage at 0°. Transformer Phase Shift and Load Tap Change are ignored in the Current Injection method, they are modeled in the Newton method only.

Solution Methodology

PTW models either an exact (iterative) or approximate Solution. Upon creating a new Project, PTW selects the exact (iterative) solution method by default. At the first instance the study using the exact (iterative) solution method first. This is because the solution method usually converges on most power systems. In the event that the steady-state load flow solution does not converge, Study is carried out using the approximate solution method. If it does not converge, a message in the Study Message dialog box will notify the problem.

Computational Methods

In the Current Injection method, loads are converted into currents that are injected into buses, and then bus voltages are solved. New currents are calculated based on the new bus voltages, and then injecting them into the system. Constant kVA, Constant

Current and Constant Impedance loads are modeled together at a single bus. Because of the flexibility of the current injections technique, complex loads like motor starting can be included in the iterations.

In the Newton-Raphson approach, load flow is solved based on the non-linear load flow equations. There are two non-linear simultaneous equations for each bus. The real and reactive powers depend on the product of the sum of the voltages connected between two buses and the admittance between the buses. The Newton-Raphson method can converge relatively fast for system with loops, multi-voltage levels and lots of PV generators.

Load Modeling

In SKM Power Tools, there are five options for load modeling. These options are divided into two groups: one group as ‘Directly Connected Loads’, and other group as ‘Loads from the Demand Load Study’. The default upon opening a new project is to model all loads as directly connected loads using the connected load values.

Directly connected loads can be modeled as connected load or 1st level demand or energy factor. When either of these two options is selected, the load flow solution calculates the load at each bus, and then solves the steady state load flow equation. Neither of these options uses results from the Demand Load Study.

When the connected load option is selected, the load flow study calculates the loads without considering any load or demand factors. If motor loads are identified, and if multiple motors are modeled in a single motor load object, the total motor connected load is the number of motors multiplied by the motor's rated size. Otherwise, the load rated size is the connected load value. Motors expressed in horsepower are converted to electrical units by dividing by the efficiency.

When the first level demand or energy factor option is selected, the load flow study calculates the loads using the first level demand factors and energy audit load factors, as appropriate. If a non-motor load is identified with both an energy audit load factor and a demand load category, then the Study will use both the energy audit load factor and the first level demand load factor multiplied by the load's rated size. For motor loads, the load is calculated as the number of motors multiplied by the motor rated size multiplied by the motor load factor. Load diversity resulting from identifying multiple levels of demand load factors is not taken into consideration.

When the second group of loads selected from ‘Demand Load Study’ can be modeled as Demand Load, Design Load (All Loads in Constant kVA), or Connected Load. The load flow study models the loads based on the results of the last Demand Load Study run. When the demand load option is selected, the load flow study takes the calculated demand load values from the demand load study. Upon creating a new project, the demand load Study includes the results from all non-motor loads by default. Demand loads with multiple levels of demand factors, such as receptacle loads where the first 10 kVA of load have a 100% demand factor and the remaining receptacle load has a 50% demand factor result in a non-coincident demand (diversity) load that is unique.

The design load value is calculated from the Demand Load Study given the demand load value and the long continuous loading factor from the Demand Load Library. The connected load is the load rated size without considering any demand factors.

It is important to remember that when modeling loads using demand load study options, the results are based on the results from the last Demand Load Study. If system topology changes, or load changes have occurred, it is required to re-run the demand load study.

Convergence Criteria in Power Flow

The two acceleration factors text boxes allow controlling the load flow Study convergence process. In many cases, the acceleration factors do not need to be changed from their default values. However, if a non-convergent solution occurs, even after an Approximate Solution method has been run, Generation Acceleration Factors and/or the Load Acceleration Factor are changed from their default of 1.0 to a factor between 0.1 and 1.0. This changes the guessing factor used to calculate the next iteration of the numerical solution. The smaller the factor, the smaller the step change used in the iteration solution.

The Bus Voltage Drop and Branch Voltage Drop text boxes provide a quick method to flag excessive voltage drops in the output report. In the report, PTW flags with a dollar sign ($) any bus or branch voltage drop value that exceeds the limits set in these text boxes. Upon creating a new project, the default values are a 5% bus voltage drop, and a 3% branch voltage drop.

Component Modeling for Power Flow Study

The following sections discuss modelling issues with various components to be used in load flow analysis.

Swing Bus Generator

Every load flow solution requires at least one swing bus be identified. Up to ten swing buses may be modeled. At the swing bus, voltage magnitude and voltage angle is to be specified. Utility equivalent impedance of the is modeled as the swing bus by selecting the Utility Impedance check box in the load flow study setup dialog box. One of the co-generator bus is also identified as the swing bus generator along with the utility connection when the Utility contribution is considered.

Loads can be directly connected to the co-generation bus and the utility swing bus. PTW accurately models the power flow in this situation even when directly connected loads are installed on type 2 or Type 3 load buses.

On-Site Generation

An on-site generator that operates in parallel with the utility source may be defined as either a PV- or PQ type generator in the component editor. The generator can have leading or lagging reactive power. Lagging reactive kVA is plotted as a positive value and referred to as an over-excited condition of the machine. Leading reactive kVA is plotted as a negative value and referred to as an under-excited condition of the generator. Any type of balanced loading within the area bounded by the capability curve is considered as safe by the generator manufacturer.

A combined total of up to 10 Swing Bus (SB) and PV-type generators may be modeled in PTW. A total of up to 60 generators may be modeled, of which no more than 10 may be a combination of PV- and SB-type generators. When modeling SB generators, they may be modeled as generator components or as utility components.
The source connection represents the system swing bus or slack bus. It maintains a constant voltage at a constant bus angle. The kW and kVAR of the swing bus vary, or “swing” in order to satisfy the power balance criteria.

The swing bus generator or utility source must supply any deficiency in generation, and all losses. If there is excess generation in the system, the source bus acts to absorb the excess generation.

Usually, a system requires only a single swing bus. Multiple swing buses may be used to model large systems having multiple connections to a utility. Therefore, the exact utility voltages and angles may be specified. Additionally, multiple independent systems require that you specify a swing bus for each system. Only one swing bus may be specified at a single bus.

In modeling generation in parallel operation with a utility connection or swing bus generator, the swing bus has unlimited power capabilities to maintain its voltage magnitude and voltage angle. Therefore, regulating-type generators (PV-type) located at the swing bus or near the utility will not produce any reactive power. In this case, model co-generation as PQ-type generators.

Co-generation modeled as PV-type generators that are not located near the utility or swing bus generator will serve to regulate the voltage at the generator bus. PTW attempts to hold the bus voltage at the target level within the reactive power range. It may not be possible to obtain the target voltage. PTW will maintain the kW output of the generator and allow the voltage to float to the reactive power limit.

PTW allows for modeling more than one generator at a bus. If the generators are PV-type generators, then you need to identify how much reactive power is generated by each machine (per unit Vary Participation factor). Since the reactive power is shared equally between the machines; therefore, if two PV machines are modeled on the same bus, then the participation factor is 0.5 for each machine. When multiple PV generators are modeled on individual buses separated by small cables, it results in a non-convergent solution because the reactive power calculated by PTW depends on very small bus voltage angles. If this occurs, multiple PV machines are modeled on a single bus, or lump the generation into a single generator model.

Load Diversity

Special attention is to be paid while simulating the Load Flow Study when demand loads are considered. PTW accurately models the loads when loops are present in the power system. Demand Load Study methodology identifies and calculates load diversity only in a radial system. The Demand Load Study detects loops, opens them temporarily to calculate load diversity, and then closes the loops. In some cases, where extensive (nested) loops exist, the automatic opening of the loops can result in odd load flow solutions. It is recommended that if multiple loops exist in the power systems and if load diversity is not a significant issue for the Study, then the load flow solution is modeled using the directly connected loads specification.

Error Messages

If the Load Flow Study detects data errors during input data processing, error messages are provided for the errors found and the study will not run. These errors must be corrected and the load flow study must be executed again.

Diverging Solution

If the Exact (Iterative) Solution method has been selected, and under certain extreme loading conditions, it is possible that the load flow study cannot determine a steady-state load flow condition and no report will be generated. An error will be reported in the Study Messages dialog box. This can occur in power systems whenever the system voltages are not sufficient to supply constant kVA loads.

MRPL SYSTEM
GENERATOR DATA

S.No.	Details	STG 1	STG 2	STG3	STG4	STG5
1	Type Of generator	STG	STG	STG	STG	STG
2	Maximum continuous rating in MW	26.252	26.252	26.252	26.252	26.252
3	Rated terminal voltage in KV	11	11	11	11	11
4	Rated power factor in %	80	80	80	80	80
5	Speed in RPM	3000	3000	1500	1500	1500
6	Direct axis synchronous reactance(Xd) in % unsatured	186.7	186.7	203.8	203.8	203.8
7	Direct axis transient reactance(Xd') in % saturated	15.8	15.8	17	17	17
8	Direct axis sub transient reactance(Xd'') in % saturated	11.4	11.4	15.7	15.7	15.7
9	Zero sequence reactance(Xo) in %	6.9	6.9	8.3	8.3	8.3
10	Quadrature axis synchronous reactance (Xq) in % unsaturated	172.4	172.4	193.8	193.8	193.8
11	Quadrature axis transient reactance (Xq') in % saturated	34.6	34.6	38.89	38.89	38.89
12	Direct axis open circuit transient time constant (T'do)	6.584	6.584	6.39	6.39	6.39
13	Quadrature Axis Open ckt transient time constant(Tqo)	0.505	0.505	0.505	0.505	0.505
14	Leakage reactance(XL) in %	14	14	13.5	13.5	13.5
15	SG 1.0 saturation function	1.07	1.07	1.07	1.07	1.07
16	SG 1.2 saturation function	1.18	1.18	1.18	1.18	1.18
17	Type of earthing					
	a. Value of resistance in Ohms					
	b.Rating of NGR/NGT	11/<3 kv,	11/<3 kv,	12KVA	12KVA	12KVA
		273.4 A	273.4 A	11/0.110kv	11/0.110kv	11/0.110kv
18	Inertia constant seconds of TG Set MW.Sec/KVA	4.878	4.878	1.16	1.16	1.16
19	Damping Constant % of TG set MW/Hz	5	5	5	5	5

MRPL SYSTEM PHASE-I & II
TRANSFORMER DATA

SL. NO.	TRANSFORMER DESIGNATION	VOLTAGE RATIO	FROM BUS	TO BUS	RATED KVA	%Z ON OWN BASE	NGR VALUE OHMS	VECTOR GROUP	OCTC SETTING
1	TR-31	11/6.9kV	11KV SWGR 201, CPP, BUS 1A	6.6KV SWGR 213, BUS 1AX	20000	10.15	4	Dyn1	+7.5 %
2	TR-41	11/6.9kV	11KV SWGR 201, CPP, BUS 1A	6.6KV SWGR 223, BUS 3AX	12500	8.17	7	Dyn1	+7.5 %
3	TRCPP1 (6.3MVA)	11/6.9kV	11KV SWGR 201, CPP, BUS 1A	6.6KV CPP BUS-L	6300	6.89	20	Dyn11	
4	TR-51	11/6.9 kV	11KV SWGR 201, CPP, BUS 1A	6.6KV SWGR 233, BUS 5AX	16000	9.63	5.5	Dyn1	+7.5 %
5	CPPTR1 (2 MVA)	11/0.433KV	11KV SWGR 201, CPP, BUS 1A	415V CPPLT1	2000	6.48	NA	Dyn11	*
6	TR21	110/11 kV	110[KEB]	11KV SWGR 201, CPP, BUS 2A	20000	12.82	21.2 +/- 10%	Dyn11	*
7	TR-37	11/0.433KV	11KV SWGR 201, CPP, BUS 2A	415V BUS 25B	2000	*	NA*		*
8	TR-42	11/6.9kV	11KV SWGR 201, CPP, BUS 2A	SWGR 223 I/C-2/PNL-16	12500	8.29	7	Dyn1	+7.5 %
9	TR-32	11/6.9kV	11KV SWGR 201, CPP, BUS 3A	6.6KV SWGR 213, BUS 2AX	20000	10.02	NA	Dyn1	+7.5 %
10	TRCPP2 (6.3MVA)	11/6.9kV	11KV SWGR 201, CPP, BUS 3A	6.6KV CPP BUS-R	6300	6.96	20	Dyn11	*
11	CPPTR2 (2 MVA)	11/0.433KV	11KV SWGR 201, CPP, BUS 3A	415V CPPLT2	2000	6.46	NA	Dyn11	*
12	TR-52	11/6.9 kV	11KV SWGR 201, CPP, BUS 3A	6.6KV SWGR 233, BUS 6AX	16000	9.61	5.5	Dyn1	+7.5 %
13	TR220	11/34.5 kV	PHASE-II SWGR 2202, BUS 1	11KV SWGR 201, CPP, BUS 3A	33000	12.9	21.37	YNyn0	*
14	TR-71	11/6.9 kV	11KV SWGR 241, CPP, BUS 4A	6.6KV SWGR 242, BUS 7AX	4000	7.17	10	Dyn1	+7.5 %
15	TR-73	11/6.9 kV	11KV SWGR 241, CPP, BUS 4A	6.6KV SWGR 245, BUS 9AX	12500	8.51	7	Dyn1	+7.5 %

SL. NO.	TRANSFORMER DESIGNATION	VOLTAGE RATIO	FROM BUS	TO BUS	RATED KVA	%Z ON OWN BASE	NGR VALUE OHMS	VECTOR GROUP	OCTC SETTING
16	TR-72	11/6.6 kV	11KV SWGR 241, CPP, BUS 5A	6.6KV SWGR 242, BUS 8AX	4000	7.13	10	Dyn1	+7.5 %
17	TR-74	11/6.9 kV	11KV SWGR 241, CPP, BUS 5A	6.6KV SWGR 245, BUS 10AX	12500	8.51	7	Dyn1	+7.5 %
18	TR-33	6.6/0.433 kV	6.6KV SWGR 213, BUS 1AX	415V SWGR 301, BUS 1B	2000	6.32	NA	Dyn11	*
19	TR-35	6.6/0.433 kV	6.6KV SWGR 213, BUS 1AX	415V SWGR 302, BUS 3B	1600	6.35	NA	Dyn11	*
20	TR-34	6.6/0.433 kV	6.6KV SWGR 213, BUS 2AX	415V SWGR 301, BUS 2B	2000	6.31	NA	Dyn11	*
21	TR-36	6.6/0.433 kV	6.6KV SWGR 213, BUS 2AX	415V SWGR 302, BUS 4B	1600	6.44	NA	Dyn11	*
22	TR-43	6.6/0.433 kV	6.6KV SWGR 223, BUS 3AX	415V SWGR 307, BUS 5B	2000	6.30	NA	Dyn11	*
23	TR-45	6.6/0.433 kV	6.6KV SWGR 223, BUS 3AX	415V SWGR 308, BUS 7B	1600	6.41	NA	Dyn11	*
24	TR-44	6.6/0.433 kV	6.6KV SWGR 223, BUS 4AX	415V SWGR 307, BUS 6B	2000	6.24	NA	Dyn11	*
25	TR-46	6.6/0.433 kV	6.6KV SWGR 223, BUS 4AX	415V SWGR 308, BUS 8B	1600	6.50	NA	Dyn11	*
26	TR-47	6.6/0.433 kV	6.6KV SWGR 223, BUS 4AX	415V SWGR 349, BUS 26B			NA	Dyn11	*
27	TR-53	6.6/0.433 kV	6.6KV SWGR 233, BUS 5AX	415V SWGR 311, BUS 9B	2000	6.29	NA	Dyn11	*
28	TR-57	6.6/0.433 kV	6.6KV SWGR 233, BUS 5AX	415V SWGR 312, BUS 11B	2000	6.17	NA	Dyn11	*
29	TR-59	6.6/0.433 kV	6.6KV SWGR 233, BUS 5AX	415V SWGR 313, BUS 13B	2000	6.24	NA	Dyn11	*
30	TR-55	6.6/0.433 kV	6.6KV SWGR 233, BUS 5AX	415V SWGR 314, BUS 15B	1600	6.51	NA	Dyn11	*
31	TR-54	6.6/0.433 kV	6.6KV SWGR 233, BUS 6AX	415V SWGR 311, BUS 10B	2000	6.17	NA	Dyn11	*
32	TR-56	6.6/0.433 kV	6.6KV SWGR 233, BUS 6AX	415V SWGR 314, BUS 16B	1600	6.44	NA	Dyn11	*

SL. NO.	TRANSFORMER DESIGNATION	VOLTAGE RATIO	FROM BUS	TO BUS	RATED KVA	%Z ON OWN BASE	NGR VALUE OHMS	VECTOR GROUP	OCTC SETTING
33	TR-58	6.6/0.433 kV	6.6KV SWGR 233, BUS 6AX	415V SWGR 312, BUS 12B	2000	6.27	NA	Dyn11	*
34	TR-60	6.6/0.433 kV	6.6KV SWGR 233, BUS 6AX	415V SWGR 313, BUS 14B	2000	6.39	NA	Dyn11	*
35	TR-75	6.6/0.433 kV	6.6KV SWGR 242, BUS 7AX	415V SWGR 331, BUS 19B	1000	4.95	NA	Dyn11	*
36	TR-76	6.6/0.433 kV	6.6KV SWGR 245, BUS 9AX	415V SWGR 341, BUS 20B	2000	6.38	NA	Dyn11	*
37	TR-80	6.6/0.433 kV	6.6KV SWGR 245, BUS 9AX	415V SWGR 346, BUS 27B	1600	6.51	NA	Dyn11	*
38	TR-277	6.6/0.433 kV	6.6KV SWGR 245, BUS 9AX	415V SWGR 2253, BUS 16B	2000	6.59	NA	Dyn11	*
39	TR-77	6.6/0.433 kV	6.6KV SWGR 245, BUS 10AX	415V SWGR 341, BUS 21B	2000	6.38	NA	Dyn11	*
40	TR-78	6.6/0.433 kV	6.6KV SWGR 245, BUS 10AX	415V SWGR 341, BUS 22B	2000	6.43	NA	Dyn11	*
41	TR-232	33/6.9 kV	33KV SWGR 2202, BUS 1	6.6KV SWGR 2213, BUS 2AX	20000	10.34	3.81+/-10%	Dyn1	*
42	TR-262	33/6.9 kV	33KV SWGR 2202, BUS 1	6.6KV SWGR 2243, BUS 6AX	20000	10.05	3.81+10%	Dyn1	*
43	TR-252	33/6.9 kV	33KV SWGR 2202, BUS 1	6.6KV SWGR 2233, BUS 4AX	16000	10.05	5.08 +/-10%	Dyn1	*
44	TR222	33/6.9 kV	33KV SWGR 2202, BUS 1	6.6KV CPP2 BUS-1	8500	8.43	13.28	Dyn11	
45	TR224	33/0.433 kV	33KV SWGR 2202, BUS 1	0.415KV LTAUX1	2000	6.44	NA	Dyn11	*
46	GT3	11/34.5 kV	26.5 MW STG-3	33KV SWGR 2202, BUS 1	33000	12.80	NA	YNd11	*
47	GT4	11/34.5 kV	26.5 MW STG-4	33KV SWGR 2202, BUS 1	33000	12.97	NA	D11yn	*
48	TR-231	33/6.9 kV	33KV SWGR 2202, BUS 2	6.6KV SWGR 2213, BUS 1AX	20000	10.34	3.81+/-10%	Dyn1	*

SL. NO.	TRANSFORMER DESIGNATION	VOLTAGE RATIO	FROM BUS	TO BUS	RATED KVA	%Z ON OWN BASE	NGR VALUE OHMS	VECTOR GROUP	OCTC SETTING
49	TR-261	33/6.9 kV	33KV SWGR 2202, BUS 2	6.6KV SWGR 2243, BUS 5AX	20000	10.05	3.81+/-10%	Dyn1	*
50	TR-251	33/6.9 kV	33KV SWGR 2202, BUS 2	6.6KV SWGR 2233, BUS 3AX	16000	9.90	5.08 +/-10%	Dyn1	*
51	TR-242	33/6.9 kV	33KV SWGR 2202, BUS 2	6.6KV SWGR 2223, BUS 8AX	10000	8.05	*	Dyn1	*
52	TR223	33/6.9 kV	33KV SWGR 2202, BUS 2	6.6KV CPP2 BUS-2	8500	8.54	13.2	Dyn11	*
53	TR225	33/0.433 kV	33KV SWGR 2202, BUS 2	0.415KV LTAUX2	2000	6.64	NA	Dyn11	*
54	GT5	11/34.5 kV	26.5 MW STG-5	33KV SWGR 2202, BUS 2	33000	12.76	NA	Dyn11	*
55	TR239	33/0.433 kV	33KV SWGR 2202, BUS 3	0.415KV SWGR 2371, BUS 49	500	4.39	NA	Dyn11	*
56	TR241	33/6.9 kV	33KV SWGR 2202, BUS 3	6.6KV SWGR 2223, BUS 7AX	10000	8.12	*	Dyn1	*
57	TR221	110/33 kV	110KV[KEB]	33KV SWGR 2202, BUS 3	20000	11.86/11.74/12.67*	*	Dyn11	*
58	TR-271	33/6.9 kV	33KV SWGR 2251, BUS 1E	6.6KV SWGR 2252, BUS 9AX	4000	7.05	9.53	Dyn1	*
59	TR-273	33/6.9 kV	33KV SWGR 2251, BUS 1E	6.6KV SWGR 2257, BUS 10AX	8000	8.1	9.53	Dyn1	*
60	TR-274	33/6.9 kV	33KV SWGR 2251, BUS 1F	6.6KV SWGR 2257, BUS 11AX	8000	8.10	9.532	Dyn1	*
61	TR-233	6.6/0.433 kV	6.6KV SWGR 2213, BUS 1AX	0.415KV SWGR 2311, BUS 02B	2000	6.58	NA*	Dyn11	*
62	TR-235	6.6/0.433 kV	6.6KV SWGR 2213, BUS 1AX	0.415KV SWGR 2312, BUS 04B	2000	6.58	NA*	Dyn11	*

SL. NO.	TRANSFORMER DESIGNATION	VOLTAGE RATIO	FROM BUS	TO BUS	RATED KVA	%Z ON OWN BASE	NGR VALUE OHMS	VECTOR GROUP	OCTC SETTING
63	TR-237	6.6/0.433 kV	6.6KV SWGR 2213, BUS 1AX	0.415KV SWGR 2313, BUS 06B	2000	6.58	NA*	Dyn11	*
64	TR-234	6.6/0.433 kV	6.6KV SWGR 2213, BUS 2AX	0.415KV SWGR 2311, BUS 03B	2000	6.58	NA*	Dyn11	*
65	TR-236	6.6/0.433 kV	6.6KV SWGR 2213, BUS 2AX	0.415KV SWGR 2312, BUS 05B	2000	6.58	NA*	Dyn11	*
66	TR-238	6.6/0.433 kV	6.6KV SWGR 2213, BUS 2AX	0.415KV SWGR 2313, BUS 07B	2000	6.58	NA*	Dyn11	*
67	TR-253	6.6/0.433 kV	6.6KV SWGR 2233, BUS 3AX	0.415KV SWGR 2331, BUS 08B	2000	6.75	NA*	Dyn11	*
68	TR-255	6.6/0.433 kV	6.6KV SWGR 2233, BUS 3AX	0.415KV SWGR 2332, BUS 10B	2000	6.71	NA*	Dyn11	*
69	TR-257	6.6/0.433 kV	6.6KV SWGR 2233, BUS 3AX	0.415KV SWGR 2333, BUS 12B	2000	6.80	NA*	Dyn11	*
70	TR-254	6.6/0.433 kV	6.6KV SWGR 2233, BUS 4AX	0.415KV SWGR 2331, BUS 08B	2000	6.57	NA*	Dyn11	*
71	TR-256	6.6/0.433 kV	6.6KV SWGR 2233, BUS 4AX	0.415KV SWGR 2332, BUS 10B	2000	6.57	NA*	Dyn11	*
72	TR-258	6.6/0.433 kV	6.6KV SWGR 2233, BUS 4AX	0.415KV SWGR 2333, BUS 12B	2000	6.79	NA*	Dyn11	*
73	TR-263	6.6/0.433 kV	6.6KV SWGR 2243, BUS 5AX	0.415KV SWGR 2341, BUS 17B	2000	6.68	NA*	Dyn11	*
74	TR-265	6.6/0.433 kV	6.6KV SWGR 2243, BUS 5AX	0.415KV SWGR 2342, BUS 19B	2000	6.68	NA*	Dyn11	*
75	TR-264	6.6/0.433 kV	6.6KV SWGR 2243, BUS 6AX	0.415KV SWGR 2341, BUS 18B	2000	6.68	NA*	Dyn11	*

SL. NO.	TRANSFORMER DESIGNATION	VOLTAGE RATIO	FROM BUS	TO BUS	RATED KVA	%Z ON OWN BASE	NGR VALUE OHMS	VECTOR GROUP	OCTC SETTING
76	TR-266	6.6/0.433 kV	6.6KV SWGR 2243, BUS 6AX	0.415KV SWGR 2342, BUS 20B	2000	6.64	NA*	Dyn11	*
77	TR-243	6.6/0.433 kV	6.6KV SWGR 2223, BUS 7AX	0.415KV SWGR 2321, BUS 25B	2000	6.76	7.62+/-10%	Dyn11	*
78	TR-245	6.6/0.433 kV	6.6KV SWGR 2223, BUS 7AX	0.415KV SWGR 2322, BUS 27B	2000	6.59	7.62+/-10%	Dyn11	*
79	TR-244	6.6/0.433 kV	6.6KV SWGR 2223, BUS 8AX	0.415KV SWGR 2321, BUS 26B	2000	6.79	7.62+/-10%	Dyn11	*
80	TR-246	6.6/0.433 kV	6.6KV SWGR 2223, BUS 8AX	0.415KV SWGR 2322, BUS 28B	2000	6.74	7.62+/-10%	Dyn11	*
81	TR-272	6.6/0.433 kV	6.6KV SWGR 2252, BUS 9AX	0.415KV SWGR 2351, BUS 14B	2000	6.65	NA	Dyn11	*
82	TR-275	6.6/0.433 kV	6.6KV SWGR 2257, BUS 10AX	0.415KV SWGR 2253, BUS 15B	2000	6.53	NA	Dyn11	*
83	TR-278	6.6/0.433 kV	6.6KV SWGR 2257, BUS 10AX	0.415KV SWGR 2381	2000	6.03	NA	Dyn11	*
84	TR-276	6.6/0.433 kV	6.6KV SWGR 2257, BUS 11AX	0.415KV SWGR 2253, BUS 16B	2000	6.43	NA	Dyn11	*
85	TR-279	6.6/0.433 kV	6.6KV SWGR 2257, BUS 11AX	0.415KV SWGR 2382	2000	6.13	NA	Dyn11	*

MRPL SYSTEM – TRANSFORMER REACTANCE DATA

Component	Field	Base Project
CCR1/TR1	X1 (pu)	3.0352
CCR1/TR1	Xo (pu)	3.0352
CCR1/TR2	X1 (pu)	3.0352
CCR1/TR2	Xo (pu)	3.0352
CCR2/TR1	X1 (pu)	2.9592
CCR2/TR1	Xo (pu)	2.9592
CCR2/TR2	X1 (pu)	2.9592
CCR2/TR2	Xo (pu)	2.9592
CPP1HT1	X1 (pu)	1.0823
CPP1HT1	Xo (pu)	1.0823
CPP1HT2	X1 (pu)	1.0935
CPP1HT2	Xo (pu)	1.0935
CPP1LT1	X1 (pu)	3.2021
CPP1LT1	Xo (pu)	3.2021
CPP1LT2	X1 (pu)	3.1920
CPP1LT2	Xo (pu)	3.1920
GT3	X1 (pu)	0.3867
GT3	Xo (pu)	0.3867
GT4	X1 (pu)	0.3919
GT4	Xo (pu)	0.3919
GT5	X1 (pu)	0.3855
GT5	Xo (pu)	0.3855
HOOK UP TR	X1 (pu)	0.0000
HOOK UP TR	Xo (pu)	0.0000
HTAT1	X1 (pu)	0.9849
HTAT1	Xo (pu)	0.9849
HTAT2	X1 (pu)	0.9979
HTAT2	Xo (pu)	0.9979
PH1 GRID TR	X1 (pu)	0.6391
PH1 GRID TR	Xo (pu)	0.6391
PHASE 2 GRID T	X1 (pu)	0.0000
PHASE 2 GRID T	Xo (pu)	0.0000
TR224	X1 (pu)	3.1818
TR224	Xo (pu)	3.1818
TR225	X1 (pu)	3.2830
TR225	Xo (pu)	3.2830
TR231	X1 (pu)	0.5146
TR231	Xo (pu)	0.5146
TR232	X1 (pu)	0.5146
TR232	Xo (pu)	0.5146
TR231	Xo (pu)	0.5146
TR232	X1 (pu)	0.5146
TR232	Xo (pu)	0.5146
TR233	X1 (pu)	3.2527
TR233	Xo (pu)	3.2527
TR234	X1 (pu)	3.2527
TR234	Xo (pu)	3.2527
TR235	X1 (pu)	3.2527
TR235	Xo (pu)	3.2527
TR236	X1 (pu)	3.2527
TR236	Xo (pu)	3.2527
TR237	X1 (pu)	3.2527
TR237	Xo (pu)	3.2527
TR238	X1 (pu)	3.2527
TR238	Xo (pu)	3.2527
TR239	X1 (pu)	8.5608
TR239	Xo (pu)	8.5608
TR241	X1 (pu)	0.8059
TR241	Xo (pu)	0.8059
TR242	X1 (pu)	0.7989
TR242	Xo (pu)	0.7989
TR243	X1 (pu)	3.3436
TR243	Xo (pu)	3.3436
TR244	X1 (pu)	3.3588
TR244	Xo (pu)	3.3588
TR245	X1 (pu)	3.2577
TR245	Xo (pu)	3.2577
TR246	X1 (pu)	3.3335
TR246	Xo (pu)	3.3335
TR251	X1 (pu)	0.6156
TR251	Xo (pu)	0.6156
TR252	X1 (pu)	0.6250
TR252	Xo (pu)	0.6250
TR253	X1 (pu)	0.8600
TR253	Xo (pu)	0.8600
TR254	X1 (pu)	0.8600
TR254	Xo (pu)	0.8600
TR255	X1 (pu)	0.8600
TR255	Xo (pu)	0.8600
TR256	X1 (pu)	0.8600
TR256	Xo (pu)	0.8600
TR257	X1 (pu)	0.8600
TR257	Xo (pu)	0.8600
TR258	X1 (pu)	0.8600
TR258	Xo (pu)	0.8600
TR261	X1 (pu)	0.5000
TR261	Xo (pu)	0.5000
TR262	X1 (pu)	0.5000
TR262	Xo (pu)	0.5000
TR263	X1 (pu)	3.3032
TR263	Xo (pu)	3.3032
TR264	X1 (pu)	3.3032
TR264	Xo (pu)	3.3032
TR265	X1 (pu)	3.3032
TR265	Xo (pu)	3.3032
TR266	X1 (pu)	3.2830
TR266	Xo (pu)	3.2830
TR271	X1 (pu)	1.7450
TR271	Xo (pu)	1.7450
TR272	X1 (pu)	0.8600
TR272	Xo (pu)	0.8600
TR273	X1 (pu)	1.0049
TR273	Xo (pu)	1.0049
TR274	X1 (pu)	1.0049
TR274	Xo (pu)	1.0049
TR275	X1 (pu)	3.2274
TR275	Xo (pu)	3.2274
TR276	X1 (pu)	3.1768
TR276	Xo (pu)	3.1768
TR278	X1 (pu)	2.9744
TR278	Xo (pu)	2.9744
TR279	X1 (pu)	3.0250
TR279	Xo (pu)	3.0250
TR31	X1 (pu)	0.5051
TR31	Xo (pu)	0.5051
TR32	X1 (pu)	0.4985
TR32	Xo (pu)	0.4985
TR33	X1 (pu)	3.1212
TR33	Xo (pu)	3.1212
TR34	X1 (pu)	3.1161

Component	Field	Base Project
TR34	Xo (pu)	3.1161
TR35	X1 (pu)	3.9204
TR35	Xo (pu)	3.9204
TR36	X1 (pu)	3.9584
TR36	Xo (pu)	3.9584
TR37	X1 (pu)	2.9592
TR37	Xo (pu)	2.9592
TR41	X1 (pu)	0.6488
TR41	Xo (pu)	0.6488
TR42	X1 (pu)	0.6584
TR42	Xo (pu)	0.6584
TR43	X1 (pu)	3.1110
TR43	Xo (pu)	3.1110
TR44	X1 (pu)	3.0807
TR44	Xo (pu)	3.0807
TR45	X1 (pu)	3.9584
TR45	Xo (pu)	3.9584
TR46	X1 (pu)	4.0152
TR46	Xo (pu)	4.0152
TR51	X1 (pu)	0.5987
TR51	Xo (pu)	0.5987
TR52	X1 (pu)	0.5974
TR52	Xo (pu)	0.5974
TR53	X1 (pu)	3.1060
TR53	Xo (pu)	3.1060
TR54	X1 (pu)	3.0452
TR54	Xo (pu)	3.0452
TR55	X1 (pu)	4.0216
TR55	Xo (pu)	4.0216
TR56	X1 (pu)	3.9773
TR56	Xo (pu)	3.9773
TR57	X1 (pu)	3.0452
TR57	Xo (pu)	3.0452
TR58	X1 (pu)	3.0958
TR58	Xo (pu)	3.0958
TR59	X1 (pu)	3.0807
TR59	Xo (pu)	3.0807
TR60	X1 (pu)	3.1566
TR60	Xo (pu)	3.1566
TR71	X1 (pu)	1.7753
TR71	Xo (pu)	1.7753
TR72	X1 (pu)	1.7652
TR72	Xo (pu)	1.7652
TR73	X1 (pu)	0.6761
TR73	Xo (pu)	0.6761
TR74	X1 (pu)	0.6761
TR74	Xo (pu)	0.6761
TR75	X1 (pu)	4.8520
TR75	Xo (pu)	4.8520
TR76	X1 (pu)	3.1515
TR76	Xo (pu)	3.1515
TR77	X1 (pu)	3.1515
TR77	Xo (pu)	3.1515
TR78	X1 (pu)	3.1768
TR78	Xo (pu)	3.1768
TR80	X1 (pu)	4.0216
TR80	Xo (pu)	4.0216

MRPL SYSTEM – CABLE DATA

Component	Field	Base Project
CBL-0001	R1 (pu)	0.0073
CBL-0001	X1 (pu)	0.1760
CBL-0001	Ro (pu)	0.0550
CBL-0001	Xo (pu)	0.7040
CBL-0001	Rpos (Ohms/km)	0.03
CBL-0001	Xpos (Ohms/km)	0.62
CBL-0001	Rzero (Ohms/km)	0.19
CBL-0001	Xzero (Ohms/km)	2.48
CBL-0002	R1 (pu)	0.0126
CBL-0002	X1 (pu)	0.0098
CBL-0002	Ro (pu)	0.0946
CBL-0002	Xo (pu)	0.0391
CBL-0002	Rpos (Ohms/km)	0.04
CBL-0002	Xpos (Ohms/km)	0.03
CBL-0002	Rzero (Ohms/km)	0.33
CBL-0002	Xzero (Ohms/km)	0.14
CBL-0003	R1 (pu)	0.0012
CBL-0003	X1 (pu)	0.0011
CBL-0003	Ro (pu)	0.0087
CBL-0003	Xo (pu)	0.0044
CBL-0003	Rpos (Ohms/km)	0.02
CBL-0003	Xpos (Ohms/km)	0.02
CBL-0003	Rzero (Ohms/km)	0.15
CBL-0003	Xzero (Ohms/km)	0.08
CBL-0004	R1 (pu)	0.0004
CBL-0004	X1 (pu)	0.0003
CBL-0004	Ro (pu)	0.0029
CBL-0004	Xo (pu)	0.0012
CBL-0004	Rpos (Ohms/km)	0.03
CBL-0004	Xpos (Ohms/km)	0.02
CBL-0004	Rzero (Ohms/km)	0.19
CBL-0004	Xzero (Ohms/km)	0.08
CBL-0006	R1 (pu)	0.0004
CBL-0006	X1 (pu)	0.0003
CBL-0006	Ro (pu)	0.0029
CBL-0006	Xo (pu)	0.0012
CBL-0006	Rpos (Ohms/km)	0.01
CBL-0006	Xpos (Ohms/km)	0.01
CBL-0006	Rzero (Ohms/km)	0.07
CBL-0006	Xzero (Ohms/km)	0.03
CBL-0006	Xzero (Ohms/km)	0.03
CBL-0007	R1 (pu)	0.0004
CBL-0007	X1 (pu)	0.0003
CBL-0007	Ro (pu)	0.0027
CBL-0007	Xo (pu)	0.0011
CBL-0007	Rpos (Ohms/km)	0.04
CBL-0007	Xpos (Ohms/km)	0.03
CBL-0007	Rzero (Ohms/km)	0.32
CBL-0007	Xzero (Ohms/km)	0.13
CBL-0008	R1 (pu)	0.0013
CBL-0008	X1 (pu)	0.0010
CBL-0008	Ro (pu)	0.0098
CBL-0008	Xo (pu)	0.0040
CBL-0008	Rpos (Ohms/km)	0.04
CBL-0008	Xpos (Ohms/km)	0.03
CBL-0008	Rzero (Ohms/km)	0.32
CBL-0008	Xzero (Ohms/km)	0.13
CBL-0011	R1 (pu)	0.0013
CBL-0011	X1 (pu)	0.0010
CBL-0011	Ro (pu)	0.0100
CBL-0011	Xo (pu)	0.0041
CBL-0011	Rpos (Ohms/km)	0.06
CBL-0011	Xpos (Ohms/km)	0.05
CBL-0011	Rzero (Ohms/km)	0.48
CBL-0011	Xzero (Ohms/km)	0.20
CBL-0012	R1 (pu)	0.0013
CBL-0012	X1 (pu)	0.0010
CBL-0012	Ro (pu)	0.0100
CBL-0012	Xo (pu)	0.0041
CBL-0012	Rpos (Ohms/km)	0.06
CBL-0012	Xpos (Ohms/km)	0.05
CBL-0012	Rzero (Ohms/km)	0.48
CBL-0012	Xzero (Ohms/km)	0.20
CBL-0013	R1 (pu)	0.0035
CBL-0013	X1 (pu)	0.0027
CBL-0013	Ro (pu)	0.0265
CBL-0013	Xo (pu)	0.0109
CBL-0013	Rpos (Ohms/km)	0.03
CBL-0013	Xpos (Ohms/km)	0.03
CBL-0013	Rzero (Ohms/km)	0.24

Component	Field	Base Project
CBL-0027	Xzero (Ohms/km)	0.11
CBL-0028	R1 (pu)	0.4161
CBL-0028	X1 (pu)	0.2739
CBL-0028	Ro (pu)	3.1209
CBL-0028	Xo (pu)	1.0964
CBL-0028	Rpos (Ohms/km)	0.04
CBL-0028	Xpos (Ohms/km)	0.03
CBL-0028	Rzero (Ohms/km)	0.32
CBL-0028	Xzero (Ohms/km)	0.11
CBL-0029	R1 (pu)	0.4161
CBL-0029	X1 (pu)	0.2739
CBL-0029	Ro (pu)	3.1209
CBL-0029	Xo (pu)	1.0964
CBL-0029	Rpos (Ohms/km)	0.04
CBL-0029	Xpos (Ohms/km)	0.03
CBL-0029	Rzero (Ohms/km)	0.32
CBL-0029	Xzero (Ohms/km)	0.11
CBL-0030	R1 (pu)	0.4161
CBL-0030	X1 (pu)	0.2739
CBL-0030	Ro (pu)	3.1209
CBL-0030	Xo (pu)	1.0964
CBL-0030	Rpos (Ohms/km)	0.04
CBL-0030	Xpos (Ohms/km)	0.03
CBL-0030	Rzero (Ohms/km)	0.32
CBL-0030	Xzero (Ohms/km)	0.11
CBL-0031	R1 (pu)	0.4161
CBL-0031	X1 (pu)	0.2739
CBL-0031	Ro (pu)	3.1209
CBL-0031	Xo (pu)	1.0964
CBL-0031	Rpos (Ohms/km)	0.04
CBL-0031	Xpos (Ohms/km)	0.03
CBL-0031	Rzero (Ohms/km)	0.32
CBL-0031	Xzero (Ohms/km)	0.11
CBL-0032	R1 (pu)	0.4161
CBL-0032	X1 (pu)	0.2739
CBL-0032	Ro (pu)	3.1209
CBL-0032	Xo (pu)	1.0964
CBL-0032	Rpos (Ohms/km)	0.04
CBL-0032	Xpos (Ohms/km)	0.03
CBL-0032	Rzero (Ohms/km)	0.32
CBL-0032	Xzero (Ohms/km)	0.11
CBL-0033	R1 (pu)	0.4161
CBL-0033	X1 (pu)	0.2739
CBL-0033	Ro (pu)	3.1209
CBL-0033	Xo (pu)	1.0964
CBL-0033	Rpos (Ohms/km)	0.04
CBL-0033	Xpos (Ohms/km)	0.03
CBL-0033	Rzero (Ohms/km)	0.32
CBL-0033	Xzero (Ohms/km)	0.11
CBL-0036	R1 (pu)	0.0178
CBL-0036	X1 (pu)	0.0128
CBL-0036	Ro (pu)	0.1333
CBL-0036	Xo (pu)	0.0510
CBL-0036	Rpos (Ohms/km)	0.13
CBL-0036	Xpos (Ohms/km)	0.09
CBL-0036	Rzero (Ohms/km)	0.97
CBL-0036	Xzero (Ohms/km)	0.37
CBL-0037	R1 (pu)	0.0192
CBL-0037	X1 (pu)	0.0138
CBL-0037	Ro (pu)	0.1444
CBL-0037	Xo (pu)	0.0523
CBL-0037	Rpos (Ohms/km)	0.13
CBL-0037	Xpos (Ohms/km)	0.09
CBL-0037	Rzero (Ohms/km)	0.97
CBL-0037	Xzero (Ohms/km)	0.35
CBL-0038	R1 (pu)	0.0221
CBL-0038	X1 (pu)	0.0159
CBL-0038	Ro (pu)	0.1666
CBL-0038	Xo (pu)	0.0638
CBL-0038	Rpos (Ohms/km)	0.13
CBL-0038	Xpos (Ohms/km)	0.09
CBL-0038	Rzero (Ohms/km)	0.97
CBL-0038	Xzero (Ohms/km)	0.37
CBL-0039	R1 (pu)	0.0237
CBL-0039	X1 (pu)	0.0170
CBL-0039	Ro (pu)	0.1777
CBL-0039	Xo (pu)	0.0680
CBL-0039	Rpos (Ohms/km)	0.13
CBL-0039	Xpos (Ohms/km)	0.09
CBL-0039	Rzero (Ohms/km)	0.97
CBL-0039	Xzero (Ohms/km)	0.37
CBL-0040	R1 (pu)	0.4161

Component	Field	Base Project
CBL-0051	Ro (pu)	0.0080
CBL-0051	Xo (pu)	0.0033
CBL-0051	Rpos (Ohms/km)	0.09
CBL-0051	Xpos (Ohms/km)	0.07
CBL-0051	Rzero (Ohms/km)	0.70
CBL-0051	Xzero (Ohms/km)	0.29
CBL-0052	R1 (pu)	0.0035
CBL-0052	X1 (pu)	0.0027
CBL-0052	Ro (pu)	0.0260
CBL-0052	Xo (pu)	0.0107
CBL-0052	Rpos (Ohms/km)	0.03
CBL-0052	Xpos (Ohms/km)	0.03
CBL-0052	Rzero (Ohms/km)	0.24
CBL-0052	Xzero (Ohms/km)	0.10
CBL-0053	R1 (pu)	0.0001
CBL-0053	X1 (pu)	0.0001
CBL-0053	Ro (pu)	0.0010
CBL-0053	Xo (pu)	0.0004
CBL-0053	Rpos (Ohms/km)	0.01
CBL-0053	Xpos (Ohms/km)	0.01
CBL-0053	Rzero (Ohms/km)	0.09
CBL-0053	Xzero (Ohms/km)	0.04
CBL-0054	R1 (pu)	0.0252
CBL-0054	X1 (pu)	0.0181
CBL-0054	Ro (pu)	0.1888
CBL-0054	Xo (pu)	0.0723
CBL-0054	Rpos (Ohms/km)	0.13
CBL-0054	Xpos (Ohms/km)	0.09
CBL-0054	Rzero (Ohms/km)	0.97
CBL-0054	Xzero (Ohms/km)	0.37
CBL-0055	R1 (pu)	0.0192
CBL-0055	X1 (pu)	0.0138
CBL-0055	Ro (pu)	0.1444
CBL-0055	Xo (pu)	0.0553
CBL-0055	Rpos (Ohms/km)	0.13
CBL-0055	Xpos (Ohms/km)	0.09
CBL-0055	Rzero (Ohms/km)	0.97
CBL-0055	Xzero (Ohms/km)	0.37
CBL-0056	R1 (pu)	0.4161
CBL-0056	X1 (pu)	0.2739
CBL-0056	Ro (pu)	3.1209
CBL-0056	Xo (pu)	1.0964
CBL-0056	Rpos (Ohms/km)	0.04
CBL-0056	Xpos (Ohms/km)	0.03
CBL-0056	Rzero (Ohms/km)	0.32
CBL-0058	Ro (pu)	3.1209
CBL-0058	Xo (pu)	1.0964
CBL-0058	Rpos (Ohms/km)	0.04
CBL-0058	Xpos (Ohms/km)	0.03
CBL-0058	Rzero (Ohms/km)	0.32
CBL-0058	Xzero (Ohms/km)	0.11
CBL-0059	R1 (pu)	0.4161
CBL-0059	X1 (pu)	0.2739
CBL-0059	Ro (pu)	3.1209
CBL-0059	Xo (pu)	1.0964
CBL-0059	Rpos (Ohms/km)	0.04
CBL-0059	Xpos (Ohms/km)	0.03
CBL-0059	Rzero (Ohms/km)	0.32
CBL-0059	Xzero (Ohms/km)	0.11
CBL-0060	R1 (pu)	0.4161
CBL-0060	X1 (pu)	0.2739
CBL-0060	Ro (pu)	3.1209
CBL-0060	Xo (pu)	1.0964
CBL-0060	Rpos (Ohms/km)	0.04
CBL-0060	Xpos (Ohms/km)	0.03
CBL-0060	Rzero (Ohms/km)	0.32
CBL-0060	Xzero (Ohms/km)	0.11
CBL-0061	R1 (pu)	0.0192
CBL-0061	X1 (pu)	0.0138
CBL-0061	Ro (pu)	0.1444
CBL-0061	Xo (pu)	0.0553
CBL-0061	Rpos (Ohms/km)	0.13
CBL-0061	Xpos (Ohms/km)	0.09
CBL-0061	Rzero (Ohms/km)	0.97
CBL-0061	Xzero (Ohms/km)	0.37
CBL-0062	R1 (pu)	0.0118
CBL-0062	X1 (pu)	0.0085
CBL-0062	Ro (pu)	0.0888
CBL-0062	Xo (pu)	0.0340
CBL-0062	Rpos (Ohms/km)	0.13
CBL-0062	Xpos (Ohms/km)	0.09
CBL-0062	Rzero (Ohms/km)	0.97
CBL-0062	Xzero (Ohms/km)	0.37
CBL-0063	R1 (pu)	0.4161
CBL-0063	X1 (pu)	0.2739
CBL-0063	Ro (pu)	3.1209
CBL-0063	Xo (pu)	1.0964
CBL-0063	Rpos (Ohms/km)	0.04
CBL-0063	Xpos (Ohms/km)	0.03
CBL-0063	Rzero (Ohms/km)	0.32

Component	Field	Base Project	Component	Field	Base Project
CBL-0056	Xzero (Ohms/km)	0.11	CBL-0063	Xzero (Ohms/km)	0.11
CBL-0058	R1 (pu)	0.4161	CBL-0064	R1 (pu)	0.4161
CBL-0058	X1 (pu)	0.2739	CBL-0064	X1 (pu)	0.2739
CBL-0070	X1 (pu)	0.2739	CBL-0076	X1 (pu)	0.2739
CBL-0070	Ro (pu)	3.1209	CBL-0076	Ro (pu)	3.1209
CBL-0070	Xo (pu)	1.0964	CBL-0076	Xo (pu)	1.0964
CBL-0070	Rpos (Ohms/km)	0.04	CBL-0076	Rpos (Ohms/km)	0.04
CBL-0070	Xpos (Ohms/km)	0.03	CBL-0076	Xpos (Ohms/km)	0.03
CBL-0070	Rzero (Ohms/km)	0.32	CBL-0076	Rzero (Ohms/km)	0.32
CBL-0070	Xzero (Ohms/km)	0.11	CBL-0076	Xzero (Ohms/km)	0.11
CBL-0071	R1 (pu)	0.4161	CBL-0077	R1 (pu)	0.0222
CBL-0071	X1 (pu)	0.2739	CBL-0077	X1 (pu)	0.0159
CBL-0071	Ro (pu)	3.1209	CBL-0077	Ro (pu)	0.1666
CBL-0071	Xo (pu)	1.0964	CBL-0077	Xo (pu)	0.0638
CBL-0071	Rpos (Ohms/km)	0.04	CBL-0077	Rpos (Ohms/km)	0.13
CBL-0071	Xpos (Ohms/km)	0.03	CBL-0077	Xpos (Ohms/km)	0.09
CBL-0071	Rzero (Ohms/km)	0.32	CBL-0077	Rzero (Ohms/km)	0.97
CBL-0071	Xzero (Ohms/km)	0.11	CBL-0077	Xzero (Ohms/km)	0.37
CBL-0072	R1 (pu)	0.4161	CBL-0078	R1 (pu)	0.0163
CBL-0072	X1 (pu)	0.2739	CBL-0078	X1 (pu)	0.0117
CBL-0072	Ro (pu)	3.1209	CBL-0078	Ro (pu)	0.1222
CBL-0072	Xo (pu)	1.0964	CBL-0078	Xo (pu)	0.0468
CBL-0072	Rpos (Ohms/km)	0.04	CBL-0078	Rpos (Ohms/km)	0.13
CBL-0072	Xpos (Ohms/km)	0.03	CBL-0078	Xpos (Ohms/km)	0.09
CBL-0072	Rzero (Ohms/km)	0.32	CBL-0078	Rzero (Ohms/km)	0.97
CBL-0072	Xzero (Ohms/km)	0.11	CBL-0078	Xzero (Ohms/km)	0.37
CBL-0073	R1 (pu)	0.4161	CBL-0079	R1 (pu)	0.4161
CBL-0073	X1 (pu)	0.2739	CBL-0079	X1 (pu)	0.2739
CBL-0073	Ro (pu)	3.1209	CBL-0079	Ro (pu)	3.1209
CBL-0073	Xo (pu)	1.0964	CBL-0079	Xo (pu)	1.0964
CBL-0073	Rpos (Ohms/km)	0.04	CBL-0079	Rpos (Ohms/km)	0.04
CBL-0073	Xpos (Ohms/km)	0.03	CBL-0079	Xpos (Ohms/km)	0.03
CBL-0073	Rzero (Ohms/km)	0.32	CBL-0079	Rzero (Ohms/km)	0.32
CBL-0073	Xzero (Ohms/km)	0.11	CBL-0079	Xzero (Ohms/km)	0.11
CBL-0074	R1 (pu)	0.4161	CBL-0082	R1 (pu)	0.4161
CBL-0074	X1 (pu)	0.2739	CBL-0082	X1 (pu)	0.2739
CBL-0074	Ro (pu)	3.1209	CBL-0082	Ro (pu)	3.1209
CBL-0074	Xo (pu)	1.0964	CBL-0082	Xo (pu)	1.0964
CBL-0074	Rpos (Ohms/km)	0.04	CBL-0082	Rpos (Ohms/km)	0.04
CBL-0074	Xpos (Ohms/km)	0.03	CBL-0082	Xpos (Ohms/km)	0.03
CBL-0074	Rzero (Ohms/km)	0.32	CBL-0082	Rzero (Ohms/km)	0.32
CBL-0074	Xzero (Ohms/km)	0.11	CBL-0082	Xzero (Ohms/km)	0.11
CBL-0075	R1 (pu)	0.4161	CBL-0083	R1 (pu)	0.4161

Component	Field	Base Project
CBL-0075	X1 (pu)	0.2739
CBL-0075	Ro (pu)	3.1209
CBL-0075	Xo (pu)	1.0964
CBL-0075	Rpos (Ohms/km)	0.04
CBL-0075	Xpos (Ohms/km)	0.03
CBL-0075	Rzero (Ohms/km)	0.32
CBL-0075	Xzero (Ohms/km)	0.11
CBL-0076	R1 (pu)	0.4161
CBL-0095	Rzero (Ohms/km)	0.32
CBL-0095	Xzero (Ohms/km)	0.11
CBL-0096	R1 (pu)	0.0002
CBL-0096	X1 (pu)	0.0001
CBL-0096	Ro (pu)	0.0012
CBL-0096	Xo (pu)	0.0005
CBL-0096	Rpos (Ohms/km)	0.02
CBL-0096	Xpos (Ohms/km)	0.02
CBL-0096	Rzero (Ohms/km)	0.16
CBL-0096	Xzero (Ohms/km)	0.06
CBL-0097	R1 (pu)	0.0178
CBL-0097	X1 (pu)	0.0138
CBL-0097	Ro (pu)	0.1333
CBL-0097	Xo (pu)	0.0550
CBL-0097	Rpos (Ohms/km)	0.04
CBL-0097	Xpos (Ohms/km)	0.03
CBL-0097	Rzero (Ohms/km)	0.32
CBL-0097	Xzero (Ohms/km)	0.13
CBL-0098	R1 (pu)	0.0074
CBL-0098	X1 (pu)	0.0053
CBL-0098	Ro (pu)	0.0555
CBL-0098	Xo (pu)	0.0213
CBL-0098	Rpos (Ohms/km)	0.13
CBL-0098	Xpos (Ohms/km)	0.09
CBL-0098	Rzero (Ohms/km)	0.97
CBL-0098	Xzero (Ohms/km)	0.37
CBL-0099	R1 (pu)	0.4161
CBL-0099	X1 (pu)	0.2739
CBL-0099	Ro (pu)	3.1209
CBL-0099	Xo (pu)	1.0964
CBL-0099	Rpos (Ohms/km)	0.04
CBL-0099	Xpos (Ohms/km)	0.03
CBL-0099	Rzero (Ohms/km)	0.32
CBL-0099	Xzero (Ohms/km)	0.11
CBL-0100	R1 (pu)	0.4161
CBL-0083	X1 (pu)	0.2739
CBL-0083	Ro (pu)	3.1209
CBL-0083	Xo (pu)	1.0964
CBL-0083	Rpos (Ohms/km)	0.04
CBL-0083	Xpos (Ohms/km)	0.03
CBL-0083	Rzero (Ohms/km)	0.32
CBL-0083	Xzero (Ohms/km)	0.11
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CBL-0102	X1 (pu)	0.1424
CBL-0102	Ro (pu)	1.4881
CBL-0102	Xo (pu)	0.5697
CBL-0102	Rpos (Ohms/km)	0.13
CBL-0102	Xpos (Ohms/km)	0.09
CBL-0102	Rzero (Ohms/km)	0.97
CBL-0102	Xzero (Ohms/km)	0.37
CBL-0103	R1 (pu)	0.0148
CBL-0103	X1 (pu)	0.0106
CBL-0103	Ro (pu)	0.1111
CBL-0103	Xo (pu)	0.0425
CBL-0103	Rpos (Ohms/km)	0.13
CBL-0103	Xpos (Ohms/km)	0.09
CBL-0103	Rzero (Ohms/km)	0.97
CBL-0103	Xzero (Ohms/km)	0.37
CBL-0104	R1 (pu)	0.0003
CBL-0104	X1 (pu)	0.0002
CBL-0104	Ro (pu)	0.0025
CBL-0104	Xo (pu)	0.0009
CBL-0104	Rpos (Ohms/km)	0.02
CBL-0104	Xpos (Ohms/km)	0.02
CBL-0104	Rzero (Ohms/km)	0.16
CBL-0104	Xzero (Ohms/km)	0.06
CBL-0105	R1 (pu)	0.0004
CBL-0105	X1 (pu)	0.0003
CBL-0105	Ro (pu)	0.0027
CBL-0105	Xo (pu)	0.0011
CBL-0105	Rpos (Ohms/km)	0.04
CBL-0105	Xpos (Ohms/km)	0.03
CBL-0105	Rzero (Ohms/km)	0.32
CBL-0105	Xzero (Ohms/km)	0.13
CBL-0106	R1 (pu)	0.0089
CBL-0106	X1 (pu)	0.0064
CBL-0106	Ro (pu)	0.0666
CBL-0106	Xo (pu)	0.0255

Component	Field	Base Project		Component	Field	Base Project
CBL-0100	X1 (pu)	0.2739		CBL-0106	Rpos (Ohms/km)	0.13
CBL-0100	Ro (pu)	3.1209		CBL-0106	Xpos (Ohms/km)	0.09
CBL-0100	Xo (pu)	1.0964		CBL-0106	Rzero (Ohms/km)	0.97
CBL-0100	Rpos (Ohms/km)	0.04		CBL-0106	Xzero (Ohms/km)	0.37
CBL-0100	Xpos (Ohms/km)	0.03		CBL-0108	R1 (pu)	0.0004
CBL-0100	Rzero (Ohms/km)	0.32		CBL-0108	X1 (pu)	0.0003
CBL-0100	Xzero (Ohms/km)	0.11		CBL-0108	Ro (pu)	0.0027
CBL-0101	R1 (pu)	0.4161		CBL-0108	Xo (pu)	0.0010
CBL-0101	X1 (pu)	0.2739		CBL-0108	Rpos (Ohms/km)	0.00
CBL-0101	Ro (pu)	3.1209		CBL-0108	Xpos (Ohms/km)	0.00
CBL-0101	Xo (pu)	1.0964		CBL-0108	Rzero (Ohms/km)	0.03
CBL-0101	Rpos (Ohms/km)	0.04		CBL-0108	Xzero (Ohms/km)	0.01
CBL-0101	Xpos (Ohms/km)	0.03		_	_	_
CBL-0101	Rzero (Ohms/km)	0.32		_	_	_
CBL-0101	Xzero (Ohms/km)	0.11		_	_	_
CBL-0102	R1 (pu)	0.1984		_	_	_
CBL-0121	Rzero (Ohms/km)	0.32		CBL-0128	R1 (pu)	0.4161
CBL-0121	Xzero (Ohms/km)	0.11		CBL-0128	X1 (pu)	0.2739
CBL-0122	R1 (pu)	0.4161		CBL-0128	Ro (pu)	3.1209
CBL-0122	X1 (pu)	0.2739		CBL-0128	Xo (pu)	1.0964
CBL-0122	Ro (pu)	3.1209		CBL-0128	Rpos (Ohms/km)	0.04
CBL-0122	Xo (pu)	1.0964		CBL-0128	Xpos (Ohms/km)	0.03
CBL-0122	Rpos (Ohms/km)	0.04		CBL-0128	Rzero (Ohms/km)	0.32
CBL-0122	Xpos (Ohms/km)	0.03		CBL-0128	Xzero (Ohms/km)	0.11
CBL-0122	Rzero (Ohms/km)	0.32		CBL-0129	R1 (pu)	0.4161
CBL-0122	Xzero (Ohms/km)	0.11		CBL-0129	X1 (pu)	0.2739
CBL-0123	R1 (pu)	0.4161		CBL-0129	Ro (pu)	3.1209
CBL-0123	X1 (pu)	0.2739		CBL-0129	Xo (pu)	1.0964
CBL-0123	Ro (pu)	3.1209		CBL-0129	Rpos (Ohms/km)	0.04
CBL-0123	Xo (pu)	1.0964		CBL-0129	Xpos (Ohms/km)	0.03
CBL-0123	Rpos (Ohms/km)	0.04		CBL-0129	Rzero (Ohms/km)	0.32
CBL-0123	Xpos (Ohms/km)	0.03		CBL-0129	Xzero (Ohms/km)	0.11
CBL-0123	Rzero (Ohms/km)	0.32		CBL-0130	R1 (pu)	0.4161
CBL-0123	Xzero (Ohms/km)	0.11		CBL-0130	X1 (pu)	0.2739
CBL-0124	R1 (pu)	0.4161		CBL-0130	Ro (pu)	3.1209
CBL-0124	X1 (pu)	0.2739		CBL-0130	Xo (pu)	1.0964
CBL-0124	Ro (pu)	3.1209		CBL-0130	Rpos (Ohms/km)	0.04
CBL-0124	Xo (pu)	1.0964		CBL-0130	Xpos (Ohms/km)	0.03
CBL-0124	Rpos (Ohms/km)	0.04		CBL-0130	Rzero (Ohms/km)	0.32
CBL-0124	Xpos (Ohms/km)	0.03		CBL-0130	Xzero (Ohms/km)	0.11
CBL-0124	Rzero (Ohms/km)	0.32		CBL-0131	R1 (pu)	0.0267
CBL-0124	Xzero (Ohms/km)	0.11		CBL-0131	X1 (pu)	0.0191
CBL-0125	R1 (pu)	0.2132		CBL-0131	Ro (pu)	0.1999

Component	Field	Base Project	Component	Field	Base Project
CBL-0125	X1 (pu)	0.1531	CBL-0131	Xo (pu)	0.0765
CBL-0125	Ro (pu)	1.5992	CBL-0131	Rpos (Ohms/km)	0.13
CBL-0125	Xo (pu)	0.6122	CBL-0131	Xpos (Ohms/km)	0.09
CBL-0125	Rpos (Ohms/km)	0.13	CBL-0131	Rzero (Ohms/km)	0.97
CBL-0125	Xpos (Ohms/km)	0.09	CBL-0131	Xzero (Ohms/km)	0.37
CBL-0125	Rzero (Ohms/km)	0.97	CBL-0132	R1 (pu)	0.0225
CBL-0125	Xzero (Ohms/km)	0.37	CBL-0132	X1 (pu)	0.0162
CBL-0126	R1 (pu)	0.0172	CBL-0132	Ro (pu)	0.1688
CBL-0126	X1 (pu)	0.0123	CBL-0132	Xo (pu)	0.0646
CBL-0126	Ro (pu)	0.1288	CBL-0132	Rpos (Ohms/km)	0.13
CBL-0126	Xo (pu)	0.0493	CBL-0132	Xpos (Ohms/km)	0.09
CBL-0126	Rpos (Ohms/km)	0.13	CBL-0132	Rzero (Ohms/km)	0.97
CBL-0126	Xpos (Ohms/km)	0.09	CBL-0132	Xzero (Ohms/km)	0.37
CBL-0126	Rzero (Ohms/km)	0.97	CBL-0133	R1 (pu)	0.4161
CBL-0126	Xzero (Ohms/km)	0.37	CBL-0133	X1 (pu)	0.2739
CBL-0127	R1 (pu)	0.4161	CBL-0133	Ro (pu)	3.1209
CBL-0127	X1 (pu)	0.2739	CBL-0133	Xo (pu)	1.0964
CBL-0127	Ro (pu)	3.1209	CBL-0133	Rpos (Ohms/km)	0.04
CBL-0127	Xo (pu)	1.0964	CBL-0133	Xpos (Ohms/km)	0.03
CBL-0127	Rpos (Ohms/km)	0.04	CBL-0133	Rzero (Ohms/km)	0.32
CBL-0127	Xpos (Ohms/km)	0.03	CBL-0133	Xzero (Ohms/km)	0.11
CBL-0127	Rzero (Ohms/km)	0.32	CBL-0134	R1 (pu)	0.4161
CBL-0127	Xzero (Ohms/km)	0.11	CBL-0134	X1 (pu)	0.2739
CBL-0128	R1 (pu)	0.4161	CBL-0134	Ro (pu)	3.1209
CBL-0146	Xzero (Ohms/km)	0.1133	CBL-0155	X1 (pu)	0.2739
CBL-0147	R1 (pu)	0.4161	CBL-0155	Ro (pu)	3.1209
CBL-0147	X1 (pu)	0.2739	CBL-0155	Xo (pu)	1.0964
CBL-0147	Ro (pu)	3.1209	CBL-0155	Rpos (Ohms/km)	0.0430
CBL-0147	Xo (pu)	1.0964	CBL-0155	Xpos (Ohms/km)	0.0283
CBL-0147	Rpos (Ohms/km)	0.0430	CBL-0155	Rzero (Ohms/km)	0.3225
CBL-0147	Xpos (Ohms/km)	0.0283	CBL-0155	Xzero (Ohms/km)	0.1133
CBL-0147	Rzero (Ohms/km)	0.3225	CBL-0156	R1 (pu)	0.0243
CBL-0147	Xzero (Ohms/km)	0.1133	CBL-0156	X1 (pu)	0.0174
CBL-0150	R1 (pu)	0.0207	CBL-0156	Ro (pu)	0.1821
CBL-0150	X1 (pu)	0.0149	CBL-0156	Xo (pu)	0.0697
CBL-0150	Ro (pu)	0.1555	CBL-0156	Rpos (Ohms/km)	0.1290
CBL-0150	Xo (pu)	0.0595	CBL-0156	Xpos (Ohms/km)	0.0926
CBL-0150	Rpos (Ohms/km)	0.1290	CBL-0156	Rzero (Ohms/km)	0.9675
CBL-0150	Xpos (Ohms/km)	0.0926	CBL-0156	Xzero (Ohms/km)	0.3704
CBL-0150	Rzero (Ohms/km)	0.9675	CBL-0157	R1 (pu)	0.0010
CBL-0150	Xzero (Ohms/km)	0.3704	CBL-0157	X1 (pu)	0.0005
CBL-0151	R1 (pu)	0.0192	CBL-0157	Ro (pu)	0.0072
CBL-0151	X1 (pu)	0.0138	CBL-0157	Xo (pu)	0.0022

Component	Field	Base Project
CBL-0151	Ro (pu)	0.1444
CBL-0151	Xo (pu)	0.0553
CBL-0151	Rpos (Ohms/km)	0.1290
CBL-0151	Xpos (Ohms/km)	0.0926
CBL-0151	Rzero (Ohms/km)	0.9675
CBL-0151	Xzero (Ohms/km)	0.3704
CBL-0152	R1 (pu)	0.4161
CBL-0152	X1 (pu)	0.2739
CBL-0152	Ro (pu)	3.1209
CBL-0152	Xo (pu)	1.0964
CBL-0152	Rpos (Ohms/km)	0.0430
CBL-0152	Xpos (Ohms/km)	0.0283
CBL-0152	Rzero (Ohms/km)	0.3225
CBL-0152	Xzero (Ohms/km)	0.1133
CBL-0153	R1 (pu)	0.4161
CBL-0153	X1 (pu)	0.2739
CBL-0153	Ro (pu)	3.1209
CBL-0153	Xo (pu)	1.0964
CBL-0153	Rpos (Ohms/km)	0.0430
CBL-0153	Xpos (Ohms/km)	0.0283
CBL-0153	Rzero (Ohms/km)	0.3225
CBL-0153	Xzero (Ohms/km)	0.1133
CBL-0154	R1 (pu)	0.4161
CBL-0154	X1 (pu)	0.2739
CBL-0154	Ro (pu)	3.1209
CBL-0154	Xo (pu)	1.0964
CBL-0154	Rpos (Ohms/km)	0.0430
CBL-0154	Xpos (Ohms/km)	0.0283
CBL-0154	Rzero (Ohms/km)	0.3225
CBL-0154	Xzero (Ohms/km)	0.1133
CBL-0155	R1 (pu)	0.4161
CBL-0176	Xzero (Ohms/km)	0.4957
CBL-0177	R1 (pu)	0.4161
CBL-0177	X1 (pu)	0.2739
CBL-0177	Ro (pu)	3.1209
CBL-0177	Xo (pu)	1.0964
CBL-0177	Rpos (Ohms/km)	0.0430
CBL-0177	Xpos (Ohms/km)	0.0283
CBL-0177	Rzero (Ohms/km)	0.3225
CBL-0177	Xzero (Ohms/km)	0.1133
CBL-0178	R1 (pu)	0.4161
CBL-0178	X1 (pu)	0.2739
CBL-0178	Ro (pu)	3.1209
CBL-0157	Rpos (Ohms/km)	0.2091
CBL-0157	Xpos (Ohms/km)	0.1176
CBL-0157	Rzero (Ohms/km)	1.5747
CBL-0157	Xzero (Ohms/km)	0.4726
CBL-0158	R1 (pu)	0.4161
CBL-0158	X1 (pu)	0.2739
CBL-0158	Ro (pu)	3.1209
CBL-0158	Xo (pu)	1.0964
CBL-0158	Rpos (Ohms/km)	0.0430
CBL-0158	Xpos (Ohms/km)	0.0283
CBL-0158	Rzero (Ohms/km)	0.3225
CBL-0158	Xzero (Ohms/km)	0.1133
CBL-0161	R1 (pu)	0.4161
CBL-0161	X1 (pu)	0.2739
CBL-0161	Ro (pu)	3.1209
CBL-0161	Xo (pu)	1.0964
CBL-0161	Rpos (Ohms/km)	0.0430
CBL-0161	Xpos (Ohms/km)	0.0283
CBL-0161	Rzero (Ohms/km)	0.3225
CBL-0161	Xzero (Ohms/km)	0.1133
CBL-0162	R1 (pu)	0.4161
CBL-0162	X1 (pu)	0.2739
CBL-0162	Ro (pu)	3.1209
CBL-0162	Xo (pu)	1.0964
CBL-0162	Rpos (Ohms/km)	0.0430
CBL-0162	Xpos (Ohms/km)	0.0283
CBL-0162	Rzero (Ohms/km)	0.3225
CBL-0162	Xzero (Ohms/km)	0.1133
CBL-0163	R1 (pu)	0.4161
CBL-0163	X1 (pu)	0.2739
CBL-0163	Ro (pu)	3.1209
CBL-0183	X1 (pu)	0.2739
CBL-0183	Ro (pu)	3.1209
CBL-0183	Xo (pu)	1.0964
CBL-0183	Rpos (Ohms/km)	0.0430
CBL-0183	Xpos (Ohms/km)	0.0283
CBL-0183	Rzero (Ohms/km)	0.3225
CBL-0183	Xzero (Ohms/km)	0.1133
CBL-0184	R1 (pu)	0.4161
CBL-0184	X1 (pu)	0.2739
CBL-0184	Ro (pu)	3.1209
CBL-0184	Xo (pu)	1.0964
CBL-0184	Rpos (Ohms/km)	0.0430

Component	Field	Base Project		Component	Field	Base Project
CBL-0178	Xo (pu)	1.0964		CBL-0184	Xpos (Ohms/km)	0.0283
CBL-0178	Rpos (Ohms/km)	0.0430		CBL-0184	Rzero (Ohms/km)	0.3225
CBL-0178	Xpos (Ohms/km)	0.0283		CBL-0184	Xzero (Ohms/km)	0.1133
CBL-0178	Rzero (Ohms/km)	0.3225		CBL-0185	R1 (pu)	0.0178
CBL-0178	Xzero (Ohms/km)	0.1133		CBL-0185	X1 (pu)	0.0128
CBL-0179	R1 (pu)	0.4161		CBL-0185	Ro (pu)	0.1333
CBL-0179	X1 (pu)	0.2739		CBL-0185	Xo (pu)	0.0510
CBL-0179	Ro (pu)	3.1209		CBL-0185	Rpos (Ohms/km)	0.1290
CBL-0179	Xo (pu)	1.0964		CBL-0185	Xpos (Ohms/km)	0.0926
CBL-0179	Rpos (Ohms/km)	0.0430		CBL-0185	Rzero (Ohms/km)	0.9675
CBL-0179	Xpos (Ohms/km)	0.0283		CBL-0185	Xzero (Ohms/km)	0.3704
CBL-0179	Rzero (Ohms/km)	0.3225		CBL-0186	R1 (pu)	0.0178
CBL-0179	Xzero (Ohms/km)	0.1133		CBL-0186	X1 (pu)	0.0128
CBL-0180	R1 (pu)	0.4161		CBL-0186	Ro (pu)	0.1333
CBL-0180	X1 (pu)	0.2739		CBL-0186	Xo (pu)	0.0510
CBL-0180	Ro (pu)	3.1209		CBL-0186	Rpos (Ohms/km)	0.1290
CBL-0180	Xo (pu)	1.0964		CBL-0186	Xpos (Ohms/km)	0.0926
CBL-0180	Rpos (Ohms/km)	0.0430		CBL-0186	Rzero (Ohms/km)	0.9675
CBL-0180	Xpos (Ohms/km)	0.0283		CBL-0186	Xzero (Ohms/km)	0.3704
CBL-0180	Rzero (Ohms/km)	0.3225		CBL-0187	R1 (pu)	0.0070
CBL-0180	Xzero (Ohms/km)	0.1133		CBL-0187	X1 (pu)	0.0018
CBL-0181	R1 (pu)	0.4161		CBL-0187	Ro (pu)	0.0185
CBL-0181	X1 (pu)	0.2739		CBL-0187	Xo (pu)	0.0071
CBL-0181	Ro (pu)	3.1209		CBL-0187	Rpos (Ohms/km)	0.3642
CBL-0181	Xo (pu)	1.0964		CBL-0187	Xpos (Ohms/km)	0.0926
CBL-0181	Rpos (Ohms/km)	0.0430		CBL-0187	Rzero (Ohms/km)	0.9675
CBL-0181	Xpos (Ohms/km)	0.0283		CBL-0187	Xzero (Ohms/km)	0.3704
CBL-0181	Rzero (Ohms/km)	0.3225		CBL-0188	R1 (pu)	0.0027
CBL-0181	Xzero (Ohms/km)	0.1133		CBL-0188	X1 (pu)	0.0015
CBL-0182	R1 (pu)	0.4161		CBL-0188	Ro (pu)	0.0204
CBL-0182	X1 (pu)	0.2739		CBL-0188	Xo (pu)	0.0061
CBL-0182	Ro (pu)	3.1209		CBL-0188	Rpos (Ohms/km)	0.1050
CBL-0182	Xo (pu)	1.0964		CBL-0188	Xpos (Ohms/km)	0.0590
CBL-0182	Rpos (Ohms/km)	0.0430		CBL-0188	Rzero (Ohms/km)	0.7875
CBL-0182	Xpos (Ohms/km)	0.0283		CBL-0188	Xzero (Ohms/km)	0.2359
CBL-0182	Rzero (Ohms/km)	0.3225		CBL-0189	R1 (pu)	0.0002
CBL-0182	Xzero (Ohms/km)	0.1133		CBL-0189	X1 (pu)	0.0001
CBL-0183	R1 (pu)	0.4161		CBL-0189	Ro (pu)	0.0012
CBL-0201	Xzero (Ohms/km)	0.4022		CBL-0209	X1 (pu)	0.0017
CBL-0203	R1 (pu)	0.0113		CBL-0209	Ro (pu)	0.0223
CBL-0203	X1 (pu)	0.0081		CBL-0209	Xo (pu)	0.0067
CBL-0203	Ro (pu)	0.0844		CBL-0209	Rpos (Ohms/km)	0.1049
CBL-0203	Xo (pu)	0.0323		CBL-0209	Xpos (Ohms/km)	0.0590

Component	Field	Base Project
CBL-0203	Rpos (Ohms/km)	0.1290
CBL-0203	Xpos (Ohms/km)	0.0926
CBL-0203	Rzero (Ohms/km)	0.9675
CBL-0203	Xzero (Ohms/km)	0.3704
CBL-0204	R1 (pu)	0.0129
CBL-0204	X1 (pu)	0.0072
CBL-0204	Ro (pu)	0.0968
CBL-0204	Xo (pu)	0.0290
CBL-0204	Rpos (Ohms/km)	0.2100
CBL-0204	Xpos (Ohms/km)	0.1180
CBL-0204	Rzero (Ohms/km)	1.5751
CBL-0204	Xzero (Ohms/km)	0.4721
CBL-0205	R1 (pu)	0.0014
CBL-0205	X1 (pu)	0.0008
CBL-0205	Ro (pu)	0.0108
CBL-0205	Xo (pu)	0.0032
CBL-0205	Rpos (Ohms/km)	0.2105
CBL-0205	Xpos (Ohms/km)	0.1176
CBL-0205	Rzero (Ohms/km)	1.5754
CBL-0205	Xzero (Ohms/km)	0.4719
CBL-0206	R1 (pu)	0.0121
CBL-0206	X1 (pu)	0.0068
CBL-0206	Ro (pu)	0.0907
CBL-0206	Xo (pu)	0.0272
CBL-0206	Rpos (Ohms/km)	0.1050
CBL-0206	Xpos (Ohms/km)	0.0590
CBL-0206	Rzero (Ohms/km)	0.7875
CBL-0206	Xzero (Ohms/km)	0.2360
CBL-0207	R1 (pu)	0.0121
CBL-0207	X1 (pu)	0.0068
CBL-0207	Ro (pu)	0.0907
CBL-0207	Xo (pu)	0.0272
CBL-0207	Rpos (Ohms/km)	0.1050
CBL-0207	Xpos (Ohms/km)	0.0590
CBL-0207	Rzero (Ohms/km)	0.7875
CBL-0207	Xzero (Ohms/km)	0.2360
CBL-0208	R1 (pu)	0.0006
CBL-0208	X1 (pu)	0.0003
CBL-0208	Ro (pu)	0.0046
CBL-0208	Xo (pu)	0.0014
CBL-0208	Rpos (Ohms/km)	0.2110
CBL-0208	Xpos (Ohms/km)	0.1191
CBL-0208	Rzero (Ohms/km)	1.5756
CBL-0208	Xzero (Ohms/km)	0.4730
CBL-0209	R1 (pu)	0.0030
CBL-0209	Rzero (Ohms/km)	0.7875
CBL-0209	Xzero (Ohms/km)	0.2360
CBL-0210	R1 (pu)	0.0001
CBL-0210	X1 (pu)	0.0001
CBL-0210	Ro (pu)	0.0008
CBL-0210	Xo (pu)	0.0002
CBL-0210	Rpos (Ohms/km)	0.1037
CBL-0210	Xpos (Ohms/km)	0.0570
CBL-0210	Rzero (Ohms/km)	0.7882
CBL-0210	Xzero (Ohms/km)	0.2385
CBL-0211	R1 (pu)	0.0030
CBL-0211	X1 (pu)	0.0017
CBL-0211	Ro (pu)	0.0223
CBL-0211	Xo (pu)	0.0067
CBL-0211	Rpos (Ohms/km)	0.1049
CBL-0211	Xpos (Ohms/km)	0.0590
CBL-0211	Rzero (Ohms/km)	0.7875
CBL-0211	Xzero (Ohms/km)	0.2360
CBL-0212	R1 (pu)	0.0001
CBL-0212	X1 (pu)	0.0000
CBL-0212	Ro (pu)	0.0007
CBL-0212	Xo (pu)	0.0002
CBL-0212	Rpos (Ohms/km)	0.1032
CBL-0212	Xpos (Ohms/km)	0.0573
CBL-0212	Rzero (Ohms/km)	0.7852
CBL-0212	Xzero (Ohms/km)	0.2350
CBL-0213	R1 (pu)	0.0508
CBL-0213	X1 (pu)	0.0094
CBL-0213	Ro (pu)	0.0807
CBL-0213	Xo (pu)	0.0239
CBL-0213	Rpos (Ohms/km)	1.0531
CBL-0213	Xpos (Ohms/km)	0.1949
CBL-0213	Rzero (Ohms/km)	1.6742
CBL-0213	Xzero (Ohms/km)	0.4957
CBL-0215	R1 (pu)	0.0101
CBL-0215	X1 (pu)	0.0072
CBL-0215	Ro (pu)	0.0755
CBL-0215	Xo (pu)	0.0289
CBL-0215	Rpos (Ohms/km)	0.1290
CBL-0215	Xpos (Ohms/km)	0.0926
CBL-0215	Rzero (Ohms/km)	0.9675
CBL-0215	Xzero (Ohms/km)	0.3704
CBL-0216	R1 (pu)	0.4161
CBL-0216	X1 (pu)	0.2739
CBL-0216	Ro (pu)	3.1209

Component	Field	Base Project		Component	Field	Base Project
CBL-0229	Xzero (Ohms/km)	0.1133		CBL-0231	X1 (pu)	0.0081
CBL-0230	R1 (pu)	0.0107		CBL-0231	Ro (pu)	0.0844
CBL-0230	X1 (pu)	0.0077		CBL-0231	Xo (pu)	0.0323
CBL-0230	Ro (pu)	0.0800		CBL-0231	Rpos (Ohms/km)	0.1290
CBL-0230	Xo (pu)	0.0306		CBL-0231	Xpos (Ohms/km)	0.0926
CBL-0230	Rpos (Ohms/km)	0.1290		CBL-0231	Rzero (Ohms/km)	0.9675
CBL-0230	Xpos (Ohms/km)	0.0926		CBL-0231	Xzero (Ohms/km)	0.3704
CBL-0230	Rzero (Ohms/km)	0.9675		CBL-0232	R1 (pu)	0.0053
CBL-0230	Xzero (Ohms/km)	0.3704		CBL-0232	X1 (pu)	0.0030
CBL-0231	R1 (pu)	0.0113		CBL-0232	Ro (pu)	0.0400
CBL-0234	Xzero (Ohms/km)	0.2360		CBL-0235	Ro (pu)	0.0032
CBL-0235	R1 (pu)	0.0020		CBL-0235	Xo (pu)	0.0010
CBL-0235	X1 (pu)	0.0004		CBL-0235	Rpos (Ohms/km)	1.0531

Component	Field	Base Project
CBL-0013	Xzero (Ohms/km)	0.10
CBL-0014	R1 (pu)	0.0981
CBL-0014	X1 (pu)	0.8329
CBL-0014	Ro (pu)	0.7356
CBL-0014	Xo (pu)	3.3315
CBL-0014	Rpos (Ohms/km)	0.13
CBL-0014	Xpos (Ohms/km)	1.10
CBL-0014	Rzero (Ohms/km)	0.97
CBL-0014	Xzero (Ohms/km)	4.38
CBL-0015	R1 (pu)	0.0013
CBL-0015	X1 (pu)	0.0010
CBL-0015	Ro (pu)	0.0100
CBL-0015	Xo (pu)	0.0041
CBL-0015	Rpos (Ohms/km)	0.06
CBL-0015	Xpos (Ohms/km)	0.05
CBL-0015	Rzero (Ohms/km)	0.48
CBL-0015	Xzero (Ohms/km)	0.20
CBL-0017	R1 (pu)	0.0017
CBL-0017	X1 (pu)	0.0526
CBL-0017	Ro (pu)	0.0124
CBL-0017	Xo (pu)	0.2106
CBL-0017	Rpos (Ohms/km)	0.04
CBL-0017	Xpos (Ohms/km)	1.37
CBL-0017	Rzero (Ohms/km)	0.32
CBL-0017	Xzero (Ohms/km)	5.46
CBL-0019	R1 (pu)	0.0435
CBL-0019	X1 (pu)	0.0081
CBL-0019	Ro (pu)	0.0692
CBL-0019	Xo (pu)	0.0205
CBL-0019	Rpos (Ohms/km)	1.05
CBL-0019	Xpos (Ohms/km)	0.19
CBL-0019	Rzero (Ohms/km)	1.67
CBL-0019	Xzero (Ohms/km)	0.50
CBL-0021	R1 (pu)	0.0005
CBL-0021	X1 (pu)	0.0004
CBL-0021	Ro (pu)	0.0035
CBL-0021	Xo (pu)	0.0015
CBL-0021	Rpos (Ohms/km)	0.03
CBL-0021	Xpos (Ohms/km)	0.02
CBL-0021	Rzero (Ohms/km)	0.19
CBL-0021	Xzero (Ohms/km)	0.08
CBL-0023	R1 (pu)	0.0178
CBL-0023	X1 (pu)	0.0128
CBL-0023	Ro (pu)	0.1333
CBL-0023	Xo (pu)	0.0510
CBL-0023	Rpos (Ohms/km)	0.13
CBL-0023	Xpos (Ohms/km)	0.09
CBL-0023	Rzero (Ohms/km)	0.97
CBL-0023	Xzero (Ohms/km)	0.37
CBL-0024	R1 (pu)	0.0178
CBL-0024	X1 (pu)	0.0128
CBL-0024	Ro (pu)	0.1333
CBL-0024	Xo (pu)	0.0510
CBL-0024	Rpos (Ohms/km)	0.13
CBL-0024	Xpos (Ohms/km)	0.09
CBL-0024	Rzero (Ohms/km)	0.97
CBL-0024	Xzero (Ohms/km)	0.37
CBL-0025	R1 (pu)	0.0207
CBL-0025	X1 (pu)	0.0149
CBL-0025	Ro (pu)	0.1555
CBL-0025	Xo (pu)	0.0595
CBL-0025	Rpos (Ohms/km)	0.13
CBL-0025	Xpos (Ohms/km)	0.09
CBL-0025	Rzero (Ohms/km)	0.97
CBL-0025	Xzero (Ohms/km)	0.37
CBL-0026	R1 (pu)	0.0207
CBL-0026	X1 (pu)	0.0149
CBL-0026	Ro (pu)	0.1555
CBL-0026	Xo (pu)	0.0595
CBL-0026	Rpos (Ohms/km)	0.13
CBL-0026	Xpos (Ohms/km)	0.09
CBL-0026	Rzero (Ohms/km)	0.97
CBL-0026	Xzero (Ohms/km)	0.37
CBL-0027	R1 (pu)	0.4161
CBL-0027	X1 (pu)	0.2739
CBL-0027	Ro (pu)	3.1209
CBL-0027	Xo (pu)	1.0964
CBL-0027	Rpos (Ohms/km)	0.04
CBL-0027	Xpos (Ohms/km)	0.03
CBL-0027	Rzero (Ohms/km)	0.32

Component	Field	Base Project
CBL-0040	X1 (pu)	0.2739
CBL-0040	Ro (pu)	3.1209
CBL-0040	Xo (pu)	1.0964
CBL-0040	Rpos (Ohms/km)	0.04
CBL-0040	Xpos (Ohms/km)	0.03
CBL-0040	Rzero (Ohms/km)	0.32
CBL-0040	Xzero (Ohms/km)	0.11
CBL-0041	R1 (pu)	0.4161
CBL-0041	X1 (pu)	0.2739
CBL-0041	Ro (pu)	3.1209
CBL-0041	Xo (pu)	1.0964
CBL-0041	Rpos (Ohms/km)	0.04
CBL-0041	Xpos (Ohms/km)	0.03
CBL-0041	Rzero (Ohms/km)	0.32
CBL-0041	Xzero (Ohms/km)	0.11
CBL-0042	R1 (pu)	0.4161
CBL-0042	X1 (pu)	0.2739
CBL-0042	Ro (pu)	3.1209
CBL-0042	Xo (pu)	1.0964
CBL-0042	Rpos (Ohms/km)	0.04
CBL-0042	Xpos (Ohms/km)	0.03
CBL-0042	Rzero (Ohms/km)	0.32
CBL-0042	Xzero (Ohms/km)	0.11
CBL-0043	R1 (pu)	0.4161
CBL-0043	X1 (pu)	0.2739
CBL-0043	Ro (pu)	3.1209
CBL-0043	Xo (pu)	1.0964
CBL-0043	Rpos (Ohms/km)	0.04
CBL-0043	Xpos (Ohms/km)	0.03
CBL-0043	Rzero (Ohms/km)	0.32
CBL-0043	Xzero (Ohms/km)	0.11
CBL-0044	R1 (pu)	0.4161
CBL-0044	X1 (pu)	0.2739
CBL-0044	Ro (pu)	3.1209
CBL-0044	Xo (pu)	1.0964
CBL-0044	Rpos (Ohms/km)	0.04
CBL-0044	Xpos (Ohms/km)	0.03
CBL-0044	Rzero (Ohms/km)	0.32
CBL-0044	Xzero (Ohms/km)	0.11
CBL-0045	R1 (pu)	0.4161
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CBL-0045	X1 (pu)	0.2739
CBL-0045	Ro (pu)	3.1209
CBL-0045	Xo (pu)	1.0964
CBL-0045	Rpos (Ohms/km)	0.04
CBL-0045	Xpos (Ohms/km)	0.03
CBL-0045	Rzero (Ohms/km)	0.32
CBL-0045	Xzero (Ohms/km)	0.11
CBL-0047	R1 (pu)	0.4161
CBL-0047	X1 (pu)	0.2739
CBL-0047	Ro (pu)	3.1209
CBL-0047	Xo (pu)	1.0964
CBL-0047	Rpos (Ohms/km)	0.04
CBL-0047	Xpos (Ohms/km)	0.03
CBL-0047	Rzero (Ohms/km)	0.32
CBL-0047	Xzero (Ohms/km)	0.11
CBL-0048	R1 (pu)	0.4161
CBL-0048	X1 (pu)	0.2739
CBL-0048	Ro (pu)	3.1209
CBL-0048	Xo (pu)	1.0964
CBL-0048	Rpos (Ohms/km)	0.04
CBL-0048	Xpos (Ohms/km)	0.03
CBL-0048	Rzero (Ohms/km)	0.32
CBL-0048	Xzero (Ohms/km)	0.11
CBL-0049	R1 (pu)	0.4161
CBL-0049	X1 (pu)	0.2739
CBL-0049	Ro (pu)	3.1209
CBL-0049	Xo (pu)	1.0964
CBL-0049	Rpos (Ohms/km)	0.04
CBL-0049	Xpos (Ohms/km)	0.03
CBL-0049	Rzero (Ohms/km)	0.32
CBL-0049	Xzero (Ohms/km)	0.11
CBL-0050	R1 (pu)	0.4161
CBL-0050	X1 (pu)	0.2739
CBL-0050	Ro (pu)	3.1209
CBL-0050	Xo (pu)	1.0964
CBL-0050	Rpos (Ohms/km)	0.04
CBL-0050	Xpos (Ohms/km)	0.03
CBL-0050	Rzero (Ohms/km)	0.32
CBL-0050	Xzero (Ohms/km)	0.11
CBL-0051	R1 (pu)	0.0011
CBL-0051	X1 (pu)	0.0008

Component	Field	Base Project
CBL-0058	Ro (pu)	3.1209
CBL-0058	Xo (pu)	1.0964
CBL-0058	Rpos (Ohms/km)	0.04
CBL-0058	Xpos (Ohms/km)	0.03
CBL-0058	Rzero (Ohms/km)	0.32
CBL-0058	Xzero (Ohms/km)	0.11
CBL-0059	R1 (pu)	0.4161
CBL-0059	X1 (pu)	0.2739
CBL-0059	Ro (pu)	3.1209
CBL-0059	Xo (pu)	1.0964
CBL-0059	Rpos (Ohms/km)	0.04
CBL-0059	Xpos (Ohms/km)	0.03
CBL-0059	Rzero (Ohms/km)	0.32
CBL-0059	Xzero (Ohms/km)	0.11
CBL-0060	R1 (pu)	0.4161
CBL-0060	X1 (pu)	0.2739
CBL-0060	Ro (pu)	3.1209
CBL-0060	Xo (pu)	1.0964
CBL-0060	Rpos (Ohms/km)	0.04
CBL-0060	Xpos (Ohms/km)	0.03
CBL-0060	Rzero (Ohms/km)	0.32
CBL-0060	Xzero (Ohms/km)	0.11
CBL-0061	R1 (pu)	0.0192
CBL-0061	X1 (pu)	0.0138
CBL-0061	Ro (pu)	0.1444
CBL-0061	Xo (pu)	0.0553
CBL-0061	Rpos (Ohms/km)	0.13
CBL-0061	Xpos (Ohms/km)	0.09
CBL-0061	Rzero (Ohms/km)	0.97
CBL-0061	Xzero (Ohms/km)	0.37
CBL-0062	R1 (pu)	0.0118
CBL-0062	X1 (pu)	0.0085
CBL-0062	Ro (pu)	0.0888
CBL-0062	Xo (pu)	0.0340
CBL-0062	Rpos (Ohms/km)	0.13
CBL-0062	Xpos (Ohms/km)	0.09
CBL-0062	Rzero (Ohms/km)	0.97
CBL-0062	Xzero (Ohms/km)	0.37
CBL-0063	R1 (pu)	0.4161
CBL-0063	X1 (pu)	0.2739
CBL-0063	Ro (pu)	3.1209
CBL-0063	Xo (pu)	1.0964
CBL-0063	Rpos (Ohms/km)	0.04
CBL-0063	Xpos (Ohms/km)	0.03
CBL-0063	Rzero (Ohms/km)	0.32
CBL-0064	X1 (pu)	0.2739
CBL-0064	Ro (pu)	3.1209
CBL-0064	Xo (pu)	1.0964
CBL-0064	Rpos (Ohms/km)	0.04
CBL-0064	Xpos (Ohms/km)	0.03
CBL-0064	Rzero (Ohms/km)	0.32
CBL-0064	Xzero (Ohms/km)	0.11
CBL-0065	R1 (pu)	0.4161
CBL-0065	X1 (pu)	0.2739
CBL-0065	Ro (pu)	3.1209
CBL-0065	Xo (pu)	1.0964
CBL-0065	Rpos (Ohms/km)	0.04
CBL-0065	Xpos (Ohms/km)	0.03
CBL-0065	Rzero (Ohms/km)	0.32
CBL-0065	Xzero (Ohms/km)	0.11
CBL-0066	R1 (pu)	0.4161
CBL-0066	X1 (pu)	0.2739
CBL-0066	Ro (pu)	3.1209
CBL-0066	Xo (pu)	1.0964
CBL-0066	Rpos (Ohms/km)	0.04
CBL-0066	Xpos (Ohms/km)	0.03
CBL-0066	Rzero (Ohms/km)	0.32
CBL-0066	Xzero (Ohms/km)	0.11
CBL-0067	R1 (pu)	0.0163
CBL-0067	X1 (pu)	0.0117
CBL-0067	Ro (pu)	0.1222
CBL-0067	Xo (pu)	0.0468
CBL-0067	Rpos (Ohms/km)	0.13
CBL-0067	Xpos (Ohms/km)	0.09
CBL-0067	Rzero (Ohms/km)	0.97
CBL-0067	Xzero (Ohms/km)	0.37
CBL-0068	R1 (pu)	0.0089
CBL-0068	X1 (pu)	0.0064
CBL-0068	Ro (pu)	0.0666
CBL-0068	Xo (pu)	0.0255
CBL-0068	Rpos (Ohms/km)	0.13
CBL-0068	Xpos (Ohms/km)	0.09
CBL-0068	Rzero (Ohms/km)	0.97
CBL-0068	Xzero (Ohms/km)	0.37
CBL-0069	R1 (pu)	0.4161
CBL-0069	X1 (pu)	0.2739
CBL-0069	Ro (pu)	3.1209
CBL-0069	Xo (pu)	1.0964
CBL-0069	Rpos (Ohms/km)	0.04
CBL-0069	Xpos (Ohms/km)	0.03

Component	Field	Base Project
CBL-0063	Xzero (Ohms/km)	0.11
CBL-0064	R1 (pu)	0.4161
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CBL-0084	R1 (pu)	0.4161
CBL-0084	X1 (pu)	0.2739
CBL-0084	Ro (pu)	3.1209
CBL-0084	Xo (pu)	1.0964
CBL-0084	Rpos (Ohms/km)	0.04
CBL-0084	Xpos (Ohms/km)	0.03
CBL-0084	Rzero (Ohms/km)	0.32
CBL-0084	Xzero (Ohms/km)	0.11
CBL-0085	R1 (pu)	0.4161
CBL-0085	X1 (pu)	0.2739
CBL-0085	Ro (pu)	3.1209
CBL-0085	Xo (pu)	1.0964
CBL-0085	Rpos (Ohms/km)	0.04
CBL-0085	Xpos (Ohms/km)	0.03
CBL-0085	Rzero (Ohms/km)	0.32
CBL-0085	Xzero (Ohms/km)	0.11
CBL-0086	R1 (pu)	0.4161
CBL-0086	X1 (pu)	0.2739
CBL-0086	Ro (pu)	3.1209
CBL-0086	Xo (pu)	1.0964
CBL-0086	Rpos (Ohms/km)	0.04
CBL-0086	Xpos (Ohms/km)	0.03
CBL-0086	Rzero (Ohms/km)	0.32
CBL-0086	Xzero (Ohms/km)	0.11
CBL-0087	R1 (pu)	0.4161
CBL-0087	X1 (pu)	0.2739
CBL-0087	Ro (pu)	3.1209
CBL-0087	Xo (pu)	1.0964
CBL-0087	Rpos (Ohms/km)	0.04
CBL-0087	Xpos (Ohms/km)	0.03
CBL-0087	Rzero (Ohms/km)	0.32
CBL-0087	Xzero (Ohms/km)	0.11
CBL-0088	R1 (pu)	0.0252
CBL-0088	X1 (pu)	0.0181
CBL-0088	Ro (pu)	0.1888
CBL-0088	Xo (pu)	0.0723
CBL-0088	Rpos (Ohms/km)	0.13
CBL-0088	Xpos (Ohms/km)	0.09
CBL-0088	Rzero (Ohms/km)	0.97
CBL-0088	Xzero (Ohms/km)	0.37
CBL-0069	Rzero (Ohms/km)	0.32
CBL-0069	Xzero (Ohms/km)	0.11
CBL-0070	R1 (pu)	0.4161
CBL-0089	Xzero (Ohms/km)	0.37
CBL-0090	R1 (pu)	0.4161
CBL-0090	X1 (pu)	0.2739
CBL-0090	Ro (pu)	3.1209
CBL-0090	Xo (pu)	1.0964
CBL-0090	Rpos (Ohms/km)	0.04
CBL-0090	Xpos (Ohms/km)	0.03
CBL-0090	Rzero (Ohms/km)	0.32
CBL-0090	Xzero (Ohms/km)	0.11
CBL-0091	R1 (pu)	0.0019
CBL-0091	X1 (pu)	0.0013
CBL-0091	Ro (pu)	0.0139
CBL-0091	Xo (pu)	0.0053
CBL-0091	Rpos (Ohms/km)	0.06
CBL-0091	Xpos (Ohms/km)	0.05
CBL-0091	Rzero (Ohms/km)	0.48
CBL-0091	Xzero (Ohms/km)	0.19
CBL-0092	R1 (pu)	0.0604
CBL-0092	X1 (pu)	0.0112
CBL-0092	Ro (pu)	0.0961
CBL-0092	Xo (pu)	0.0284
CBL-0092	Rpos (Ohms/km)	1.05
CBL-0092	Xpos (Ohms/km)	0.19
CBL-0092	Rzero (Ohms/km)	1.67
CBL-0092	Xzero (Ohms/km)	0.50
CBL-0093	R1 (pu)	0.0074
CBL-0093	X1 (pu)	0.0053
CBL-0093	Ro (pu)	0.0555
CBL-0093	Xo (pu)	0.0213
CBL-0093	Rpos (Ohms/km)	0.13
CBL-0093	Xpos (Ohms/km)	0.09
CBL-0093	Rzero (Ohms/km)	0.97
CBL-0093	Xzero (Ohms/km)	0.37
CBL-0094	R1 (pu)	0.4161
CBL-0094	X1 (pu)	0.2739
CBL-0094	Ro (pu)	3.1209
CBL-0094	Xo (pu)	1.0964
CBL-0094	Rpos (Ohms/km)	0.04
CBL-0094	Xpos (Ohms/km)	0.03
CBL-0094	Rzero (Ohms/km)	0.32

Component	Field	Base Project
CBL-0089	R1 (pu)	0.0252
CBL-0089	X1 (pu)	0.0181
CBL-0089	Ro (pu)	0.1888
CBL-0089	Xo (pu)	0.0723
CBL-0089	Rpos (Ohms/km)	0.13
CBL-0089	Xpos (Ohms/km)	0.09
CBL-0089	Rzero (Ohms/km)	0.97
CBL-0110	R1 (pu)	0.0012
CBL-0110	X1 (pu)	0.0020
CBL-0110	Ro (pu)	0.0088
CBL-0110	Xo (pu)	0.0082
CBL-0110	Rpos (Ohms/km)	0.06
CBL-0110	Xpos (Ohms/km)	0.10
CBL-0110	Rzero (Ohms/km)	0.43
CBL-0110	Xzero (Ohms/km)	0.40
CBL-0111	R1 (pu)	0.0010
CBL-0111	X1 (pu)	0.0005
CBL-0111	Ro (pu)	0.0072
CBL-0111	Xo (pu)	0.0022
CBL-0111	Rpos (Ohms/km)	0.21
CBL-0111	Xpos (Ohms/km)	0.12
CBL-0111	Rzero (Ohms/km)	1.57
CBL-0111	Xzero (Ohms/km)	0.47
CBL-0112	R1 (pu)	0.0002
CBL-0112	X1 (pu)	0.0002
CBL-0112	Ro (pu)	0.0003
CBL-0112	Xo (pu)	0.0006
CBL-0112	Rpos (Ohms/km)	0.09
CBL-0112	Xpos (Ohms/km)	0.14
CBL-0112	Rzero (Ohms/km)	0.15
CBL-0112	Xzero (Ohms/km)	0.35
CBL-0113	R1 (pu)	0.0001
CBL-0113	X1 (pu)	0.0002
CBL-0113	Ro (pu)	0.0002
CBL-0113	Xo (pu)	0.0005
CBL-0113	Rpos (Ohms/km)	0.09
CBL-0113	Xpos (Ohms/km)	0.14
CBL-0113	Rzero (Ohms/km)	0.15
CBL-0113	Xzero (Ohms/km)	0.35
CBL-0114	R1 (pu)	0.0002
CBL-0114	X1 (pu)	0.0002
CBL-0114	Ro (pu)	0.0003

Component	Field	Base Project
CBL-0094	Xzero (Ohms/km)	0.11
CBL-0095	R1 (pu)	0.4161
CBL-0095	X1 (pu)	0.2739
CBL-0095	Ro (pu)	3.1209
CBL-0095	Xo (pu)	1.0964
CBL-0095	Rpos (Ohms/km)	0.04
CBL-0095	Xpos (Ohms/km)	0.03
CBL-0115	Xzero (Ohms/km)	0.24
CBL-0116	R1 (pu)	0.0020
CBL-0116	X1 (pu)	0.0017
CBL-0116	Ro (pu)	0.0147
CBL-0116	Xo (pu)	0.0067
CBL-0116	Rpos (Ohms/km)	0.06
CBL-0116	Xpos (Ohms/km)	0.06
CBL-0116	Rzero (Ohms/km)	0.48
CBL-0116	Xzero (Ohms/km)	0.22
CBL-0117	R1 (pu)	0.0001
CBL-0117	X1 (pu)	0.0001
CBL-0117	Ro (pu)	0.0008
CBL-0117	Xo (pu)	0.0004
CBL-0117	Rpos (Ohms/km)	0.06
CBL-0117	Xpos (Ohms/km)	0.06
CBL-0117	Rzero (Ohms/km)	0.48
CBL-0117	Xzero (Ohms/km)	0.22
CBL-0118	R1 (pu)	0.0001
CBL-0118	X1 (pu)	0.0001
CBL-0118	Ro (pu)	0.0006
CBL-0118	Xo (pu)	0.0003
CBL-0118	Rpos (Ohms/km)	0.06
CBL-0118	Xpos (Ohms/km)	0.06
CBL-0118	Rzero (Ohms/km)	0.48
CBL-0118	Xzero (Ohms/km)	0.22
CBL-0119	R1 (pu)	0.0118
CBL-0119	X1 (pu)	0.0085
CBL-0119	Ro (pu)	0.0888
CBL-0119	Xo (pu)	0.0340
CBL-0119	Rpos (Ohms/km)	0.13
CBL-0119	Xpos (Ohms/km)	0.09
CBL-0119	Rzero (Ohms/km)	0.97
CBL-0119	Xzero (Ohms/km)	0.37
CBL-0120	R1 (pu)	0.0083
CBL-0120	X1 (pu)	0.0060

Component	Field	Base Project
CBL-0114	Xo (pu)	0.0006
CBL-0114	Rpos (Ohms/km)	0.09
CBL-0114	Xpos (Ohms/km)	0.14
CBL-0114	Rzero (Ohms/km)	0.15
CBL-0114	Xzero (Ohms/km)	0.35
CBL-0115	R1 (pu)	0.0033
CBL-0115	X1 (pu)	0.0018
CBL-0115	Ro (pu)	0.0247
CBL-0115	Xo (pu)	0.0074
CBL-0115	Rpos (Ohms/km)	0.11
CBL-0115	Xpos (Ohms/km)	0.06
CBL-0115	Rzero (Ohms/km)	0.79
CBL-0134	Xo (pu)	1.0964
CBL-0134	Rpos (Ohms/km)	0.04
CBL-0134	Xpos (Ohms/km)	0.03
CBL-0134	Rzero (Ohms/km)	0.32
CBL-0134	Xzero (Ohms/km)	0.11
CBL-0135	R1 (pu)	0.4161
CBL-0135	X1 (pu)	0.2739
CBL-0135	Ro (pu)	3.1209
CBL-0135	Xo (pu)	1.0964
CBL-0135	Rpos (Ohms/km)	0.04
CBL-0135	Xpos (Ohms/km)	0.03
CBL-0135	Rzero (Ohms/km)	0.32
CBL-0135	Xzero (Ohms/km)	0.11
CBL-0136	R1 (pu)	0.4161
CBL-0136	X1 (pu)	0.2739
CBL-0136	Ro (pu)	3.1209
CBL-0136	Xo (pu)	1.0964
CBL-0136	Rpos (Ohms/km)	0.04
CBL-0136	Xpos (Ohms/km)	0.03
CBL-0136	Rzero (Ohms/km)	0.32
CBL-0136	Xzero (Ohms/km)	0.11
CBL-0137	R1 (pu)	0.0001
CBL-0137	X1 (pu)	0.0001
CBL-0137	Ro (pu)	0.0005
CBL-0137	Xo (pu)	0.0002
CBL-0137	Rpos (Ohms/km)	0.04
CBL-0137	Xpos (Ohms/km)	0.04

Component	Field	Base Project
CBL-0120	Ro (pu)	0.0622
CBL-0120	Xo (pu)	0.0238
CBL-0120	Rpos (Ohms/km)	0.13
CBL-0120	Xpos (Ohms/km)	0.09
CBL-0120	Rzero (Ohms/km)	0.97
CBL-0120	Xzero (Ohms/km)	0.37
CBL-0121	R1 (pu)	0.4161
CBL-0121	X1 (pu)	0.2739
CBL-0121	Ro (pu)	3.1209
CBL-0121	Xo (pu)	1.0964
CBL-0121	Rpos (Ohms/km)	0.04
CBL-0121	Xpos (Ohms/km)	0.03
CBL-0140	Xpos (Ohms/km)	0.06
CBL-0140	Rzero (Ohms/km)	0.48
CBL-0140	Xzero (Ohms/km)	0.2226
CBL-0141	R1 (pu)	0.0042
CBL-0141	X1 (pu)	0.0036
CBL-0141	Ro (pu)	0.0312
CBL-0141	Xo (pu)	0.0143
CBL-0141	Rpos (Ohms/km)	0.0645
CBL-0141	Xpos (Ohms/km)	0.0555
CBL-0141	Rzero (Ohms/km)	0.4837
CBL-0141	Xzero (Ohms/km)	0.2220
CBL-0142	R1 (pu)	0.0001
CBL-0142	X1 (pu)	0.0001
CBL-0142	Ro (pu)	0.0008
CBL-0142	Xo (pu)	0.0004
CBL-0142	Rpos (Ohms/km)	0.0648
CBL-0142	Xpos (Ohms/km)	0.0559
CBL-0142	Rzero (Ohms/km)	0.4827
CBL-0142	Xzero (Ohms/km)	0.2207
CBL-0143	R1 (pu)	0.0192
CBL-0143	X1 (pu)	0.0138
CBL-0143	Ro (pu)	0.1444
CBL-0143	Xo (pu)	0.0553
CBL-0143	Rpos (Ohms/km)	0.1290
CBL-0143	Xpos (Ohms/km)	0.0926
CBL-0143	Rzero (Ohms/km)	0.9675
CBL-0143	Xzero (Ohms/km)	0.3704

Component	Field	Base Project	Component	Field	Base Project
CBL-0137	Rzero (Ohms/km)	0.32	CBL-0144	R1 (pu)	0.4161
CBL-0137	Xzero (Ohms/km)	0.15	CBL-0144	X1 (pu)	0.2739
CBL-0138	R1 (pu)	0.0001	CBL-0144	Ro (pu)	3.1209
CBL-0138	X1 (pu)	0.0001	CBL-0144	Xo (pu)	1.0964
CBL-0138	Ro (pu)	0.0005	CBL-0144	Rpos (Ohms/km)	0.0430
CBL-0138	Xo (pu)	0.0002	CBL-0144	Xpos (Ohms/km)	0.0283
CBL-0138	Rpos (Ohms/km)	0.04	CBL-0144	Rzero (Ohms/km)	0.3225
CBL-0138	Xpos (Ohms/km)	0.04	CBL-0144	Xzero (Ohms/km)	0.1133
CBL-0138	Rzero (Ohms/km)	0.32	CBL-0145	R1 (pu)	0.4161
CBL-0138	Xzero (Ohms/km)	0.16	CBL-0145	X1 (pu)	0.2739
CBL-0139	R1 (pu)	0.0042	CBL-0145	Ro (pu)	3.1209
CBL-0139	X1 (pu)	0.0036	CBL-0145	Xo (pu)	1.0964
CBL-0139	Ro (pu)	0.0316	CBL-0145	Rpos (Ohms/km)	0.0430
CBL-0139	Xo (pu)	0.0145	CBL-0145	Xpos (Ohms/km)	0.0283
CBL-0139	Rpos (Ohms/km)	0.06	CBL-0145	Rzero (Ohms/km)	0.3225
CBL-0139	Xpos (Ohms/km)	0.06	CBL-0145	Xzero (Ohms/km)	0.1133
CBL-0139	Rzero (Ohms/km)	0.48	CBL-0146	R1 (pu)	0.4161
CBL-0139	Xzero (Ohms/km)	0.22	CBL-0146	X1 (pu)	0.2739
CBL-0140	R1 (pu)	0.0001	CBL-0146	Ro (pu)	3.1209
CBL-0140	X1 (pu)	0.0001	CBL-0146	Xo (pu)	1.0964
CBL-0140	Ro (pu)	0.0010	CBL-0146	Rpos (Ohms/km)	0.0430
CBL-0140	Xo (pu)	0.0005	CBL-0146	Xpos (Ohms/km)	0.0283
CBL-0140	Rpos (Ohms/km)	0.07	CBL-0146	Rzero (Ohms/km)	0.3225
CBL-0163	Xo (pu)	1.0964	CBL-0169	Xpos (Ohms/km)	0.0283
CBL-0163	Rpos (Ohms/km)	0.0430	CBL-0169	Rzero (Ohms/km)	0.3225
CBL-0163	Xpos (Ohms/km)	0.0283	CBL-0169	Xzero (Ohms/km)	0.1133
CBL-0163	Rzero (Ohms/km)	0.3225	CBL-0170	R1 (pu)	0.4161
CBL-0163	Xzero (Ohms/km)	0.1133	CBL-0170	X1 (pu)	0.2739
CBL-0164	R1 (pu)	0.4161	CBL-0170	Ro (pu)	3.1209
CBL-0164	X1 (pu)	0.2739	CBL-0170	Xo (pu)	1.0964
CBL-0164	Ro (pu)	3.1209	CBL-0170	Rpos (Ohms/km)	0.0430
CBL-0164	Xo (pu)	1.0964	CBL-0170	Xpos (Ohms/km)	0.0283
CBL-0164	Rpos (Ohms/km)	0.0430	CBL-0170	Rzero (Ohms/km)	0.3225
CBL-0164	Xpos (Ohms/km)	0.0283	CBL-0170	Xzero (Ohms/km)	0.1133
CBL-0164	Rzero (Ohms/km)	0.3225	CBL-0171	R1 (pu)	0.4161
CBL-0164	Xzero (Ohms/km)	0.1133	CBL-0171	X1 (pu)	0.2739
CBL-0165	R1 (pu)	0.4161	CBL-0171	Ro (pu)	3.1209
CBL-0165	X1 (pu)	0.2739	CBL-0171	Xo (pu)	1.0964
CBL-0165	Ro (pu)	3.1209	CBL-0171	Rpos (Ohms/km)	0.0430
CBL-0165	Xo (pu)	1.0964	CBL-0171	Xpos (Ohms/km)	0.0283
CBL-0165	Rpos (Ohms/km)	0.0430	CBL-0171	Rzero (Ohms/km)	0.3225
CBL-0165	Xpos (Ohms/km)	0.0283	CBL-0171	Xzero (Ohms/km)	0.1133

Component	Field	Base Project
CBL-0165	Rzero (Ohms/km)	0.3225
CBL-0165	Xzero (Ohms/km)	0.1133
CBL-0166	R1 (pu)	0.4161
CBL-0166	X1 (pu)	0.2739
CBL-0166	Ro (pu)	3.1209
CBL-0166	Xo (pu)	1.0964
CBL-0166	Rpos (Ohms/km)	0.0430
CBL-0166	Xpos (Ohms/km)	0.0283
CBL-0166	Rzero (Ohms/km)	0.3225
CBL-0166	Xzero (Ohms/km)	0.1133
CBL-0167	R1 (pu)	0.4161
CBL-0167	X1 (pu)	0.2739
CBL-0167	Ro (pu)	3.1209
CBL-0167	Xo (pu)	1.0964
CBL-0167	Rpos (Ohms/km)	0.0430
CBL-0167	Xpos (Ohms/km)	0.0283
CBL-0167	Rzero (Ohms/km)	0.3225
CBL-0167	Xzero (Ohms/km)	0.1133
CBL-0168	R1 (pu)	0.4161
CBL-0168	X1 (pu)	0.2739
CBL-0168	Ro (pu)	3.1209
CBL-0168	Xo (pu)	1.0964
CBL-0168	Rpos (Ohms/km)	0.0430
CBL-0168	Xpos (Ohms/km)	0.0283
CBL-0168	Rzero (Ohms/km)	0.3225
CBL-0168	Xzero (Ohms/km)	0.1133
CBL-0169	R1 (pu)	0.4161
CBL-0169	X1 (pu)	0.2739
CBL-0169	Ro (pu)	3.1209
CBL-0169	Xo (pu)	1.0964
CBL-0169	Rpos (Ohms/km)	0.0430
CBL-0189	Xo (pu)	0.0004
CBL-0189	Rpos (Ohms/km)	0.1056
CBL-0189	Xpos (Ohms/km)	0.0594
CBL-0189	Rzero (Ohms/km)	0.7887
CBL-0189	Xzero (Ohms/km)	0.2376
CBL-0190	R1 (pu)	0.0026
CBL-0190	X1 (pu)	0.0015
CBL-0190	Ro (pu)	0.0195
CBL-0190	Xo (pu)	0.0058
CBL-0190	Rpos (Ohms/km)	0.1051
CBL-0190	Xpos (Ohms/km)	0.0591
CBL-0190	Rzero (Ohms/km)	0.7875

Component	Field	Base Project
CBL-0172	R1 (pu)	0.4161
CBL-0172	X1 (pu)	0.2739
CBL-0172	Ro (pu)	3.1209
CBL-0172	Xo (pu)	1.0964
CBL-0172	Rpos (Ohms/km)	0.0430
CBL-0172	Xpos (Ohms/km)	0.0283
CBL-0172	Rzero (Ohms/km)	0.3225
CBL-0172	Xzero (Ohms/km)	0.1133
CBL-0173	R1 (pu)	0.4161
CBL-0173	X1 (pu)	0.2739
CBL-0173	Ro (pu)	3.1209
CBL-0173	Xo (pu)	1.0964
CBL-0173	Rpos (Ohms/km)	0.0430
CBL-0173	Xpos (Ohms/km)	0.0283
CBL-0173	Rzero (Ohms/km)	0.3225
CBL-0173	Xzero (Ohms/km)	0.1133
CBL-0174	R1 (pu)	0.0243
CBL-0174	X1 (pu)	0.0174
CBL-0174	Ro (pu)	0.1821
CBL-0174	Xo (pu)	0.0697
CBL-0174	Rpos (Ohms/km)	0.1290
CBL-0174	Xpos (Ohms/km)	0.0926
CBL-0174	Rzero (Ohms/km)	0.9675
CBL-0174	Xzero (Ohms/km)	0.3704
CBL-0176	R1 (pu)	0.2055
CBL-0176	X1 (pu)	0.0380
CBL-0176	Ro (pu)	0.3267
CBL-0176	Xo (pu)	0.0967
CBL-0176	Rpos (Ohms/km)	1.0531
CBL-0176	Xpos (Ohms/km)	0.1949
CBL-0176	Rzero (Ohms/km)	1.6742
CBL-0195	Xpos (Ohms/km)	0.0283
CBL-0195	Rzero (Ohms/km)	0.3225
CBL-0195	Xzero (Ohms/km)	0.1133
CBL-0196	R1 (pu)	0.4161
CBL-0196	X1 (pu)	0.2739
CBL-0196	Ro (pu)	3.1209
CBL-0196	Xo (pu)	1.0964
CBL-0196	Rpos (Ohms/km)	0.0430
CBL-0196	Xpos (Ohms/km)	0.0283
CBL-0196	Rzero (Ohms/km)	0.3225
CBL-0196	Xzero (Ohms/km)	0.1133
CBL-0197	R1 (pu)	0.4161

Component	Field	Base Project	Component	Field	Base Project
CBL-0190	Xzero (Ohms/km)	0.2359	CBL-0197	X1 (pu)	0.2739
CBL-0191	R1 (pu)	0.0002	CBL-0197	Ro (pu)	3.1209
CBL-0191	X1 (pu)	0.0001	CBL-0197	Xo (pu)	1.0964
CBL-0191	Ro (pu)	0.0017	CBL-0197	Rpos (Ohms/km)	0.0430
CBL-0191	Xo (pu)	0.0005	CBL-0197	Xpos (Ohms/km)	0.0283
CBL-0191	Rpos (Ohms/km)	0.1043	CBL-0197	Rzero (Ohms/km)	0.3225
CBL-0191	Xpos (Ohms/km)	0.0579	CBL-0197	Xzero (Ohms/km)	0.1133
CBL-0191	Rzero (Ohms/km)	0.7878	CBL-0198	R1 (pu)	0.4161
CBL-0191	Xzero (Ohms/km)	0.2363	CBL-0198	X1 (pu)	0.2739
CBL-0192	R1 (pu)	0.0070	CBL-0198	Ro (pu)	3.1209
CBL-0192	X1 (pu)	0.0018	CBL-0198	Xo (pu)	1.0964
CBL-0192	Ro (pu)	0.0185	CBL-0198	Rpos (Ohms/km)	0.0430
CBL-0192	Xo (pu)	0.0071	CBL-0198	Xpos (Ohms/km)	0.0283
CBL-0192	Rpos (Ohms/km)	0.3642	CBL-0198	Rzero (Ohms/km)	0.3225
CBL-0192	Xpos (Ohms/km)	0.0926	CBL-0198	Xzero (Ohms/km)	0.1133
CBL-0192	Rzero (Ohms/km)	0.9675	CBL-0199	R1 (pu)	0.4161
CBL-0192	Xzero (Ohms/km)	0.3704	CBL-0199	X1 (pu)	0.2739
CBL-0193	R1 (pu)	0.4161	CBL-0199	Ro (pu)	3.1209
CBL-0193	X1 (pu)	0.2739	CBL-0199	Xo (pu)	1.0964
CBL-0193	Ro (pu)	3.1209	CBL-0199	Rpos (Ohms/km)	0.0430
CBL-0193	Xo (pu)	1.0964	CBL-0199	Xpos (Ohms/km)	0.0283
CBL-0193	Rpos (Ohms/km)	0.0430	CBL-0199	Rzero (Ohms/km)	0.3225
CBL-0193	Xpos (Ohms/km)	0.0283	CBL-0199	Xzero (Ohms/km)	0.1133
CBL-0193	Rzero (Ohms/km)	0.3225	CBL-0200	R1 (pu)	0.4161
CBL-0193	Xzero (Ohms/km)	0.1133	CBL-0200	X1 (pu)	0.2739
CBL-0194	R1 (pu)	0.4161	CBL-0200	Ro (pu)	3.1209
CBL-0194	X1 (pu)	0.2739	CBL-0200	Xo (pu)	1.0964
CBL-0194	Ro (pu)	3.1209	CBL-0200	Rpos (Ohms/km)	0.0430
CBL-0194	Xo (pu)	1.0964	CBL-0200	Xpos (Ohms/km)	0.0283
CBL-0194	Rpos (Ohms/km)	0.0430	CBL-0200	Rzero (Ohms/km)	0.3225
CBL-0194	Xpos (Ohms/km)	0.0283	CBL-0200	Xzero (Ohms/km)	0.1133
CBL-0194	Rzero (Ohms/km)	0.3225	CBL-0201	R1 (pu)	0.0110
CBL-0194	Xzero (Ohms/km)	0.1133	CBL-0201	X1 (pu)	0.0079
CBL-0195	R1 (pu)	0.4161	CBL-0201	Ro (pu)	0.0822
CBL-0195	X1 (pu)	0.2739	CBL-0201	Xo (pu)	0.0342
CBL-0195	Ro (pu)	3.1209	CBL-0201	Rpos (Ohms/km)	0.1290
CBL-0195	Xo (pu)	1.0964	CBL-0201	Xpos (Ohms/km)	0.0927
CBL-0195	Rpos (Ohms/km)	0.0430	CBL-0201	Rzero (Ohms/km)	0.9675
CBL-0216	Xo (pu)	1.0964	CBL-0222	Xpos (Ohms/km)	0.0926
CBL-0216	Rpos (Ohms/km)	0.0430	CBL-0222	Rzero (Ohms/km)	0.9675
CBL-0216	Xpos (Ohms/km)	0.0283	CBL-0222	Xzero (Ohms/km)	0.3704
CBL-0216	Rzero (Ohms/km)	0.3225	CBL-0224	R1 (pu)	0.0101
CBL-0216	Xzero (Ohms/km)	0.1133	CBL-0224	X1 (pu)	0.0072

Component	Field	Base Project
CBL-0217	R1 (pu)	0.4161
CBL-0217	X1 (pu)	0.2739
CBL-0217	Ro (pu)	3.1209
CBL-0217	Xo (pu)	1.0964
CBL-0217	Rpos (Ohms/km)	0.0430
CBL-0217	Xpos (Ohms/km)	0.0283
CBL-0217	Rzero (Ohms/km)	0.3225
CBL-0217	Xzero (Ohms/km)	0.1133
CBL-0218	R1 (pu)	0.0004
CBL-0218	X1 (pu)	0.0003
CBL-0218	Ro (pu)	0.0029
CBL-0218	Xo (pu)	0.0011
CBL-0218	Rpos (Ohms/km)	0.0322
CBL-0218	Xpos (Ohms/km)	0.0232
CBL-0218	Rzero (Ohms/km)	0.2419
CBL-0218	Xzero (Ohms/km)	0.0925
CBL-0219	R1 (pu)	0.0101
CBL-0219	X1 (pu)	0.0072
CBL-0219	Ro (pu)	0.0755
CBL-0219	Xo (pu)	0.0289
CBL-0219	Rpos (Ohms/km)	0.1290
CBL-0219	Xpos (Ohms/km)	0.0926
CBL-0219	Rzero (Ohms/km)	0.9675
CBL-0219	Xzero (Ohms/km)	0.3704
CBL-0220	R1 (pu)	0.4161
CBL-0220	X1 (pu)	0.2739
CBL-0220	Ro (pu)	3.1209
CBL-0220	Xo (pu)	1.0964
CBL-0220	Rpos (Ohms/km)	0.0430
CBL-0220	Xpos (Ohms/km)	0.0283
CBL-0220	Rzero (Ohms/km)	0.3225
CBL-0220	Xzero (Ohms/km)	0.1133
CBL-0221	R1 (pu)	0.4161
CBL-0221	X1 (pu)	0.2739
CBL-0221	Ro (pu)	3.1209
CBL-0221	Xo (pu)	1.0964
CBL-0221	Rpos (Ohms/km)	0.0430
CBL-0221	Xpos (Ohms/km)	0.0283
CBL-0221	Rzero (Ohms/km)	0.3225
CBL-0221	Xzero (Ohms/km)	0.1133
CBL-0222	R1 (pu)	0.0101
CBL-0222	X1 (pu)	0.0072
CBL-0222	Ro (pu)	0.0755
CBL-0222	Xo (pu)	0.0289
CBL-0224	Ro (pu)	0.0755
CBL-0224	Xo (pu)	0.0289
CBL-0224	Rpos (Ohms/km)	0.1290
CBL-0224	Xpos (Ohms/km)	0.0926
CBL-0224	Rzero (Ohms/km)	0.9675
CBL-0224	Xzero (Ohms/km)	0.3704
CBL-0225	R1 (pu)	0.4161
CBL-0225	X1 (pu)	0.2739
CBL-0225	Ro (pu)	3.1209
CBL-0225	Xo (pu)	1.0964
CBL-0225	Rpos (Ohms/km)	0.0430
CBL-0225	Xpos (Ohms/km)	0.0283
CBL-0225	Rzero (Ohms/km)	0.3225
CBL-0225	Xzero (Ohms/km)	0.1133
CBL-0226	R1 (pu)	0.0580
CBL-0226	X1 (pu)	0.0107
CBL-0226	Ro (pu)	0.0922
CBL-0226	Xo (pu)	0.0273
CBL-0226	Rpos (Ohms/km)	1.0531
CBL-0226	Xpos (Ohms/km)	0.1949
CBL-0226	Rzero (Ohms/km)	1.6742
CBL-0226	Xzero (Ohms/km)	0.4957
CBL-0227	R1 (pu)	0.0580
CBL-0227	X1 (pu)	0.0107
CBL-0227	Ro (pu)	0.0922
CBL-0227	Xo (pu)	0.0273
CBL-0227	Rpos (Ohms/km)	1.0531
CBL-0227	Xpos (Ohms/km)	0.1949
CBL-0227	Rzero (Ohms/km)	1.6742
CBL-0227	Xzero (Ohms/km)	0.4957
CBL-0228	R1 (pu)	0.4161
CBL-0228	X1 (pu)	0.2739
CBL-0228	Ro (pu)	3.1209
CBL-0228	Xo (pu)	1.0964
CBL-0228	Rpos (Ohms/km)	0.0430
CBL-0228	Xpos (Ohms/km)	0.0283
CBL-0228	Rzero (Ohms/km)	0.3225
CBL-0228	Xzero (Ohms/km)	0.1133
CBL-0229	R1 (pu)	0.4161
CBL-0229	X1 (pu)	0.2739
CBL-0229	Ro (pu)	3.1209
CBL-0229	Xo (pu)	1.0964
CBL-0229	Rpos (Ohms/km)	0.0430
CBL-0229	Xpos (Ohms/km)	0.0283

Component	Field	Base Project
CBL-0222	Rpos (Ohms/km)	0.1290
CBL-0232	Xo (pu)	0.0120
CBL-0232	Rpos (Ohms/km)	0.1050
CBL-0232	Xpos (Ohms/km)	0.0590
CBL-0232	Rzero (Ohms/km)	0.7875
CBL-0232	Xzero (Ohms/km)	0.2360
CBL-0233	R1 (pu)	0.0002
CBL-0233	X1 (pu)	0.0001
CBL-0233	Ro (pu)	0.0013
CBL-0233	Xo (pu)	0.0004
CBL-0233	Rpos (Ohms/km)	0.1058
CBL-0235	Xpos (Ohms/km)	0.1949
CBL-0235	Rzero (Ohms/km)	1.6742
CBL-0235	Xzero (Ohms/km)	0.4957
CBL-0229	Rzero (Ohms/km)	0.3225
CBL-0233	Xpos (Ohms/km)	0.0591
CBL-0233	Rzero (Ohms/km)	0.7872
CBL-0233	Xzero (Ohms/km)	0.2365
CBL-0234	R1 (pu)	0.0054
CBL-0234	X1 (pu)	0.0030
CBL-0234	Ro (pu)	0.0402
CBL-0234	Xo (pu)	0.0120
CBL-0234	Rpos (Ohms/km)	0.1050
CBL-0234	Xpos (Ohms/km)	0.0590
CBL-0234	Rzero (Ohms/km)	0.7875

MRPL SYSTEM MOTOR LOAD DATA

Load Identification No.	Rating (kVA)
MTRI-0001	1760.00
MTRI-0002	1760.00
MTRI-0003	590.00
MTRI-0004	590.00
MTRI-0005	3700.00
MTRI-0006	3700.00
MTRI-0042	1000.00
MTRI-0043	1000.00
MTRI-0044	1870.00
MTRI-0045	1870.00
MTRI-0046	460.00
MTRI-0047	660.00
MTRI-0049	1450.00
MTRI-0051	310.00
MTRI-0052	310.00
MTRI-0053	1000.00
MTRI-0054	1000.00
MTRI-0083	1950.00
MTRI-0084	1950.00
MTRI-0101	1430.00
MTRI-0102	1430.00
MTRI-0103	3720.00
MTRI-0104	3720.00
MTRI-0112	20.00
MTRI-0113	20.00
MTRI-0114	20.00
MTRI-0115	20.00
MTRI-0116	400.00
MTRI-0117	400.00
MTRI-0118	400.00
MTRI-0119	400.00
MTRI-0120	420.00
MTRI-0121	420.00
MTRI-0122	420.00
MTRI-0123	420.00
MTRI-0124	420.00
MTRI-0125	420.00
MTRI-0126	420.00
MTRI-0127	420.00
MTRI-0128	200.00
MTRI-0129	310.00
MTRI-0130	420.00
MTRI-0132	420.00
MTRI-0133	420.00
MTRI-0134	420.00
MTRI-0135	3460.00
MTRI-0136	3460.00
MTRI-0137	490.00
MTRI-0138	490.00
MTRI-0139	490.00
MTRI-0140	490.00
MTRI-0141	490.00
MTRI-0142	490.00
MTRI-0143	330.00
MTRI-0144	330.00
MTRI-0145	35.00
MTRI-0146	35.00
MTRI-0147	35.00
MTRI-0148	35.00
MTRI-0149	590.00
MTRI-0150	590.00
MTRI-0152	540.00
MTRI-0153	540.00
MTRI-0154	540.00
MTRI-0155	540.00
MTRI-0156	350.00
MTRI-0157	350.00
MTRI-0158	540.00
MTRI-0159	540.00
MTRI-0160	350.00
MTRI-0161	350.00
MTRI-0163	2.00
MTRI-0164	1450.00

APPENDIX B

VOLATAGE STABILITY INDEX COMPUTATION

Voltage stability is concerned with the ability of a power system to maintain acceptable voltages at all nodes in the system under normal condition and after being subject to a disturbance [5]. As power system become more complex and heavily loaded, along with economical and environmental constraints, voltage instability becomes an increasingly serious problem, leading systems to operate close to their limits. Voltage instability is essentially a local phenomenon; however its consequences may have widespread impact leading to overall system blackout. The study of voltage stability has been analyzed under different approaches that can be basically classified into dynamic and static analysis.

The dynamic analysis implies the use of a model characterized by nonlinear differential and algebraic equations which include generators dynamics, tap changing transformers, etc, through transient stability simulations.

The static voltage stability methods depend mainly on the steady state model in the analysis, such as power flow model or a linearized dynamic model described by the steady state operation.

An accurate knowledge of how close the actual system’s operating point is from the voltage stability limit is crucial to operators. Therefore, to find a voltage stability index has become an important task for many voltage stability studies. The static voltage stability index provides reliable information about proximity of voltage instability in a power system. Usually, the index value changes between 0 (no load) and 1 (voltage collapse).

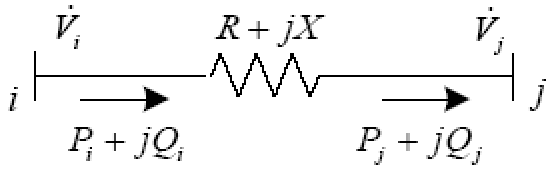

Figure A.1 Sample Power System

From Figure A.1 the real and reactive power injections at ith node can be derived as

$$P_i = \frac{\left(P_i^2 + Q_i^2\right)R}{V_i^2} + P_j \qquad \text{(A-1)}$$

$$Q_i = \frac{\left(P_i^2 + Q_i^2\right)X}{V_i^2} + Q_j \qquad \text{(A-2)}$$

from equations A-1 and A-2, real power injection at node i can be derived in terms of real and reactive powers at receiving node (Pj, Qj) and voltage at sending node (Vi) as

$$\left(R^2 + X^2\right)P_i^2 + \left(2RXQ_j - 2X^2P_j - V_i^2R\right)P_i + \left(V_i^2RP_j + X^2P_j^2 + R^2Q_j^2 - 2RXP_jQ_j\right) = 0$$

This is a quadratic equation and condition for real roots (b2-4ac>0) comes as

$$1 - \frac{4\left[\left(XP_j - RQ_j\right)^2 + \left(XQ_j + RP_j\right)V_i^2\right]}{V_i^4} \geq 0$$

$$1 - L_j \geq 0$$

$$L_j = \frac{4\left[\left(XP_j - RQ_j\right)^2 + \left(XQ_j + RP_j\right)V_i^2\right]}{V_i^4}$$

Where Lj stands for the voltage stability index of branch j. (Lj ≤1)

The voltage stability index (VSI) of total distribution system is defined by

$$VSI = \max\left\{L_1, L_2, \cdots, L_{N-1}\right\}$$

APPENDIX C

DATA FOR 33 BUS, 69 BUS AND 90 BUS SYSTEMS

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33 Bus System : Load Data

Bus	Pload (pu)	Qload (pu)
1	0.0000	0.0000
2	0.0100	0.0060
3	0.0090	0.0040
4	0.0120	0.0080
5	0.0060	0.0030
6	0.0060	0.0020
7	0.0200	0.0100
8	0.0200	0.0100
9	0.0060	0.0020
10	0.0060	0.0020
11	0.0045	0.0030
12	0.0060	0.0035
13	0.0060	0.0035
14	0.0120	0.0080
15	0.0060	0.0010
16	0.0060	0.0020
17	0.0060	0.0020
18	0.0090	0.0040
19	0.0090	0.0040
20	0.0090	0.0040
21	0.0090	0.0040
22	0.0090	0.0040
23	0.0090	0.0050
24	0.0420	0.0200
25	0.0420	0.0200
26	0.0060	0.0025
27	0.0060	0.0025
28	0.0060	0.0020
29	0.0120	0.0070
30	0.0200	0.0600
31	0.0150	0.0070
32	0.0210	0.0100
33	0.0060	0.0040

33 Bus System : Line Data

From	To	R (pu)	X (pu)
1	2	0.0058	0.0029
2	3	0.0308	0.0157
3	4	0.0228	0.0116
4	5	0.0238	0.0121
5	6	0.0511	0.0441
6	7	0.0117	0.0386
7	8	0.1068	0.0771
8	9	0.0643	0.0462
9	10	0.0651	0.0462
10	11	0.0123	0.0041
11	12	0.0234	0.0077
12	13	0.0916	0.0721
13	14	0.0338	0.0445
14	15	0.0369	0.0328
15	16	0.0466	0.0340
16	17	0.0804	0.1074
17	18	0.0457	0.0358
2	19	0.0102	0.0098
19	20	0.0939	0.0846
20	21	0.0255	0.0298
21	22	0.0442	0.0585
3	23	0.0282	0.0192
23	24	0.0560	0.0442
24	25	0.0559	0.0437
6	26	0.0127	0.0065
26	27	0.0177	0.0090
27	28	0.0661	0.0583
28	29	0.0502	0.0437
29	30	0.0317	0.0161
30	31	0.0608	0.0601
31	32	0.0194	0.0226
32	33	0.0213	0.0331

69 Bus System : Load Data

Bus	Pload (pu)	Qload (pu)	Bus	Pload (pu)	Qload (pu)
1	0.000000	0.000000	36	0.000260	0.000186
2	0.000000	0.000000	37	0.000260	0.000186
3	0.000000	0.000000	38	0.000000	0.000000
4	0.000000	0.000000	39	0.000240	0.000170
5	0.000000	0.000000	40	0.000240	0.000170
6	0.000026	0.000022	41	0.000012	0.000010
7	0.000404	0.000300	42	0.000000	0.000000
8	0.000750	0.000540	43	0.000060	0.000043
9	0.000300	0.000220	44	0.000000	0.000000
10	0.000280	0.000190	45	0.000392	0.000263
11	0.001450	0.001040	46	0.000392	0.000263
12	0.001450	0.001040	47	0.000000	0.000000
13	0.000080	0.000055	48	0.000790	0.000564
14	0.000080	0.000055	49	0.003847	0.002745
15	0.000000	0.000000	50	0.003847	0.002745
16	0.000455	0.000300	51	0.000405	0.000283
17	0.000600	0.000350	52	0.000036	0.000027
18	0.000600	0.000350	53	0.000044	0.000035
19	0.000000	0.000000	54	0.000264	0.000190
20	0.000010	0.000006	55	0.000240	0.000172
21	0.001140	0.000810	56	0.000000	0.000000
22	0.000053	0.000035	57	0.000000	0.000000
23	0.000000	0.000000	58	0.000000	0.000000
24	0.000280	0.000200	59	0.001000	0.000720
25	0.000000	0.000000	60	0.000000	0.000000
26	0.000140	0.000100	61	0.012440	0.008880
27	0.000140	0.000100	62	0.000320	0.000230
28	0.000260	0.000186	63	0.000000	0.000000
29	0.000260	0.000186	64	0.002270	0.001620
30	0.000000	0.000000	65	0.000590	0.000420
31	0.000000	0.000000	66	0.000180	0.000130
32	0.000000	0.000000	67	0.000180	0.000130
33	0.000140	0.000100	68	0.000280	0.000200
34	0.000195	0.000140	69	0.000280	0.000200
35	0.000060	0.000040			

69 Bus System : Line Data

From	To	R (pu)	X (pu)	From	To	R (pu)	X (pu)
1	2	0.000312	0.000749	3	36	0.002745	0.006738
2	3	0.000312	0.000749	36	37	0.039931	0.097644
3	4	0.000936	0.002246	37	38	0.065699	0.076743
4	5	0.015661	0.018343	38	39	0.018967	0.022149
5	6	0.228357	0.116300	39	40	0.001123	0.001310
6	7	0.237778	0.121104	40	41	0.454405	0.530898
7	8	0.057526	0.029324	41	42	0.193417	0.226048
8	9	0.030760	0.015661	42	43	0.025581	0.029824
9	10	0.510995	0.168897	43	44	0.005740	0.007238
10	11	0.116799	0.038621	44	45	0.067945	0.085665
11	12	0.443860	0.146685	45	46	0.000562	0.000749
12	13	0.642643	0.212135	4	47	0.002121	0.005241
13	14	0.651378	0.215254	47	48	0.053096	0.129964
14	15	0.660113	0.218124	48	49	0.180814	0.442425
15	16	0.122664	0.040555	49	50	0.051287	0.125471
16	17	0.233598	0.077242	8	51	0.057900	0.029512
17	18	0.002932	0.000998	51	52	0.207081	0.069505
18	19	0.204398	0.067571	9	53	0.108563	0.055280
19	20	0.131399	0.043051	53	54	0.126657	0.064514
20	21	0.213133	0.070441	54	55	0.177320	0.090282
21	22	0.008735	0.002870	55	56	0.175510	0.089408
22	23	0.099267	0.032818	56	57	0.992041	0.332989
23	24	0.216065	0.071439	57	58	0.488970	0.164092
24	25	0.467195	0.154422	58	59	0.189798	0.062767
25	26	0.192731	0.063703	59	60	0.240898	0.073124
26	27	0.108064	0.035689	60	61	0.316642	0.161285
3	28	0.002745	0.006738	61	62	0.060770	0.030947
28	29	0.039931	0.097644	62	63	0.090469	0.046046
29	30	0.248197	0.082046	63	64	0.443299	0.225799
30	31	0.043800	0.014475	64	65	0.649506	0.330805
31	32	0.218998	0.072375	11	66	0.125534	0.038122
32	33	0.523473	0.175697	66	67	0.002932	0.000873
33	34	1.065664	0.352268	12	68	0.461330	0.152487
34	35	0.919666	0.304039	68	69	0.002932	0.000998

90 Bus System : Load Data

Bus	Pload (pu)	Qload (pu)	Bus	Pload (pu)	Qload (pu)	Bus	Pload (pu)	Qload (pu)
1	0.0000	0.0000	31	0.0600	0.0300	61	0.0000	0.0000
2	0.0000	0.0000	32	0.0000	0.0000	62	0.6150	0.3350
3	0.0000	0.0000	33	0.4350	0.2250	63	0.4550	0.2250
4	0.0000	0.0000	34	0.3350	0.1150	64	0.0000	0.0000
5	0.8250	0.4550	35	0.0000	0.0000	65	0.4450	0.1700
6	0.0000	0.0000	36	0.0000	0.0000	66	0.0000	0.0000
7	0.3300	0.1150	37	0.6150	0.3550	67	0.0650	0.0450
8	0.0000	0.0000	38	0.0000	0.0000	68	0.0000	0.0000
9	0.3800	0.1700	39	0.4100	0.1600	69	0.0000	0.0000
10	0.0000	0.0000	40	0.0000	0.0000	70	0.0000	0.0000
11	0.0000	0.0000	41	0.3100	0.1700	71	1.2250	0.6150
12	1.1550	0.6150	42	1.7000	0.6000	72	0.0700	0.0550
13	0.3900	0.1750	43	0.0000	0.0000	73	0.0000	0.0000
14	0.0000	0.0000	44	0.0000	0.0000	74	0.0650	0.0550
15	1.1700	0.5750	45	0.1150	0.0850	75	0.0000	0.0000
16	0.0000	0.0000	46	0.1200	0.0900	76	0.1400	0.0850
17	0.0000	0.0000	47	0.0000	0.0000	77	0.6150	0.2550
18	1.2150	0.6200	48	0.1250	0.0950	78	0.0000	0.0000
19	0.0000	0.0000	49	0.0000	0.0000	79	0.0000	0.0000
20	0.3350	0.1200	50	0.1700	0.0700	80	0.1750	0.0600
21	0.4400	0.1650	51	0.0000	0.0000	81	0.1600	0.0700
22	0.0000	0.0000	52	0.1450	0.0950	82	0.0000	0.0000
23	0.6150	0.3800	53	0.0000	0.0000	83	0.0000	0.0000
24	0.0000	0.0000	54	0.0800	0.0600	84	0.1200	0.0650
25	0.2250	0.1050	55	0.0850	0.0550	85	0.6200	0.2850
26	0.0000	0.0000	56	0.0000	0.0000	86	0.0000	0.0000
27	0.0600	0.0450	57	0.0000	0.0000	87	0.4900	0.3350
28	0.6150	0.4550	58	0.9050	0.3350	88	0.0000	0.0000
29	0.0000	0.0000	59	0.0000	0.0000	89	0.4400	0.2700
30	0.0000	0.0000	60	0.0000	0.0000	90	0.3850	0.2600

90 Bus System : Line Data

From	To	R (pu)	X (pu)	From	To	R (pu)	X (pu)	From	To	R (pu)	X (pu)
1	2	0.00020	0.00150	30	32	0.00150	0.00750	70	72	0.00100	0.00250
2	3	0.00040	0.00190	32	33	0.00170	0.00820	69	73	0.00010	0.00030
3	4	0.00030	0.00200	32	34	0.00160	0.00800	73	74	0.00010	0.00040
4	5	0.00010	0.00120	29	35	0.00030	0.00100	73	75	0.00015	0.00045
4	6	0.00002	0.00005	35	36	0.00015	0.00210	75	76	0.00020	0.00090
6	7	0.00020	0.00100	36	37	0.00012	0.00030	75	77	0.00030	0.00160
6	8	0.00040	0.00080	36	37	0.00120	0.00760	56	59	0.00001	0.00005
8	9	0.00020	0.00080	38	39	0.00200	0.00900	59	60	0.00004	0.00009
8	10	0.00010	0.00070	38	40	0.00120	0.00950	60	61	0.00010	0.00060
10	11	0.00050	0.00100	40	41	0.00250	0.00870	61	62	0.00020	0.00080
11	12	0.00040	0.00080	40	42	0.01280	0.04250	61	63	0.00010	0.00050
11	13	0.00020	0.00100	35	43	0.00900	0.03100	60	64	0.00020	0.00070
10	14	0.00070	0.00120	43	44	0.00850	0.01250	64	65	0.00010	0.00090
14	15	0.00100	0.00720	44	45	0.00120	0.00750	64	66	0.00120	0.00750
14	16	0.00120	0.00210	44	46	0.00150	0.01610	66	67	0.00150	0.00790
16	17	0.00150	0.00250	43	47	0.00020	0.00150	66	68	0.00250	0.00850
17	18	0.00100	0.00700	47	48	0.00030	0.00250	59	78	0.00010	0.00120
17	19	0.00020	0.00090	47	49	0.00010	0.00050	78	79	0.00020	0.00070
19	20	0.00120	0.00720	49	50	0.00020	0.00060	79	80	0.00030	0.00080
19	21	0.00150	0.00920	49	51	0.00150	0.00250	79	81	0.00050	0.00120
16	22	0.00200	0.00800	51	52	0.00030	0.00150	78	82	0.00040	0.00070
22	23	0.00070	0.00140	51	53	0.00090	0.00210	82	83	0.00020	0.00060
22	24	0.00090	0.00210	53	54	0.00010	0.00040	83	84	0.00010	0.00070
24	25	0.00150	0.00280	53	55	0.00060	0.00100	83	85	0.00020	0.00050
24	26	0.00170	0.00270	3	56	0.00010	0.00090	82	86	0.00020	0.00080
26	27	0.00130	0.00230	56	57	0.00015	0.00080	86	87	0.00010	0.00090
26	28	0.00170	0.00250	57	58	0.00100	0.00400	86	88	0.00040	0.00070
2	29	0.00050	0.00210	57	69	0.00040	0.00090	88	89	0.00050	0.00090
29	30	0.00100	0.00500	69	70	0.00020	0.00080	88	90	0.00030	0.00100
30	31	0.00010	0.00700	70	71	0.00150	0.00170				

APPENDIX D

PSO ALGORITHM IMPLEMENTAION FOR 33 BUS SYSTEM

The Particle Swarm Optimization is a stochastic optimization technique. The swarm is considered as particle having The velocity depends in inertia and interaction. The objective or fitness function is used for measurement of quality. In this manner the global best position is captured [107] .

PSO Algorithm

(1) System Data is given as input.
(2) Power flow analysis is done to compute power loss
(3) The initial population of particles are generated with random positions and velocities
(4) The objective value is compared with the individual best. If the objective value is lower than P_{best} , then this value is set as current P_{best}.
(5) The particle with minimum P_{best} of all particles is set as current overall best (g_{best})
(6) The velocity and positions of particle are updated using (5) and (6).
(7) After maximum number of iterations is reached, the optimal solution is obtained as best location and size of DG.

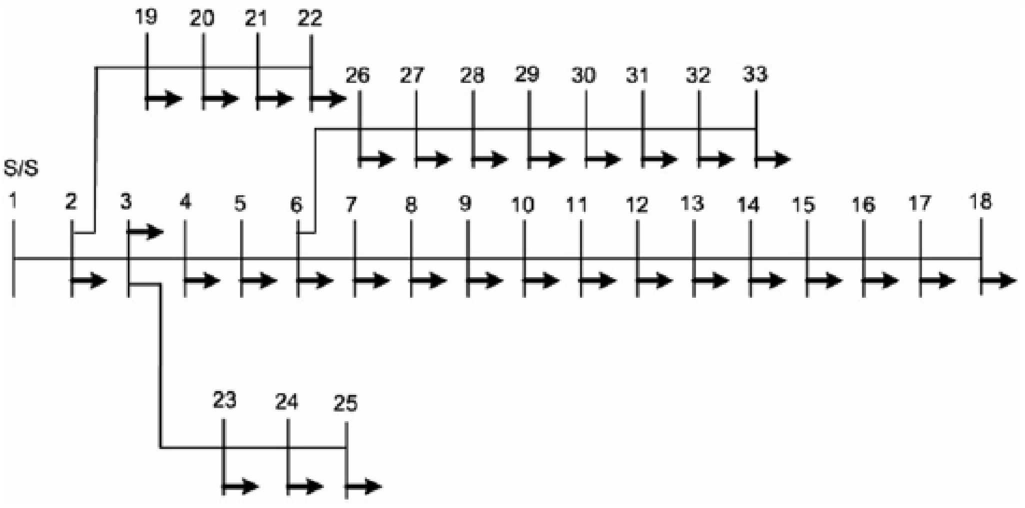

Figure D.1 Single line diagram of 33 bus distribution system

Table D.1 Optimal Size and Locations of DGs

Bus No.	DG Capacity (MW)	P_{Loss} (kW)	Q_{Loss} (kVAr)
6	2.591	88.3	63
15	0.473		
25	0.637		

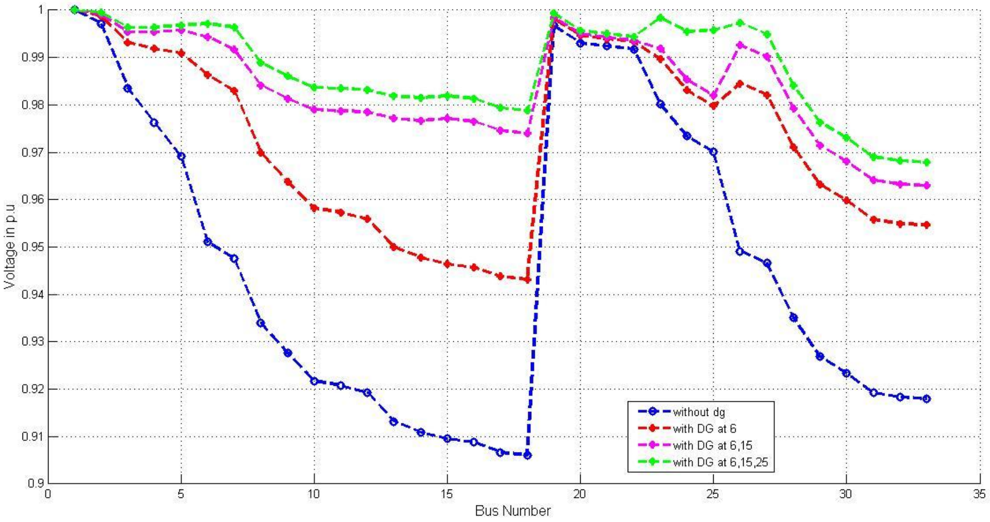

Figure D.2 Voltage Profile Plot of 33 Bus System with DG Sources

Discussions on PSO Algorithm

In PSO Algorithm approach, both DG siting and sizing are computed simultaneously. However this may not be a feasible solution because of the factors below:

(a) In case sufficient potential is not available at the suggested bus then optimal DG size cannot be inserted.

(b) The short circuit levels at the bus may limit the maximum size of DG which can be inserted in any bus.

(c) The priority list cannot be prepared to look towards next feasible option.

Hence it is better to embed the flexibility to designer to choose the most feasible solution which can be practically implementable. The designer can choose the combination of locations and DG sizes from the priority list based on the constraints of the system.