CONTINGENCY ASSESSMENT OF RADIAL DISTRIBUTION SYSTEM

A dissertation submitted in fulfillment of the requirements for the award of the degree

of

MASTER OF ENGINEERING

in

Power System

Submitted by

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DECLARATION

I hereby certify that the work, which is presented in dissertation, entitled **Contingency Assessment of Radial Distribution System**, in partial fulfillment of the requirements for the award of the degree of **Master of Engineering** in **Power Systems**, submitted in Electrical & Instrumentation Engineering Department, Thapar Institute of Engineering & Technology (TIET), Patiala is an authentic record of my own work carried out under the guidance of **Ms. Manbir Kaur**, Associate Professor, EIED, TIET. It refers other researcher's work which are duly listed in the reference section. The matter presented in this dissertation has not been submitted elsewhere for the award of any other degree from any other institution except as reported in text and references.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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.........dedicated to my Parents

ABSTRACT

The complexity of the distribution systems has increased many folds due to its vast expansion and hence it has become prone to faults which eventually affects the continuity of supply and increase the network losses. The impact of outages due to any failure or overloads of network components in the distribution system can be reduced by the reconfiguration of network and embedding sizable distribution generation at optimal locations. In the scenario of deregulation, net present value analysis of the system is quite significant for decision making. In this study, contingencies are solved by finding out the best switching sequence of fixed number of tie lines and sectionalizers for the reconfiguration of system with an objective to improve the operating conditions. Further, genetic algorithm (GA) has been used to find the optimal location and size of embedded distribution generation in order to improve voltage profile and to reduce losses for given load demand. The proposed study of reconfiguration and distributed generation has been implemented on loaded IEEE 33 and IEEE 69 bus radial distribution systems for simulations to study the impact of different contingencies. The simulation results obtained are satisfactory. The results suggest that investment is distribution generation is attractive when reconfiguration is used to minimize load curtailment.

Keywords: Contingency, Distribution system, Distributed Generation, Genetic algorithm, IEEE bus, Radial, Reconfiguration, Sectionalisers, Tie line, Voltage Sensitivity Index (VSI).

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List of Notations

N	No. of buses
B	No. of branches
LD	Line data
BD	Bus data
IT	Iteration Number
I_i^{IT}	Current at the i^{th} bus in IT^{th} iteration
P_i, Q_i	Active and reactive power load at the i^{th} bus
P_i', Q_i'	Total active and reactive power load connected at and after i^{th} bus
V_i^{IT-1}	Voltage at the i^{th} bus in $(IT-1)^{th}$ iteration
Y_i	Admittance at the i^{th} bus
Z_{ij}	Impedance of ij^{th} branch
J_{ij}	Current flowing through ij^{th} branch in IT^{th} iteration
$Ploss_T$	Total active power loss
$Qloss_T$	Total reactive power loss
R_{ij}	Resistance of ij^{th} branch
X_{ij}	Reactance of ij^{th} branch
J_{ij}^{max}	Maximum current flow in the ij^{th} branch
$V_i^{max},\ V_i^{min}$	Upper and lower limit of the voltage at i^{th} bus
f	Objective function to be minimized
$g_i(x)$	Inequality constraints
$h_j(x)$	Equality constraints
m	No. of inequality constraints
p	No. of equality constraints
C	Connection matrix
P^{d_curt}	Total curtailed load
F	Fitness function
$PDG_i,\ QDG_i$	Active and reactive power supplied by DG at i^{th} bus
$PDG_i^{max},\ PDG_i^{min}$	Upper and lower limit of the distributed generation connected i^{th} bus
con	Contingency counter
C^{loss}	Cost of active power loss
C^{d_curt}	Cost of demand curtailment

List of Abbreviations

RDS	Radial Distribution System
NR	Network Reconfiguration
DG	Distributed Generation
GA	Genetic Algorithm
VSI	Voltage Stability Index
PSO	Particle Swarm Optimization
BIBC	Branch Injection to Branch Current
BCBV	Branch Current to Bus voltage
ANN	Artificial Neural Network
BFS	Breadth First Search
DFS	Depth First Search
IS	Indian Standard

CHAPTER 1

INTRODUCTION

1.1. Overview

Distribution system provides a connection between the main feeder and individual load points. Any disturbance on the system will directly have adverse effect on the load side. Therefore the analysis of distribution system is very important. Distribution network can be categorized into two types:

1. Radial distribution network
2. Meshed distribution network

The radial distribution network consists of main feeders originating from the substation connecting major load centers. Individual load points are connected to the main feeder by lateral distributors. This type of network is used in rural areas with isolated loads. The mesh distribution network is an interconnected network with multiple connections to the point of supply. This type of network is more reliable but costly, usually used in urban areas.

Distribution system inherits some features [1] characterized as:

1. Large number of busses and branches.
2. Large resistance to reactance (R/X) ratio.
3. Unbalanced distributed load.

Because of these characteristics, the distribution system falls under the category of ill-conditioned power system. For an ill-conditioned power system, the conventional power flow methods like Gauss-Seidel, Newton Raphson and Fast decoupled load flow fail to converge [2].

To solve distribution system power flow problem, the solution method should have following features:

1. Ability to solve power flow of radial and mesh network with a large number of buses and branches.
2. Efficient and robust.
3. Require less computational time.

The radial distribution system has an advantage of simple design and low cost but it also suffers from some disadvantages:

1. Heavy loading of the line near the source.
2. Low voltage at end node due to the large voltage drop across main feeder and laterals.
3. Any outage of equipment or line causes interruption of supply to all the users connected after it.

The methods used to overcome most of the disadvantages mentioned above are:

1. Network Reconfiguration
2. Distributed Generation

Network reconfiguration is a loss minimization technique suitable for the low voltage distribution system. It also improves the reliability of the system by isolating faults and provides protection [3]. The system is reconfigured for the redirection of power by opening and closing of tie line switches and sectionalizer. Network reconfiguration is used for

- Power loss minimization
- Load balancing
- Reduction service interruption frequency
- Post fault service restoration
- Service maintenance

Distributed Generation (DG) is a small power generating unit connected to the distribution network [4]. The penetration of DG in the distributed system is increasing day by day to meet the increasing power demand of electricity and also enhance the use of renewable energy sources.

Reconfiguration of a system incorporating DGs are gaining more recognition due to the following advantages:

- Loss minimization
- Voltage profile improvement
- Enhancing system stability
- Reduce congestion
- Improving system reliability

The optimal location and proper size of DG are given due importance because improper location and size of a DG can adversely affect the system [5].

Incorporation of DGs at various locations along with switches used for network reconfiguration of the system have increased the system complexity [6]. These switches also play important role during (N-1) contingency as they provide alternate route for the power supply. Therefore, contingency analysis of the distribution system is important for analyzing the system under different contingencies. It is also used for identifying best system topology during contingency for improvement of system reliability.

1.2. Literature Review

Methods and techniques used by various researchers for the computation and analysis of distribution system power flow, network reconfiguration, distributed generation and contingency analysis are discussed below:

Shirmohammadi *et al.*[2] discussed kirchoff's laws based method for the radial or weakly meshed distribution system with balanced or unbalanced loading. This method has computed branch current in backward sweep and node voltage in the forward sweep.

Luo and Semlyen [7] proposed a load flow method using active and reactive power as a flow variable for the radial system. This method has been recommended for power flow analysis of a weakly meshed system as it can directly handle PV buses connected to the system by considering loop breakpoints.

Rajicic *et al.*[8] used oriented element ordering scheme for calculation of power flows in branch and node voltages. For element ordering all the network elements have been classified as branch and link and then ordering algorithm has been applied.

Teng [1] proposed a matrix-based method to compute radial load flow. The method of formation of branch injection to branch current (BIBC) matrix and branch current to bus voltage (BCBV) matrix has been described in the paper. This method has been reported fast and efficient for static power flow analysis.

Jabr [9] modeled radial distribution as a convex optimization problem. Execution time and accuracy of the method relies on the optimization technique has used. Inner point algorithm has been implemented to solve the constrained optimization problem.

Chang *et al.*[10] derived an improved backward/forward sweep method for radial load flow analysis. Distribution line and transformer model have been considered in this method. In backward sweep, the upstream bus voltage of each line has been calculated using KVL and KCL. In forward sweep each downstream bus voltage gets updated by the product of calculated bus voltage and respective ratios.

Ghosh and Sherpa [11] proposed a method independent of branch numbering. The load flow can be computed for any numbering scheme for node and branches. The method has applied to different load models.

Aman *et al.*[12] presented a load flow method which has been reported efficient to be used for network reconfiguration. The method has utilized the concept of graph search technique such as breadth first search (BFS) and depth first search (DFS) for line data rearrangement. BIBC and BVBC matrix have been used to compute load flow.

Shirmohammadi and Hong [13] employed the heuristic approach to solve the optimum configuration problem using branch and bound based method. The final switching sequence was independent of initial switch position in the proposed method.

Baran and Wu [14] employed approximate power flow equation with branch exchange to configure the system for loss reduction and load balancing. Reconfiguration problem is formulated as minimum spanning tree problem.

Abu-Mouti and El-Hawary [15] employed sufficient sensitivity test for locating DG and heuristic curve fitting technique for determining the optimal size of DG. The size of DG has increased in steps and graph between power loss and DG size has been plotted. The point at which the power loss is minimum has been considered as optimal size of DG.

Fan *et al.*[16] proposed single loop optimization approach to solve distribution network reconfiguration problem. An approximation has been applied to linearize nonlinear problem for implementing linear programming. To solve linear programming problem simplex method has used.

Siti *et al.*[3] included dynamic phase load balancing and the effect of phase rearrange between Distribution Transformer and feeder with the radial configuration. The artifical neural network has been used for network reconfiguration in conjunction with the heuristic method for phase load balance and loss minimization.

Kashem *et al.*[17] employed multilayer perceptron-based artificial neural network (ANN) for network reconfiguration to reduce real power losses. ANN model has been trained by the back propagation algorithm.

Queiroz and Lyra [18] considered the load variation while reconfiguring the distribution system. The method has proposed for the avoiding frequent change in network configuration and use energy flow instead of instantaneous power flow. Adaptive heuristic genetic algorithm has been used to solve the optimization problem.

Bernardon *et al.*[19] presented a method based on the fuzzy multi criteria decision making algorithm. The objective function has considered the minimization of power loss and number of interrupted customers per year for improvement the reliability of the system.

Das [20] employed fuzzy multi objective algorithm for network reconfiguration. The objective function has considered load balancing, power loss minimization and minimum node voltage deviation. The objective has been first fuzzified and then maximized for each tie switch operation.

Amanulla *et al.*[21] employed the minimal cut set algorithm to find minimum component set between feeder and load. Binary particle swarm optimization (BPSO) has been used to reconfigure the system with minimum loss and maximum reliability.

Wang and Nehrir [4] presented an analytical approach for the placement of DG for minimizing the network losses. A study has been made to analyze DG connected radial system with time-invariant and variant loads.

Rao *et al.*[5] employed harmony search method to solve the configuration problem of radial distribution system with distributed generation for loss minimization and voltage profile improvement. Sensitivity analysis has used for the location of DG units and a study has been carried out for three different load levels.

Ochoa and Harrison [22] proposed multi-period AC optimal power flow to allocate distributed generation size and location in a way for minimizing energy losses of the system. A study has been carried out to access the trade-off between increased generation capacity and energy losses.

Gozel and Hocaoglu [23] employed a lost sensitivity factor to determine the optimal size and location of DG. The loss sensitivity factor is based on equivalent current injection utilizing bus-injection to branch-current (BIBC) and branch-current to bus-voltage (BCBV) matrices.

Hung and Mithulananthan [24] presented an improved analytical expression for calculating optimal size of four DGs. An optimal power flow technique has also been described for obtaining the amount of reactive power to be generated by DG units.

Abri *et al.*[25] employed mix integer linear programming to find the optimal location and size of DG unit. The method has also been used to improve the voltage stability margin of the network.

Atwa *et al.*[26] employed mixed integer linear programming to minimize the annual energy losses. Probabilistic generation load model based method has been used for optimal allocation of DG units.

Huang *et al.*[27] proposed a method of energy loss minimization using reconfiguration and phase balancing. Power flow has been analyzed using backward forward sweep algorithm. Particle swarm optimization (PSO) has been used for network reconfiguration in stage 1 and load balancing in stage 2. Energy loss and voltage unbalance factor are considered for the formulation of multi objective function.

Guan *et al.*[28] employed the symbol coded quantum PSO method for network reconfiguration for loss minimization. DG might generate reactive power more than their limits. Therefore a study has been presented in this paper to analyze the effect of the different models of DG on distribution system.

Acharya *et al.*[29] proposed an analytical expression based on exact loss for allocating optimum location and size for distributed generation. Furthermore, from the results it has been observed that the best location and size for loss reduction has not been obtained by loss sensitivity-based methods.

Sulaiman *et al.*[30] presented a contingency analysis of distribution system having distributed generation. The genetic algorithm (GA) has been used to find the optimal size and location of DG. It also analyzed the effect of the location and size of DG on the system before and after contingency.

Quevedo *et al.*[31] proposed an optimal contingency assessment model for analyzing the distribution network with wind power generation and energy storage under different outage conditions. The model has employed mixed integer linear programming for contingency analysis.

1.3. Gap of Study

The effect of the reconfiguration and distributed generation on distribution system is explained in the various works, explained in the literature survey but the effect of contingencies on the distribution system under different conditions is yet to be analyzed. The methods to improve the stability of radial distribution system in the event of a contingency are not yet explored.

1.4. Scope of Work

The scope of this work is to study, formulate and utilize the following topics:

1. Power flow analysis of the radial distribution system.
2. Reconfiguration of the radial distribution system.
3. Location and sizing of distributed generation in the radial distribution system.
4. Contingency analysis of radial distributed system under different scenarios.

1.5. Objective of Work

The objectives of study are to:

1. obtain power flow solution of radial distribution system.

2. reconfigure the test system for minimizing network losses.
3. obtain the best location and size of DG for test distribution system.
4. analyze the radially distributed system under different contingencies.
5. identify the best switching sequence to solve contingencies.

1.6. Organization of the Dissertation

Chapter 1 includes the introduction, literature survey of the work carried out by different researchers, objective along with gap of study.

Chapter 2 discusses the radial power flow solution.

Chapter 3 explains the topic of network reconfiguration,

Chapter 4 describes the concept of voltage stability index and distributed generation allocation with its solution methodology.

Chapter 5 discusses the formulation of contingencies based problem under different conditions.

Chapter 6 presents the results and discussion in detail.

Chapter 7 summarizes the conclusion of the results and includes future scope.

CHAPTER 2

RADIAL POWER FLOW ANALYSIS

2.1. Introduction

Power flow solution is used as an important tool for the analysis of distribution system as it provides information such as maximum current flowing through a line and voltage drop associated with it, power loss in each branch etc. This information can be used for designing, planning and operation of power system.

Iterative methods like gauss seidel and jacobian based method like newton raphson, fast decoupled are effectively used to obtain power flow solution of transmission system. But these methods fail to converge when applied to distribution system because distribution network posses high resistance to reactance ratio (R/X) which causes it to be ill conditioned [7][8]. Therefore it is necessary to develop method for radial power flow (RPF).

2.2. Radial Power Flow Analysis

In radial distribution system the power is delivered from the main feeder (main branch) to the lateral distributer (sub branches) and then to sub laterals. Radial distribution system has a special feature that there is a unique path from any given bus to the source. This feature has a disadvantage that any outage of equipment or line causes interruption of supply to all the users connected afterwards, therefore it is least reliable but the cheapest network configuration. Although, the same feature is used by different methods to solve the power flow problem related to radial distribution system, one of such method is backward/forward sweep method used to obtain power flow solution of radial distribution system [2]. Backward/forward sweep is a topology based iterative method in which three set equations are solved in each iteration.

- **Nodal current calculation**
  Initial voltage of all the buses is assumed to be flat. Nodal current injection I_i^{IT} according to specified power injection P_i, Q_i and bus voltage for iteration (IT) is defined in Equation 2.1

$$I_i^{IT} = \left(\frac{P_i - Q_i}{V_i^{IT-1}}\right)^* - Y_i V_i^{IT-1} \qquad i = 1, 2, 3...n \tag{2.1}$$

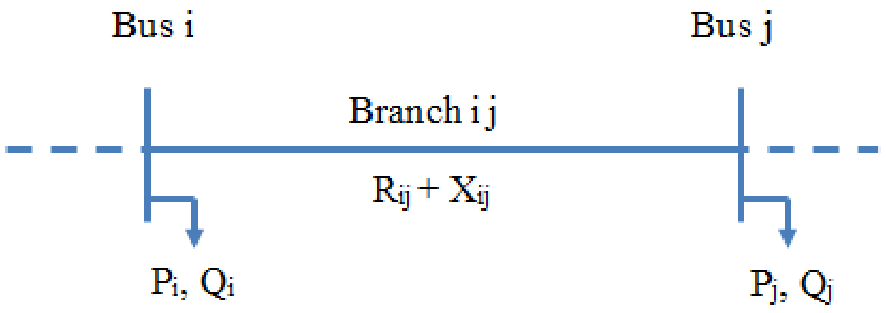

Figure 2.1: Schematic diagram of two bus system.

- **Backward Sweep**
  The second set of equations is used to obtain current flow solution. The current flows in each branch get updated in each iteration by considering the node voltages of the previous iteration. It starts from the last branch and proceeding in the backward direction towards the root node branch. This indicates that backward sweep starts at the extreme end node and proceeds towards source node. Current J_{ij} in branch ij shown in Fig. 2.1 is calculated from Equation 2.2

$$J_{ij}^{IT} = I_i^{IT} - \sum (\; current \; in \; branch \; connected \; to \; node \; j \;) \tag{2.2}$$

- **Forward Sweep**
  The third set of equations is used to calculate voltage at each bus. The voltage at each bus gets updated in each iteration by considering branch current in present iteration. It starts from the root node and proceeding in the forward direction towards the end node. The root node (feeder bus) voltage is set as 1 p.u. During the forward sweep the current in each branch is held constant at the value obtained in backward sweep. For ij^{th} branch, the voltage at bus j calculated using updated voltage at bus i and branch current calculated in the backward sweep using Equation 2.3

$$V_j^{IT} = V_i^{IT} - Z_{ij} J_{ij}^{IT} \tag{2.3}$$

- **Convergence Criterion**
  The voltages at each bus are calculated using forward sweep and maximum mismatch voltage at each bus is obtained by comparing it with the voltage at the bus in previous iteration. If the obtained maximum mismatch is less than the estimated mismatch ϵ then termination of program occurred. Otherwise it will terminate after maximum

number of iterations assigned.

$$\epsilon \geq \left|V_i^{IT} - V_i^{IT-1}\right| \qquad i = 1, 2, 3...n \tag{2.4}$$

- **Power loss calculation**
  Final branch current J_{ij} obtained from backward/forward sweep method is used to calculate active and reactive power losses as described in Eq. 2.5

$$Ploss_T = \sum_{ij=1}^{n-1} R_{ij} J_{ij}^2 \tag{2.5a}$$

$$Qloss_T = \sum_{ij=1}^{n-1} X_{ij} J_{ij}^2 \tag{2.5b}$$

2.3. Rearranging Line Data

Backward/forward sweep algorithm based radial load flow method has some limitations in terms of line-data arrangement. Inappropriate line-data input results in wrong power flow solutions. To arrange the line data, various approaches like branch renumbering, bus renumbering and parentchild node [1][2][7] have been reported. But such techniques work for the system with no topological change such as shunt capacitor bank and distributed generator placement in radial distribution system. In order to solve problem like network reconfiguration, an approach with some intelligent mechanism to arrange the line data with different sectionalizer and tie line switch combination is required. Also ensuring that all buses are connected to feeder bus and the radiality of the system must be maintained.

Graph Search algorithm

Two commonly used search methods for checking the connectivity among all the nodes or to obtain sequence of node connection are [12]:

Breadth First Search (BFS) It is a uniform search method that begins at the starting node and explores all the adjacent nodes, then for each of those adjacent nodes it explores their unexplored adjacent nodes, and continues until it finds all the connected nodes. For example, in Fig. 2.2 , the traveled path using BFS method starts from source node A will be A B C D E F G.

Depth First Search (DFS) It is a uniform search method that begins at the starting node and explores one adjacent nodes at a time till it reach to its end. Then it returns towards the starting node checking any unexplored connected node and explore the lateral till the end. This continues until it explores all the laterals and finds all the connected nodes. For example, in Fig. 2.2, the traveled path using DFS method starts from source node A will be A B D G E C F.

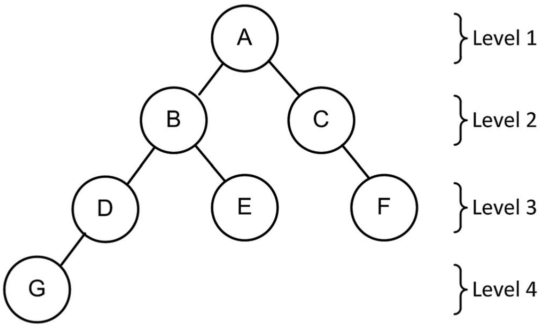

Figure 2.2: Graph for search algorithms .

For the current application in radial load flow solution, breadth first search method is used to arrange line data is described in Algorithm 2.1

Algorithm 2.1 Line data rearrangement using BFS method

```
STEP 1: Load line data with N bus and B branches;
STEP 2: Store line data in LD array $LD = [se \quad re]$
STEP 3: Generate an empty array "NLD" to store rearranged line data.
STEP 4: Generate an array $K$ to count branch connected to each bus.
STEP 5: Start Rearrangement
            Search for feeder bus and move connected branches from LD to NLD
              While all element of K $\neq 0$
                Find last element "m" of array NLD in LD
                Move all the connected branches from LD to NLD
                If $m$ is in $re$ column of LD then
                  Interchange $se$ and $re$ for that particular bus
                End If
                Reduce Count in array K according to the branch transfer to NLD
              End While
STEP 6: Replace newly generated NLD with LD.
STEP 7: Stop.
```

2.4. Conclusion

Results of radial power flow solution for IEEE 33 and 69 bus radial distribution system are evaluated and organized in Chapter 6. The method of radial power flow has been utilized in Chapter 3, 4 and 5.

- **Flowchart of Radial Power Flow Solution**

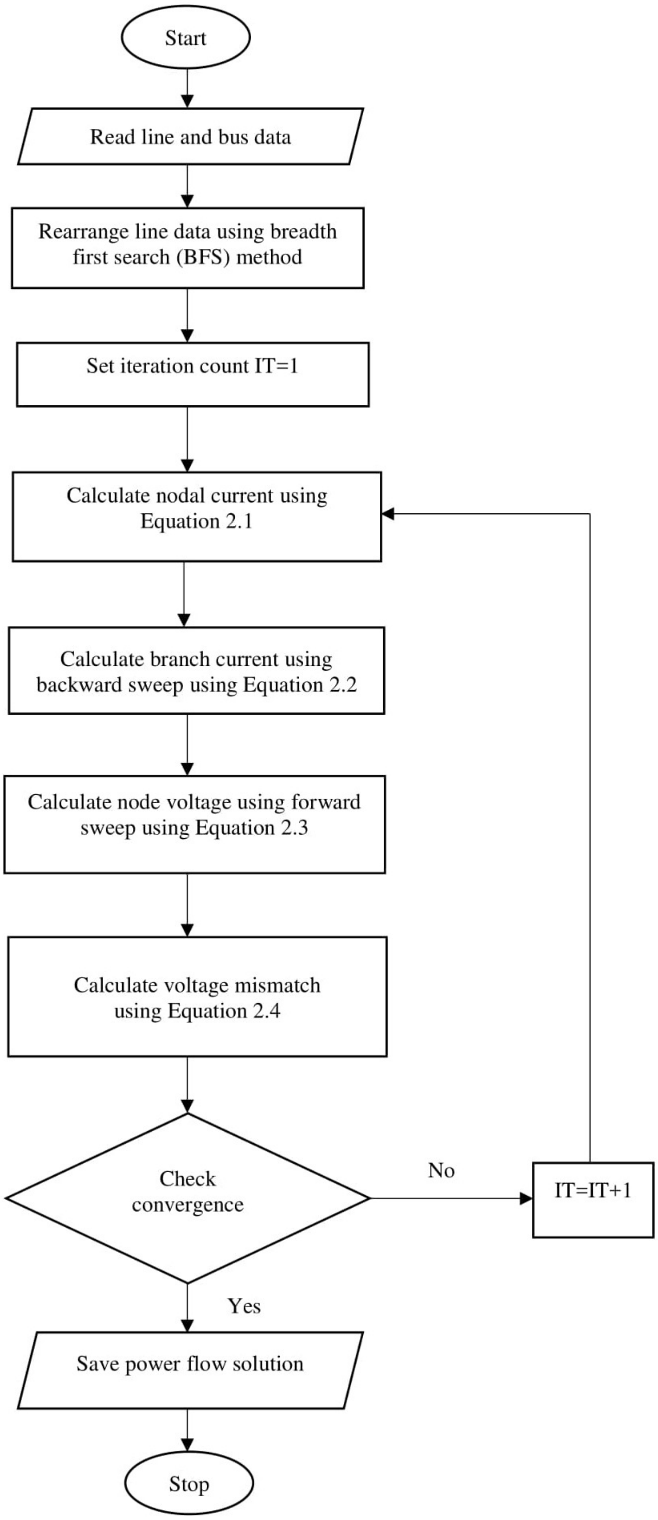

Figure 2.3: Flowchart of radial power flow solution.

CHAPTER 3

NETWORK RECONFIGURATION

3.1. Introduction

Reconfiguration of distribution system aims to find the best system topology to minimize power loss, fulfill energy demand and improve system performance. This is usually done by opening and closing of switches. Switches are basically the circuit breakers that are used in line are remotely controlled at substation.
The two type of switch used are:

Tie line switch: These are usually the close switches that allow the flow of power a line under normal condition.

Sectionalizers: These are usually the open switches which operate only when diversion of power is required.

In general, there are two approaches to solve the network reconfiguration problem are:

1. Heuristic and meta heuristic method
2. Exact method

Heuristic and meta heuristic are the approximate methods used to find best possible solution in a search space to optimize a problem. These methods are popular as they are time efficient and suitable for solving complex problem with large number of variables. In network reconfiguration, these methods are used for planning purposes to find the best possible location of tie line and sectionalizer for minimizing network losses. During planning of system, it is assumed that the distribution system has large number of remotely operated switches and therefore heuristic and meta heuristic methods are effectively applied. The radial distribution systems used in rural areas having isolated load, do not always have large number of remotely control switches. Therefore for post planning analysis like contingency analysis and for the system having limited number of switches exact method can also find its application.
Exact method is suitable for analysis of small networks as they are accurate and simple involving minimum complexity.

3.2. Problem Formulation

The aim of network reconfiguration is to determinate the best configuration of distribution system for minimizing active power losses. This section describes the objective function and constraints

3.2.1. Objective Function

The mathematical formulation of minimization problem is defined as Equation 3.1

$$F(x) = min(f) \tag{3.1}$$

$$Subjected\ to \quad \begin{cases} g_i(x) \leq 0, & i = 1, 2, ..., m \\ h_j(x) = 0 & j = 1, 2, ..., p \end{cases} \tag{3.2}$$

The mathematical formulation of objective function for network reconfiguration is defined in Equation 3.3

$$minimize \quad f, \qquad f = \sum_{ij=1}^{B} P_{Loss}(i, j) \tag{3.3}$$

Where, active power loss of ij^{th} branch can be formulated as

$$P_{Loss}(i, j) = R_{ij}\left(\frac{P_i^2 + Q_i^2}{\|V_i\|^2}\right) \tag{3.4}$$

3.2.2. Constraints

There are certain constraints which need to be satisfied in the optimal reconfiguration of distribution network. These constraints with their mathematical formulation are listed below:

Power Flow Constraint :

The real time power balance Equation is defined in Equation 3.5

$$P_{sub} = \sum_{i=1}^{N} P_i + \sum_{ij=1}^{B} P_{Loss}(i, j) \tag{3.5a}$$

$$Q_{sub} = \sum_{i=1}^{N} Q_i + \sum_{ij=1}^{B} Q_{Loss}(i, j) \tag{3.5b}$$

Voltage constraint :

The bus voltage magnitude should be maintained between $+6\%$ and -9% of the nominal voltage as per IS 12360:1988. But in this dissertation $\pm5\%$ of the voltage deviation from the nominal value is considered as **strict limit** and $\pm10\%$ of the voltage deviation from the nominal value is considered as **loose limit**.

$$V_i^{min} \leq V_i \leq V_i^{max} \tag{3.6}$$

Current constraint :

The current in each branch must be maintained below the maximum capacity of the branch this can be described as in Equation 3.7

$$J_{ij} \leq J_{ij}^{max} \tag{3.7}$$

Radiality constraint :

The system must remain radial before and after the reconfiguration this can be insured by satisfying the the conditions described below:

- No of sectionalizer closed = No of tie line switch open.
- Each bus must have at least one connected branch.
- There should be **no loop** in the network.

3.3. Assumptions

The assumption taken into the consideration for network reconfiguration are:

1. Location of tie line switches and sectionalizer are predefined in planning phase.
2. Switching cost is neglected.
3. ±5% Strict voltage limit and ±10% loose voltage limit is taken.

3.4. Solution Methodology

The methodology to obtain best network topology is described in following steps:

Step 1 Load line (LD1), sectionalizer (SD1) and bus (BD) data of the network having **N** buses and **B** branches.

LD1 = [From Bus(fb) To Bus(tb) Resistance(R) Reactance(X) Status(0,1)]

SD1 = [From Bus(fb) To Bus(tb) Resistance(R) Reactance(X) Status(0,1)]

BD = [Bus No.(N) Bus Type Active Load(P) reactive Load(Q)]

Step 2 Identify **n** tie line switches and **m** sectionalizers

$Tie = [s_1\ s_2\ s_3....s_n]$ & $Sec = [s_1\ s_2\ s_3....s_m]$

Where,

$$s_i = \begin{cases} 1 & if\ line\ is\ connected \\ 0 & if\ line\ is\ disconnected. \end{cases} \tag{3.8}$$

Step 3 Generate all possible switching sequence for sectionalizer (s_status) and tie line switches (Tie_status).

Where,

No. of rows of s_status = max(ii) = 2^n

No. of rows of tie_status = max(jj) = 2^m

Step 4 Set $ii = 0$ and $jj = 0$

Step 5 Increment ii by 1

Step 6 Increment jj by 1 and change the status of tie lines and sectionalizer according to the selected switching configuration. Form a new line data matrix **LD** having the line data of all the line with status **1**.

Step 7 Form a connection matrix **(C)** from **LD**

Connection matrix stores the value of number of connection each bus have.

Step 8 Check Radiality of the network:

1. No. of Tie line switch open = No. of Sectionalizer close.
2. Element of connection matrix (C) should not be equal to zero

$$element(C) \neq 0 \tag{3.9}$$

3. No loop in the network: To check number of loop in the network use depth first search (DFS) method.

If any of the above condition gets violated then move to **Step 6**.

Step 9 Adjust the line data using breadth first search (BFS) method.

Step 10 Carry out the radial power flow analysis using backward/forward sweep algorithm.

Step 11 Check for voltage and current constraints.

If any constraint gets violated then move to **Step 6**.

Step 12 Save power flow results and losses with switching sequence.

Step 13 Check $ii = max(ii)$

If not then move to **Step 6**.

Step 14 Check $jj = max(jj)$

If not then move to **Step 5**.

Step 15 Select the switching sequence associated with minimum active power loss.

Step 16 Stop.

3.5. Conclusion

Result of network reconfiguration for 33 and 69 bus radial distribution system is evaluated and organized in Chapter 6. The concept of network reconfiguration is utilized in contingency analysis of distribution system in chapter 5.

CHAPTER 4
DISTRIBUTED GENARATION ALLOCATION

4.1. Introduction

The increase in population has given rise to the industrial and technological advancements, which has further increased the demand for power. This increase has further lead to the depletion of conventional energy resources. In order to meet this increasing demand, in addition to the conventional sources some alternative method is required like DG. It can be defined as the small generator or source of power placed near the consumer end, supplying power to the local areas. The position of such generators plays a significant role, i.e. the inappropriate location of these resources may lead to the increased power losses and voltage instability in the system. Till now, various methods have been proposed to find the proper location of the DG while minimizing the losses. But, in order to achieve, these methods suffer the issues related to local optimality [25][26][27]. Thus, In this work genetic algorithm based methodology have been proposed to allocate the size and location of the DG.

4.1.1. Genetic Algorithm

Genetic algorithm (GA) can be defined as the population based search method which mainly emphasizes the evolutionary ideas based on the principles of natural selection and genetics [32]. The coding of the search data is done in the form of binary strings known as chromosomes, which all together forms the population. The fitness of each chromosomes is calculated. The fittest chromosomes receive maximum opportunity to transfer genetically coded information to successive generation. In this way, genetic algorithm simultaneously evaluate a number of solutions lying in the search space (also called state space). Algorithm continuously reduces the search space, focusing in the area with best performance. Genetic algorithm basically has three elements:

- **Reproduction**
  Defined as the selection operator, reproduction is used to decide which chromosome of the current population will participate to form the next generation, where the chromosome with maximum fitness value has more chances of being selected and forming the new generation.
- **Crossover**
  In crossover operation, two selected parent chromosomes breed to generate one or more

children which inherit some useful characteristic from both the parents. The crossover site is selected randomly along the string length.

- **Mutation**

  In order to maintain the population diversity, mutation is used to create new genetic material in the population. It is performed by occasional random alteration of chromosome variables.

Fitness function

Genetic algorithm is more suitable for solving maximization problem as it is based on the principle of survival of the fittest. Therefore for solving the minimization problem the fitness function $F(x)$ can formulated in terms of objective function as

$$F(x) = F(x) = \frac{1}{1 + f(x)} \tag{4.1}$$

To increase the convergence speed the fitness value of i^{th} chromosome is normalized between 0 and 1 range. For this the fitness function can be defined as in Equation 4.2

$$F_i(x) = \frac{1}{1 + k\big(\frac{f_i(x)}{f_{min}} - 1\big)} \tag{4.2}$$

Parameters of genetic algorithm

The performance and the efficiency of genetic algorithm is affected by the:

- **Crossover probability**

  This parameter decides how often the crossover operation will be performed. In order to create a new population which is superior to its prior population this operation is performed. Crossover probability lies between 0 and 1 and it is used to control the crossover rate. If the value of crossover probability is 0 % then it means that offspring have inherited exact copy of chromosomes from their parents.
- **Mutation probability**

  This parameter decides how often the place of chromosome gets altered. If the value of mutation probability is 0 % then new population has no change in variables.

4.2. Problem Formulation

The main aim of Optimal generation allocation is to determine the optimal location and size of DG for minimizing active power losses in a distribution network. This section describes the the above defined objective function and its related constraints.

4.2.1. Objective Function

The mathematical formulation of objective function for network reconfiguration is defined in Equation 4.3

$$minimize \quad f, \qquad f = \sum_{ij=1}^{B} P_{Loss}(i,j) \tag{4.3}$$

Where, active power loss of ij^{th} branch can be formulated as

$$P_{Loss}(i,j) = R_{ij}\left(\frac{P_i^2 + Q_i^2}{\|V_i\|^2}\right) \tag{4.4}$$

4.2.2. Constraints

There are certain constraints which need to be satisfied in the optimal reconfiguration of distribution network. These constraints with their mathematical formulation are listed below:

Power Flow Constraint :

The real time power balance equation is defined in Equation 5.4

$$P_{sub} = \sum_{i=1}^{N} P_i + \sum_{ij=1}^{B} P_{Loss}(i,j) - \sum PDG_i \tag{4.5a}$$

$$Q_{sub} = \sum_{i=1}^{N} Q_i + \sum_{ij=1}^{B} Q_{Loss}(i,j) - \sum QDG_i \tag{4.5b}$$

Voltage Constraint :

The bus voltage magnitude should be maintained between +6% and −9% of the nominal voltage as per IS 12360:1988. But in this dissertation ±5% of the voltage deviation from the nominal value is considered as **strict limit** and ±10% of the voltage deviation from the nominal value is considered as **loose limit**.

$$V_i^{min} \leq V_i \leq V_i^{max} \tag{4.6}$$

Current Constraint :

The current in each branch must be maintained below the maximum capacity of the branch this can be described as

$$J_{ij} \leq J_{ij}^{max} \tag{4.7}$$

Location of DG :

All buses are eligible for the placement of DG except the bus connected to substation.

Size of DG :

The size of DG must remain with in the limit as:

$$PDG_i^{min} \leq PDG_i \leq PDG_i^{max} \tag{4.8}$$

4.3. Assumptions

The assumption taken into the consideration for network reconfiguration are:

1. The distribution system is a balanced three phase system which can be represented by equivalent single line diagram.
2. Load is modelled as constant power.
3. Power supplied by DG at unity power factor.
4. Distributed generation is considered as negative load
5. ±5 % strict voltage limit and ±10 % loose voltage limit is taken.

4.4. Solution Methodology

The main objective of using GA in distribution system is to obtain and economical and reliable network with some favorable technical features such as minimum power loss, improved node voltage profile, improved branch current to thermal limit ratio and maximize power from DG. The methodology to obtain optimal location size of DG is described in following steps:

Step 1 Read line data, bus data, maximum allowed generation (GEN), length of chromosome (l), population size (L), crossover probability (p_c) and mutation probability (p_m).

Step 2 Encode DG parameter (i.e. location & size) using binary coding.

$$chromosome = \underbrace{\begin{array}{|c|c|c|c|c|c|}\hline X_1(L) & X_1(S) & ... & ... & X_n(L) & X_n(S) \\ \hline \end{array}}_{\text{Length = No. of DG * 2}} \tag{4.9}$$

Where,

$X_i(L)$ =Location of i^{th} DG.

$X_i(S)$ =Size of i^{th} DG.

Step 3 Initialize population with random values.

Step 4 Set $F^{min} = 0,\ F^{max} = 1$

Step 5 Set generation counter, $k = 0$

Step 6 Set population counter, $j = 0$ and increment $k = k + 1$

Step 7 Increment $j = j + 1$

Step 8 Decode binary string using Equation

$$y_i = \sum_{i=1}^{l} 2^{i-1} b_{ij} \tag{4.10}$$

Step 9 Apply the decoded value of DG's location and size to modify the bus data.
Step 10 Perform radial power flow analysis on modified network
Step 11 Evaluate fitness function using Equation 4.2
If $(F^j > F^{max})$ then set $F^{max} = F^j$ and if $(F^j < F^{min})$ then set $F^{min} = F^j$
Step 12 If $(j > L)$ then move to step 7 and repeat.
Step 13 Save chromosomes with maximum fitness value (Elitism) .
Step 14 Use roulette wheel method for the selection of parents for cross over.
Step 15 Apply single point crossover on parents selected in previous step.
Step 16 Apply mutation on randomly selected chromosomes.
Step 17 If $(k < GEN)$ then move to step 6 and repeat.
Step 18 Save final variables as optimum location and size of DG
Step 19 Stop

4.5. Voltage Sensitivity Index

Voltage stability of the system can be defined as the ability of the system to remain in the state of equilibrium under normal operating condition and also to bring the system back to its initial state after being exposed to some disturbance. The voltage profile of the system deteriorates if the power consumption of the system goes beyond a certain limit. Due to the higher R/X ratio of distribution network as compared to transmission network, there is a high probability of distribution system to be affected by any disturbance in the system. Voltage sensitivity index has been used for the identification of system voltage limits. The index quantifies the closeness of any particular point to the steady state value of voltage stability margin [17][33]. In case of distribution network, value of both R and X are taken into consideration for finding voltage sensitivity index. To operate the system in stable region, the value of voltage sensitivity index should be greater than zero considering each bus. In order to improve the voltage regulation, the optimal location and size of DG plays a vital role. Thus, in this work the voltage sensitivity index has been evaluated considering the system with and without distributed generation to analyze the effect of DG on system voltage stability.

4.5.1. Algorithm for Voltage sensitivity Index

The following algorithm is referred from [33].

The current flowing in ij^{th} branch as shown in Fig 4.1 can be expressed as in Equation 4.11

$$J_{ij} = \frac{|V_i\angle\delta_i - V_j\angle\delta_j|}{R_{ij} + jX_{ij}} \tag{4.11}$$

$$P_i' - jQ_j' = V_j^* \times J_{ij} \tag{4.12}$$

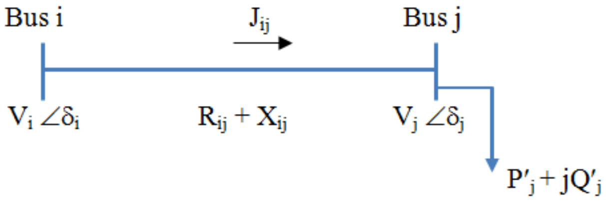

Figure 4.1: Schematic diagram of two bus system

Equating Equation 4.11 and 4.12

$$\frac{P_i' - jQ_j'}{V_j^*} = \frac{|V_i\angle\delta_i - V_j\angle\delta_j|}{R_{ij} + jX_{ij}} \tag{4.13}$$

Solving Equation 4.13

$$|V_j|^4 - \left(|V_j|^2 - 2 \times P_j'R_{ij} - 2 \times Q_j'X_{ij}\right)|V_j|^2 + \left(P_j'^2 + Q_j'^2\right)\left(R_{ij}^2 + X_{ij}^2\right) = 0 \tag{4.14}$$

$$b_{ij} = |V_j|^2 - 2 \times P_j'R_{ij} - 2 \times Q_j'X_{ij} \tag{4.15}$$

$$c_{ij} = \left(P_j'^2 + Q_j'^2\right)\left(R_{ij}^2 + X_{ij}^2\right) \tag{4.16}$$

Solving Equation 4.16 , we get

$$|V_j| = 0.707\sqrt{b_{ij} - \sqrt{b_{ij}^2 - 4c_{ij}}} \tag{4.17}$$

For a feasible load flow solution Equation 4.18 must satisfy

$$b_{ij}^2 - 4c_{ij} \geq 0 \tag{4.18}$$

$$|V_j|^4 - \left\{P_j'R_{ij} + Q_j'X_{ij}\right\}^2 - 4\left\{P_j'R_{ij} + Q_j'X_{ij}\right\}|V_j|^2 \geq 0 \tag{4.19}$$

$$VSI = |V_j|^4 - \left\{P_j'R_{ij} + Q_j'X_{ij}\right\}^2 - 4\left\{P_j'R_{ij} + Q_j'X_{ij}\right\}|V_j|^2 \tag{4.20}$$

For the radial distribution system stable operation

$$VSI \geq 0 \tag{4.21}$$

4.6. Conclusion

Results of distributed generation allocation have been utilized in contingency analysis in chapter 5. The complete set of results of this chapter have been organized in chapter 6.

CHAPTER 5
CONTINGENCY ANALYSIS

5.1. Introduction

Contingency analysis provide tools to analyse system behavior under the event of outage in any system component. Radial distribution system suffer from a drawback as any outage of equipment or line causes interruption of supply to all the user connected after it. Therefore for radial distribution system contingency analysis provide information about the loss of energy, loss of revenue, load curtailment and variation in system parameters during the event of contingency [6][31]. It also provides information about the effect of network reconfiguration and distributed generation on distribution system during the event of contingency.

In this work, contingency analysis is used to analyze the behavior of two test distribution networks and also to determine the best network topology for each contingency to maintain system parameters under the limit improve system reliability. This chapter includes the concept of network reconfiguration and results of distributed generation discussed in previous chapters.

5.2. Problem Formulation

The main objective of contingency analysis is to investigate the effect of (N-1) contingencies in the distribution system under different scenarios and to identify the best switching sequence to solve the contingencies. This section describes the objective function and constraints.

5.2.1. Objective Function

The objective is to minimize the loss of revenue (LR) due to contingency (con) can be defined as in Equation.5.1

$$minimize \quad LR, \qquad LR = (\ \alpha\ + \beta\ ) \tag{5.1}$$

Where,

1. Network Cost (α)

$$\alpha = \sum_{ij=1}^{B} R_{ij} J_i^2 \times C^{loss} \tag{5.2}$$

2. Curtailment Cost (β)

$$\beta = \sum P^{d\_curt} \times C^{d\_curt} \tag{5.3}$$

5.2.2. Constraints

There are certain constraints which need to be satisfied in the optimal reconfiguration of distribution network. These constraints with their mathematical formulation are listed below:

Power Flow Constraint :

The real time power balance equation is defined in Equation 5.4

$$P_{sub} = \sum_{i=1}^{N} P_i + \sum_{ij=1}^{B} P_{Loss}(i,j) - \sum PDG_i \tag{5.4a}$$

$$Q_{sub} = \sum_{i=1}^{N} Q_i + \sum_{ij=1}^{B} Q_{Loss}(i,j) - \sum QDG_i \tag{5.4b}$$

Voltage Constraint :

The bus voltage magnitude should be maintained between +6% and −9% of the nominal voltage as per IS 12360:1988. But in this dissertation ±5% of the voltage deviation from the nominal value is considered as **strict limit** and ±10% of the voltage deviation from the nominal value is considered as **loose limit**.

$$V_i^{min} \leq V_i \leq V_i^{max} \tag{5.5}$$

Current Constraint :

The current in each branch must be maintained below the maximum capacity of the branch this can be described as

$$J_{ij} \leq J_{ij}^{max} \tag{5.6}$$

Radiality Constraint :

The system having contingency must remain radial after the reconfiguration which can be insured by satisfying the the conditions described below:

- No. of sectionalizer closed = No. of tie line switch open + No. of Contingencies
- Each bus must have at least one connected branch.
- There should be **no loop** in the network.

5.3. Assumptions

1. The distribution system is a balanced three phase system which can be represented by equivalent single line diagram
2. Load is modeled as constant power.
3. Tie line switch and sectionalizer locations are predefined in planning phase.

4. Islanded radial operation of system is not considered.
5. Distributed generation is considered as negative load.
6. Location of tie line switches and sectionalizer are predefined in planning phase.
7. Switching cost is neglected.
8. ±5% strict voltage limit and ±10% loose voltage limit is taken.

5.4. Solution Methodology

The contingency analysis of radial distribution system has been classified in three different cases utilizing the concept of network reconfiguration and results of distributed generation are explained in previous chapters. The cases with solution methodology are described below:

1. Contingencies at base network :

Step 1 Load the line and bus data

Step 2 Set contingency counter *con = 0*

Step 3 Increment *con = con + 1*

Step 4 Apply the contingency (con) and remove selected branch.

Step 5 Now calculate the total curtailed load of islanded part of the network.

Step 6 Apply radial power flow at remaining part of network and calculate total active and reactive power loss.

Step 7 Calculate and store the loss of revenue for the respective contingency (con).

Step 8 Increment con by 1 and move to Step 4 until all contingencies are explored.

Step 8 Save the result obtained.

Step 9 Stop

2. Reconfiguration after contingency at base network :

Step 1 Load the line and bus data

Step 2 Set contingency counter, *con = 0*

Step 3 Increment *con = con + 1*

Step 4 Apply the contingency (con) and remove selected branch.

Step 5 Apply network reconfiguration and calculate total active and reactive power loss.

Step 6 Calculate and store the loss of revenue for the respective contingency (con).

Step 7 Increment con by 1 and move to Step 4 until all contingencies are explored.

Step 8 Save the result obtained.

Step 9 Stop

3. Reconfiguration after contingency at network with DG :

Step 1 Load the line and bus data

Step 2 Include DG's of optimal size at optimal location in the network.

Step 3 Set contingency counter $con = 0$

Step 4 Increment $con = con + 1$

Step 5 Apply the contingency (con) and remove selected branch.

Step 6 Apply network reconfiguration and calculate total active and reactive power loss.

Step 7 Calculate and store the loss of revenue for the respective contingency (con).

Step 8 Increment con by 1 and move to Step 5 until all contingencies are explored.

Step 9 Save the result obtained.

Step 10 Stop

CHAPTER 6

RESULTS AND DISCUSSION

This chapter contains the results of radial power flow, network reconfiguration, distributed generation and contingency analysis of distribution network discussed in last four chapters. The test systems taken for the analysis are

1. IEEE 33 Bus Distribution System
2. IEEE 69 Bus Distribution System

The line and bus data specifications of the test systems are given in Appendix A.1 and A.2 respectively.

6.1. Power Flow Analysis

6.1.1. IEEE 33 Bus Distribution System

The first test system is taken as IEEE 33 bus distribution system shown in Fig. 6.7. The test system has 33 buses and 32 branches with one main feeder and three lateral distributers. This test system has base voltage of 12.66 kV with 100 MVA as base MVA. Bus 1 is take as slack bus with constant voltage of 1 p.u. Total active and reactive load connected to the distribution network is 3715 kW and 3200 kVAr respectively.

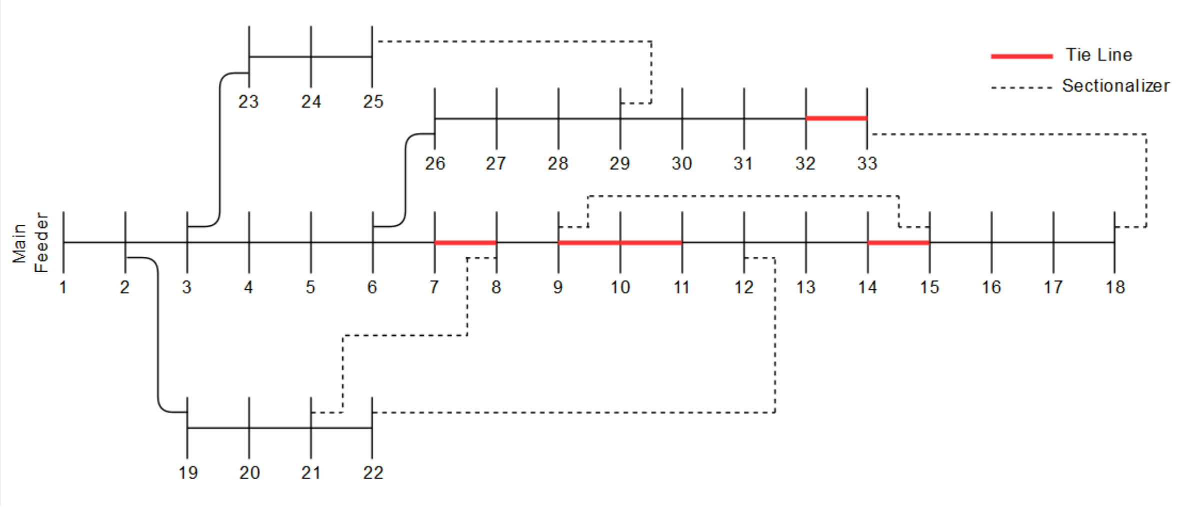

Figure 6.1: IEEE 33 bus distribution system

Voltage magnitude and angle of each bus has been shown in Table. 6.1 and Fig.6.2 where as active and reactive power loss with X/R ratio at each branch has been shown in Table. 6.2.

Table 6.1: Voltage magnitude and angle for IEEE 33 bus system

Bus No.	Voltage Magnitude (p.u)	Voltage Angle (p.u)	Bus No.	Voltage Magnitude (p.u)	Voltage Angle (p.u)
1	1	0	18	0.903841	-0.01217
2	0.997027	0.000252	19	0.996499	6.29E-05
3	0.982904	0.001671	20	0.992921	-0.00111
4	0.975401	0.002813	21	0.992216	-0.00144
5	0.967982	0.003973	22	0.991579	-0.0018
6	0.949528	0.002302	23	0.979318	0.001131
7	0.946004	-0.00174	24	0.972647	-0.00042
8	0.932349	-0.00442	25	0.969321	-0.00118
9	0.926016	-0.00572	26	0.947602	0.002984
10	0.92016	-0.00684	27	0.945043	0.003954
11	0.919291	-0.00671	28	0.933602	0.005402
12	0.917776	-0.00651	29	0.925382	0.006762
13	0.911601	-0.00813	30	0.921824	0.0086
14	0.909311	-0.00953	31	0.917663	0.007126
15	0.907884	-0.01021	32	0.916747	0.006724
16	0.906502	-0.01062	33	0.916463	0.006589
17	0.904454	-0.012			

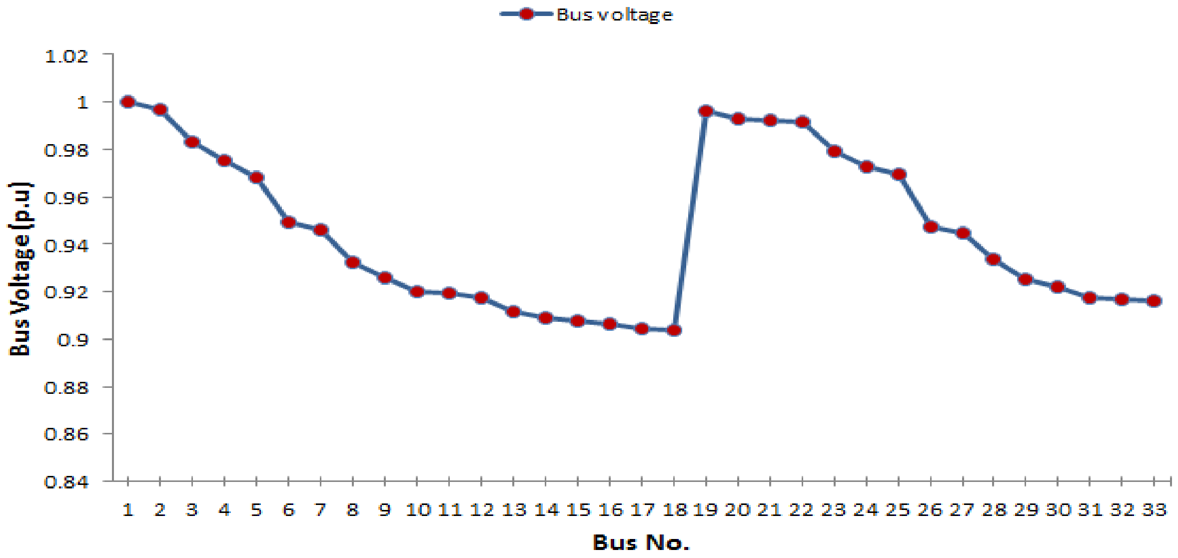

Figure 6.2: Bus voltage magnitude of IEEE 33 bus system

Table 6.2: Active and reactive power losses of IEEE 33 Bus system

Sending End Bus	**Receiving End Bus**	**Active Power Loss (kW)**	**Reactive Power Loss (kVAr)**	**X/R Ratio**
1	2	12.28405	6.261932	0.509761
2	3	51.99799	26.48417	0.509331
3	4	20.00894	10.19035	0.50929
4	5	18.80607	9.578216	0.509315
5	6	38.47281	33.21157	0.863248
6	7	1.945919	6.432343	3.305556
7	8	11.87164	8.567644	0.72169
8	9	4.265066	3.064222	0.718447
9	10	3.619193	2.575195	0.711538
10	11	0.564953	0.186785	0.330621
11	12	0.899074	0.29729	0.330662
12	13	2.720666	2.140579	0.786785
13	14	0.744069	0.979407	1.316285
14	15	0.364291	0.324225	0.890017
15	16	0.287245	0.209766	0.730269
16	17	0.256808	0.342875	1.335144
17	18	0.054229	0.042524	0.784153
2	19	0.160956	0.153595	0.954268
19	20	0.832186	0.749863	0.901077
20	21	0.100759	0.117712	1.168254
21	22	0.043635	0.057694	1.322189
3	23	3.181856	2.174127	0.683289
23	24	5.144042	4.06196	0.789644
24	25	1.287544	1.007475	0.782478
6	26	2.587875	1.318159	0.50936
26	27	3.311176	1.68588	0.509148
27	28	11.30394	9.966471	0.881681
28	29	7.835493	6.826096	0.871176
29	30	3.896736	1.98484	0.50936
30	31	1.594077	1.575427	0.9883
31	32	0.213254	0.248556	1.165539
32	33	0.013172	0.020481	1.554839

Table 6.3 shows the total active and reactive power losses of the system. The active and reactive power losses are 5.61% and 6.21% of their total loads.

Table 6.3: Total active and reactive power losses of IEEE 33 bus system

Total Active Power Loss kW	**Total Reactive Power Loss kVAr**	**Minimum Voltage (p.u)**	**Minimum Voltage Bus**
210.6697	142.8374	0.903841	18

6.1.2. IEEE 69 Bus Distribution System

The second test system is taken as IEEE 33 bus distribution system shown in Fig. 6.3. The test system has 69 buses and 68 branches with one main feeder and seven lateral distributers. This test system has base voltage of 12.66 kV with 100 MVA as base MVA. Bus 1 is taken as slack bus with constant voltage of 1 p.u. Total active and reactive load connected to the distribution network are 3802.2 kW and 2694.6 kVAr respectively.

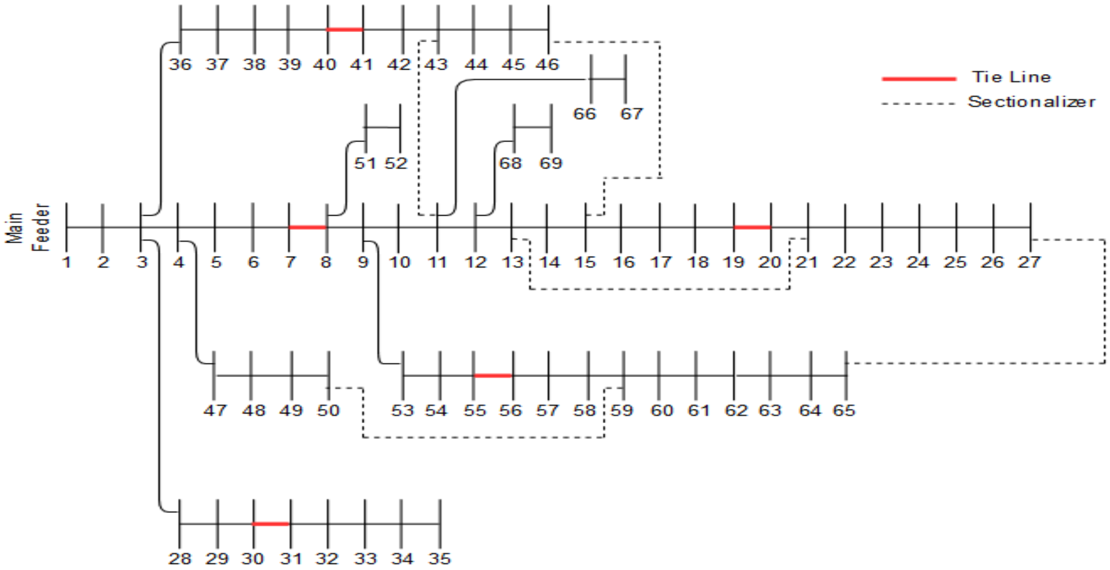

Figure 6.3: IEEE 69 bus distribution system

Voltage magnitude and angle of each bus is shown in Table. 6.4 and Fig. 6.4 where as active and reactive power loss with X/R ratio at each branch is given in Table. 6.5.

Table 6.4: Voltage magnitude and angle for IEEE 69 bus system

Bus No.	**Voltage Magnitude (p.u)**	**Voltage Angle (p.u)**	**Bus No.**	**Voltage Magnitude (p.u)**	**Voltage Angle (p.u)**
1	1	0	36	0.999919	-5.18E-05
2	0.999966	-2.14E-05	37	0.999747	-0.00016
3	0.999933	-4.29E-05	38	0.999589	-0.00021
4	0.999839	-0.0001	39	0.999543	-0.00022
5	0.99902	-0.00032	40	0.999541	-0.00022
6	0.990086	0.000861	41	0.998843	-0.00041
7	0.980793	0.002115	42	0.998551	-0.00049
8	0.978577	0.002415	43	0.998512	-0.0005
9	0.977443	0.002569	44	0.998504	-0.0005
10	0.972445	0.00405	45	0.998406	-0.00054

11	0.971344	0.004378	46	0.998405	-0.00054
12	0.968184	0.005301	47	0.999789	-0.00013
13	0.96526	0.006113	48	0.998543	-0.00092
14	0.962363	0.00692	49	0.994699	-0.00334
15	0.959495	0.007723	50	0.994154	-0.00369
16	0.958962	0.007873	51	0.978541	0.002421
16	0.958962	0.007873	51	0.978541	0.002421
17	0.958082	0.00812	52	0.978532	0.002424
18	0.958073	0.008122	53	0.974657	0.002952
19	0.957609	8.27E-03	54	0.971414	0.003399
20	0.957311	0.008368	55	0.966941	0.00402
21	0.956829	0.008523	56	0.962572	0.00463
22	0.956822	0.008525	57	0.940098	0.011552
23	0.95675	0.008549	58	0.929038	0.015087
24	0.956594	0.008599	59	0.924761	0.0165
25	0.956425	0.008654	60	0.919736	0.018324
26	0.956355	0.008677	61	0.912339	0.019529
27	0.956336	0.008683	62	0.91205	0.019577
28	0.999926	-4.72E-05	63	0.911662	0.01964
29	0.999854	-9.26E-05	64	0.909762	0.019952
30	0.999733	-5.55E-05	65	0.909187	0.020046
31	0.999712	-4.90E-05	66	0.971287	0.004398
32	0.999605	-1.62E-05	67	0.971286	0.004399
33	0.999349	6.10E-05	68	0.967854	0.005407
34	0.999013	0.000163	69	0.967852	0.005407
35	0.998946	0.000182			

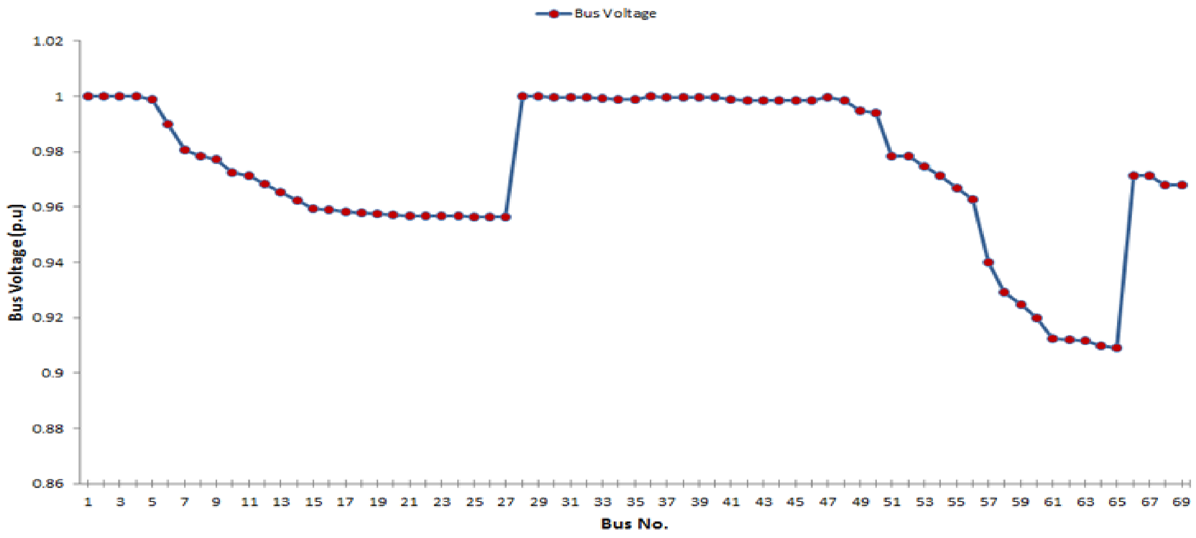

Figure 6.4: Bus voltage magnitude of IEEE 69 bus system

Table 6.5: Active and reactive power losses of IEEE 69 Bus system

Sending End Bus	**Receiving End Bus**	**Active Power Loss (kW)**	**Reactive Power Loss (kVAr)**	**X/R Ratio**
1	2	0.074987	0.179969	2.4
2	3	0.074987	0.179969	2.4
3	4	0.194959	0.467902	2.4
4	5	1.9367	2.268485	1.171315
5	6	28.24033	14.38251	0.50929
6	7	29.34822	14.94749	0.509315
7	8	6.894512	3.514556	0.509761
8	9	3.37501	1.718311	0.509128
9	10	4.775771	1.578512	0.330525
10	11	1.014439	0.335437	0.330662
11	12	2.19108	0.724097	0.330475
12	13	1.285918	0.424478	0.330097
13	14	1.245457	0.411573	0.33046
14	15	1.204605	0.398044	0.330435
15	16	0.223843	0.074007	0.330621
16	17	0.320401	0.105944	0.330662
17	18	0.002604	0.000886	0.340426
18	19	0.104121	0.034421	0.330586
19	20	0.066935	0.02193	0.327635
20	21	0.107405	0.035498	0.330504
21	22	0.000536	0.000176	0.328571
22	23	0.005139	0.001699	0.33061
23	24	0.011185	0.003698	0.330638
24	25	0.006048	0.001999	0.330529
25	26	0.002495	0.000825	0.330528
26	27	0.00035	0.000116	0.330254
3	28	0.000347	0.000851	2.454545
28	29	0.002583	0.006317	2.445313
29	30	0.005829	0.001927	0.330568
30	31	0.001029	0.00034	0.330484
31	32	0.005143	0.0017	0.330484
32	33	0.012293	0.004126	0.335638
33	34	0.010403	0.003439	0.330562
34	35	0.000479	0.000158	0.330597
3	36	0.001405	0.003449	2.454545
36	37	0.015073	0.036859	2.445313
37	38	0.017316	0.020227	1.168091
38	39	0.004999	0.005838	1.167763
39	40	0.000198	0.000232	1.166667
40	41	0.048683	0.056878	1.168337

41	42	0.020104	0.023495	1.16871
42	43	0.002659	0.0031	1.165854
43	44	0.000513	0.000647	1.26087
44	45	0.006076	0.00766	1.26079
45	46	1.26E-05	1.67E-05	1.333333
4	47	0.023285	0.057528	2.470588
47	48	0.582814	1.426558	2.447709
48	49	1.633507	3.996962	2.44686
49	50	0.115897	0.283539	2.446472
8	51	0.001757	0.000896	0.509698
51	52	4.38E-05	1.47E-05	0.335643
9	53	5.781261	2.943792	0.509195
53	54	6.71145	3.418542	0.50936
54	55	9.124723	4.645839	0.509148
55	56	8.79013	4.477873	0.509421
56	57	49.6847	16.67719	0.33566
57	58	24.48925	8.218288	0.335588
58	59	9.505715	3.143573	0.330703
59	60	10.67103	3.239173	0.303548
60	61	14.02628	7.144422	0.50936
61	62	0.112053	0.057062	0.50924
62	63	0.134932	0.068676	0.508966
63	64	0.661168	0.336772	0.50936
64	65	0.041212	0.02099	0.509318
11	66	0.002624	0.000797	0.303678
66	67	1.53E-05	4.56E-06	0.297872
12	68	0.023324	0.00771	0.330538
68	69	3.71E-05	1.26E-05	0.340426

Table. 6.6 shows the total active and reactive power losses of the system. The active and reactive power losses are 5.91% and 3.79% of their total loads.

Table 6.6: Total Active and reactive power losses of IEEE 69 Bus system

Total Active Power Loss kW	**Total Reactive Power Loss kVAr**	**Minimum Voltage (p.u))**	**Minimum Voltage Bus**
224.9804	102.156	0.909187	65

6.2. Network Reconfiguration

6.2.1. Reconfiguration of IEEE 33 Bus Distribution System

The network reconfiguration method explained in Chapter 3 for minimizing the active power loss is applied on IEEE 33 bus system. All buses except bus 1 are considered as load bus.

The location of network switches are assumed to be known as:

Tie line switches : [7-8, 9-10, 10-11, 14-15, 32-33]

Sectionalizer : [8-21, 9-15, 12-22, 18-33, 25-29]

The 'ON' and 'OFF' switches are denoted by '1' and '0' respectively. The maximum current capacity for line 1 to 9 and remaining lines are taken as 400 A and 200 A respectively. The active power loss and minimum voltage for all possible radial configurations are shown in Table 6.7.

Table 6.7: Reconfiguration of IEEE 33 bus system

Serial No.	Sectionalizer Position					Tie line position					Active Loss (kW)	Min. Voltage (p.u)	Min. Voltage Bus
1	0	0	0	0	0	1	1	1	1	1	210.6697	0.903841	18
2	1	0	0	0	0	0	1	1	1	1	158.1456	0.929875	18
3	0	1	0	0	0	1	0	1	1	1	210.1827	0.907272	10
4	0	1	0	0	0	1	1	0	1	1	208.0439	0.910189	11
5	0	1	0	0	0	1	1	1	0	1	204.1685	0.916594	33
6	1	1	0	0	0	0	0	1	1	1	157.6484	0.933202	10
7	1	1	0	0	0	0	1	0	1	1	155.7687	0.933633	33
8	1	1	0	0	0	0	1	1	0	1	152.3839	0.933637	33
9	0	0	1	0	0	0	1	1	1	1	156.296	0.933632	33
10	0	0	1	0	0	1	0	1	1	1	154.3605	0.928784	33
11	0	0	1	0	0	1	1	0	1	1	155.806	0.92772	33
12	1	0	1	0	0	0	0	1	1	1	145.9309	0.933642	33
13	1	0	1	0	0	0	1	0	1	1	144.8775	0.933643	33
14	0	1	1	0	0	0	0	1	1	1	163.3008	0.926747	8
15	0	1	1	0	0	0	1	0	1	1	165.9825	0.924072	8
16	0	1	1	0	0	0	1	1	0	1	157.5338	0.933631	33
17	0	1	1	0	0	1	0	1	0	1	164.0552	0.923902	33
18	0	1	1	0	0	1	1	0	0	1	168.3126	0.922805	33
19	1	1	1	0	0	0	0	1	0	1	141.9347	0.933646	33
20	1	1	1	0	0	0	1	0	0	1	142.4475	0.933645	33
21	0	0	0	1	0	0	1	1	1	1	324.2966	0.823541	8
22	0	0	0	1	0	1	0	1	1	1	257.5537	0.862657	10

23	0	0	0	1	0	1	1	0	1	1	247.4249	0.869439	11
24	0	0	0	1	0	1	1	1	0	1	212.8038	0.901121	15
25	0	0	0	1	0	1	1	1	1	0	213.4132	0.896619	33
26	1	0	0	1	0	0	0	1	1	1	234.9188	0.868022	10
27	1	0	0	1	0	0	1	0	1	1	220.8918	0.875902	11
28	1	0	0	1	0	0	1	1	0	1	168.934	0.913448	15
29	1	0	0	1	0	0	1	1	1	0	159.1703	0.921257	33
30	0	1	0	1	0	0	0	1	1	1	316.5006	0.836881	8
31	0	1	0	1	0	0	1	0	1	1	316.6421	0.835658	8
32	0	1	0	1	0	0	1	1	0	1	328.5398	0.820241	14
33	0	1	0	1	0	1	0	1	1	0	211.7497	0.903746	33
34	0	1	0	1	0	1	1	0	1	0	209.4138	0.905012	33
35	0	1	0	1	0	1	1	1	0	0	204.5678	0.911778	33
36	1	1	0	1	0	0	0	1	1	0	157.6171	0.928184	33
37	1	1	0	1	0	0	1	0	1	0	155.5513	0.929419	33
38	1	1	0	1	0	0	1	1	0	0	151.2869	0.936014	33
39	0	0	1	1	0	0	1	1	0	1	170.4868	0.913446	15
40	0	0	1	1	0	1	0	1	0	1	177.9435	0.908444	15
41	0	0	1	1	0	1	1	0	0	1	181.4069	0.907345	15
42	0	0	1	1	0	0	1	1	1	0	155.9459	0.929362	33
43	0	0	1	1	0	1	0	1	1	0	151.5217	0.933045	32
44	0	0	1	1	0	1	1	0	1	0	152.4488	0.931988	32
45	1	0	1	1	0	0	0	1	0	1	163.8232	0.913452	15
46	1	0	1	1	0	0	1	0	0	1	163.5319	0.913453	15
47	1	0	1	1	0	0	0	1	1	0	144.5469	0.93699	33
48	1	0	1	1	0	0	1	0	1	0	143.2874	0.937872	32
49	0	1	1	1	0	0	0	1	0	1	212.3493	0.879069	8
50	0	1	1	1	0	0	1	0	0	1	225.3961	0.871828	8
51	0	1	1	1	0	0	0	1	1	0	164	0.921356	8
52	0	1	1	1	0	0	1	0	1	0	166.9358	0.918647	8
53	0	1	1	1	0	0	1	1	0	0	157.7167	0.926074	33
54	0	1	1	1	0	1	0	1	0	0	162.9178	0.926884	32
55	0	1	1	1	0	1	1	0	0	0	167.3938	0.925786	32
56	1	1	1	1	0	0	0	1	0	0	139.3297	0.937876	32
57	1	1	1	1	0	0	1	0	0	0	140.0572	0.937875	32

The best switching configuration for minimum active power loss is:
Sectionalizer : [1 1 1 1 0]
Tie line switches : [0 0 1 0 0]

The effect of network reconfiguration is summarized in the Table 6.8 and in Fig. 6.7 shown below:

Table 6.8: Effect of reconfiguration on IEEE 33 bus system

	Without Reconfiguration	**With Reconfiguration**
Active power loss (kW)	210.6697	139.3297
Reactive power loss (kVAr)	142.8374	102.1702
Min Voltage (p.u)	0.9038	0.9379
Minimum Voltage Bus	18	32
Max. Branch Current (1-9) (A)	365.0104	358.5287
Max. Branch Current (Remaining) (A)	112.9077	117.3898

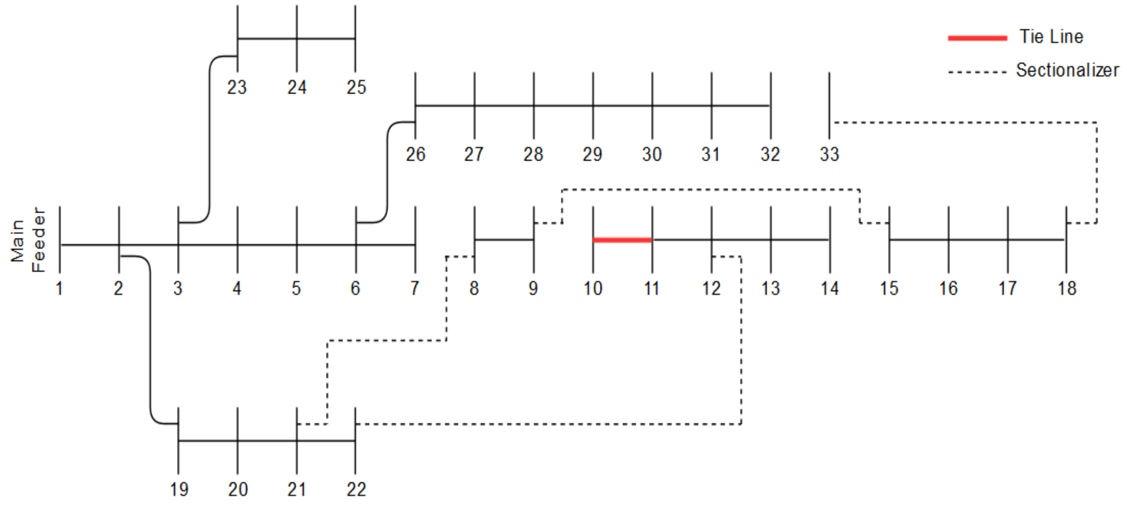

Figure 6.5: Reconfigured IEEE 33 bus distribution system

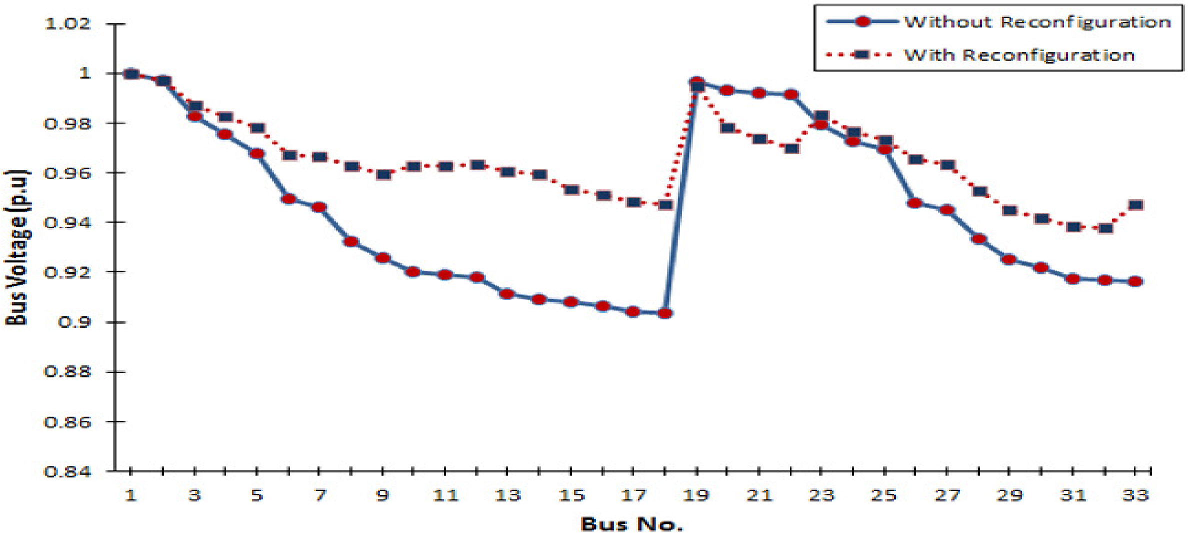

Figure 6.6: Bus voltage magnitude of IEEE 33 bus system with reconfiguration

6.2.2. Reconfiguration of IEEE 69 Bus Distribution System

The network reconfiguration method described in Chapter 3 for the minimizing active power loss is applied on IEEE 69 bus system. All buses except bus 1 are considered as load bus.
The location of network switches are assumed to be known as:
Tie line switches : [7-8, 19-20, 30-31, 40-41, 55-56]
Sectionalizer : [11-43, 13-21, 15-46, 27-65, 50-59]

The 'ON' and 'OFF' switches are denoted by '1' and '0' respectively. The maximum current capacity for line 1 to 9 and remaining lines are taken as 400 A and 300 A respectively. The active power loss and minimum voltage for all possible radial configurations are shown in Table 6.9.

Table 6.9: Reconfiguration of IEEE 69 bus system

Serial No.	**Sectionalizer Position**					**Tie line position**					**Active Loss (kW)**	**Min. Voltage (p.u)**	**Min. Voltage Bus**
1	0	0	0	0	0	1	1	1	1	1	224.9804	0.909187	65
2	1	0	0	0	0	0	1	1	1	1	578.7133	0.78383	65
3	1	0	0	0	0	1	1	1	0	1	231.1278	0.908421	65
4	0	1	0	0	0	1	0	1	1	1	222.8638	0.909201	65
5	1	1	0	0	0	0	0	1	1	1	575.7071	0.783921	65
6	1	1	0	0	0	1	0	1	0	1	228.9995	0.908435	65
7	0	0	1	0	0	0	1	1	1	1	1272.135	0.631204	65
8	0	0	1	0	0	1	1	1	0	1	234.154	0.908399	65
9	0	1	1	0	0	0	0	1	1	1	1341.766	0.622138	65
10	0	1	1	0	0	1	0	1	0	1	231.3054	0.908418	65
11	0	0	0	1	0	1	0	1	1	1	256.3845	0.894733	20
12	0	0	0	1	0	1	1	1	1	0	669.3488	0.77162	56
13	1	0	0	1	0	0	0	1	1	1	654.6522	0.761759	20
14	1	0	0	1	0	1	0	1	0	1	262.3033	0.893954	20
15	1	0	0	1	0	0	1	1	1	0	1118.34	0.652879	56
16	1	0	0	1	0	1	1	1	0	0	682.7355	0.769663	56
17	0	1	0	1	0	1	0	1	1	0	533.5391	0.797017	56
18	1	1	0	1	0	0	0	1	1	0	884.3722	0.690316	56
19	1	1	0	1	0	1	0	1	0	0	545.7614	0.795169	56
20	0	0	1	1	0	0	0	1	1	1	1750.114	0.558133	20
21	0	0	1	1	0	1	0	1	0	1	264.0222	0.893941	20
22	0	0	1	1	0	0	1	1	1	0	621.0268	0.772914	56

23	0	0	1	1	0	1	1	1	0	0	709.3466	0.765399	56
24	0	1	1	1	0	0	0	1	1	0	1113.158	0.649917	56
25	0	1	1	1	0	1	0	1	0	0	557.2222	0.793412	56
26	0	0	0	0	1	0	1	1	1	1	167.4584	0.904392	27
27	0	0	0	0	1	1	1	1	1	0	85.23097	0.956283	65
28	1	0	0	0	1	0	1	1	0	1	182.3774	0.899403	27
29	1	0	0	0	1	0	1	1	1	0	105.2639	0.946646	27
30	1	0	0	0	1	1	1	1	0	0	88.20504	0.956281	65
31	0	1	0	0	1	0	0	1	1	1	164.9286	0.909304	27
32	0	1	0	0	1	1	0	1	1	0	83.23261	0.956283	65
33	1	1	0	0	1	0	0	1	0	1	179.7957	0.904345	27
34	1	1	0	0	1	0	0	1	1	0	103.1046	0.951294	27
35	1	1	0	0	1	1	0	1	0	0	86.19611	0.956281	65
36	0	0	1	0	1	0	1	1	0	1	186.084	0.896396	27
37	0	0	1	0	1	0	1	1	1	0	115.3211	0.939605	55
38	0	0	1	0	1	1	1	1	0	0	91.05199	0.956281	65
39	0	1	1	0	1	0	0	1	0	1	182.6138	0.901138	41
40	0	1	1	0	1	0	0	1	1	0	121.3336	0.936314	55
41	0	1	1	0	1	1	0	1	0	0	88.36627	0.956281	65
42	0	0	0	1	1	0	0	1	1	1	153.7287	0.9205	18
43	0	0	0	1	1	0	1	1	1	0	244.4769	0.86178	55
44	0	0	0	1	1	1	0	1	1	0	90.96237	0.946134	20
45	1	0	0	1	1	0	0	1	0	1	166.6107	0.915658	18
46	1	0	0	1	1	0	0	1	1	0	104.6891	0.946155	20
47	1	0	0	1	1	0	1	1	0	0	276.2421	0.850899	46
48	1	0	0	1	1	1	0	1	0	0	93.32992	0.946132	20
49	0	1	0	1	1	0	0	1	1	0	240.7897	0.863681	55
50	1	1	0	1	1	0	0	1	0	0	270.3615	0.853537	46
51	0	0	1	1	1	0	0	1	0	1	168.6478	0.911449	41
52	0	0	1	1	1	0	0	1	1	0	118.3283	0.946154	20
53	0	0	1	1	1	0	1	1	0	0	269.4873	0.854386	55
54	0	0	1	1	1	1	0	1	0	0	94.93659	0.946131	20
55	0	1	1	1	1	0	0	1	0	0	268.7292	0.855049	55

The best switching configuration for minimum active power loss is:

Sectionalizer : [0 1 0 0 1]

Tie Line switches : [1 0 1 1 0]

The effect of network reconfiguration is summarized in the Table 6.10 shown below:

Table 6.10: Effect of reconfiguration on IEEE 69 bus system

	Without Reconfiguration	**With Reconfiguration**
Active power loss (kW)	224.9804	83.2326
Reactive power loss (kVAr)	102.1560	97.9328
Min Voltage (p.u)	0.9092	0.9563
Minimum Voltage Bus	65	65
Max. Branch Current (1-9) (A)	387.2650	377.9281
Max. Branch Current (Remaining) (A)	182.2790	251.8644

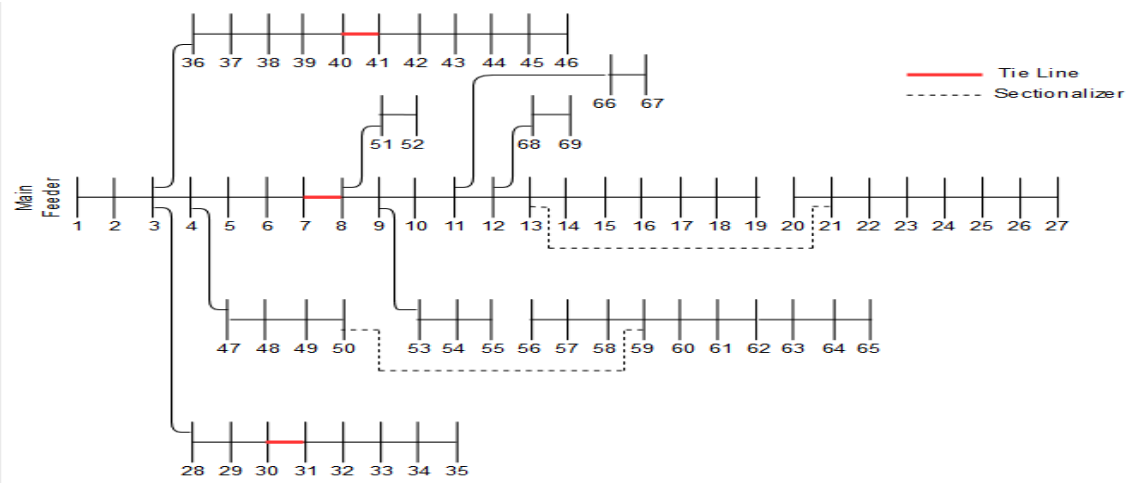

Figure 6.7: Reconfigured 69 bus distribution system

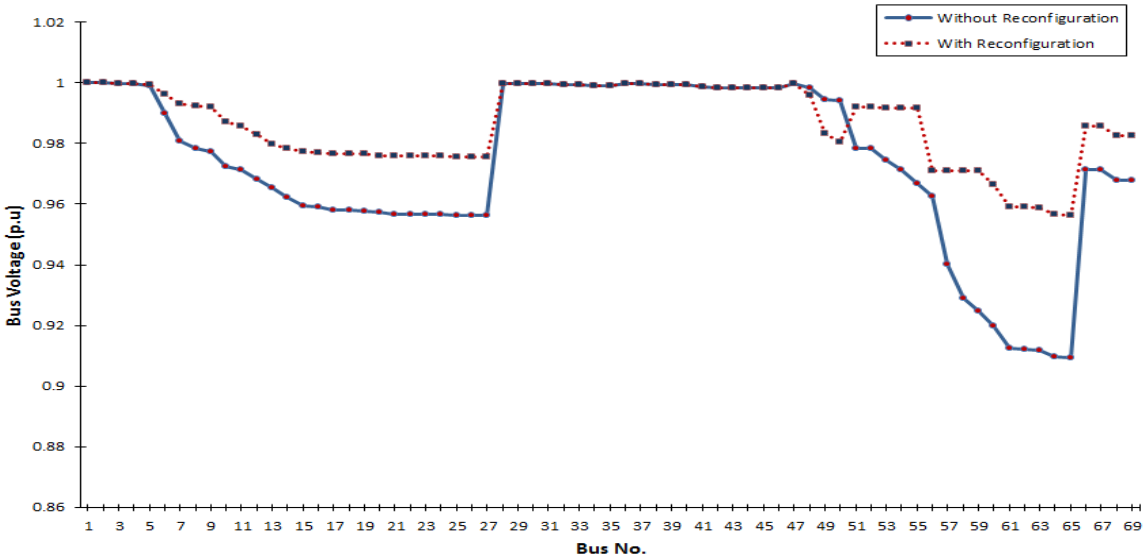

Figure 6.8: Bus voltage magnitude of 69 bus system with reconfiguration

6.3. Distributed Generation Allocation

Location and size of DG are determined using genetic algorithm. The GA parameters are set as followed.

- Selection: Roulette wheel
- Crossover probability, c = 0.8,
- Mutation probability, m = 0.005,
- Population = 20,
- Maximum Generation = 150
- Number of DG unit = 1 and 2
- DG size = $0.01MW < PDG_i < 2.5MW$

6.3.1. Generation Allocation of IEEE 33 Bus Distribution System

The effect of one and two DGs in the network are shown and compared in Table 6.11. The variation in voltage sensitivity index and bus voltage magnitude are shown in Fig. 6.9 and 6.10 respectively.

Table 6.11: Distributed generation allocation on IEEE 33 bus 3system

	Without DG	**With One DG**	**With Two DGs**
DG Location	–	6	13,30
DG Size (kW)	–	2589.9	851.58, 1157.5
Active power loss (kW)	210.6697	110.74	86.88
Reactive power loss (kVAr)	142.8374	81.51	59.60
Min Voltage (p.u)	0.9038	0.9424	0.9686
Min. Voltage Bus	18	18	33
Min. VSI	0.6698	0.79156	0.8816
Min. VSI Bus	18	18	33

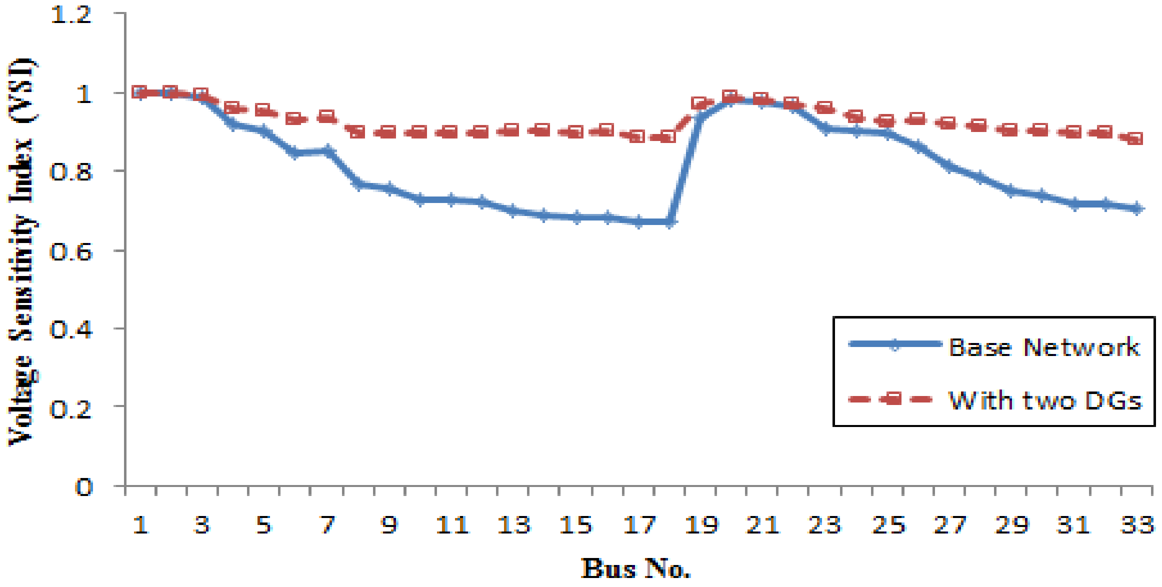

Figure 6.9: Voltage sensitivity index of IEEE 33 bus system with DGs

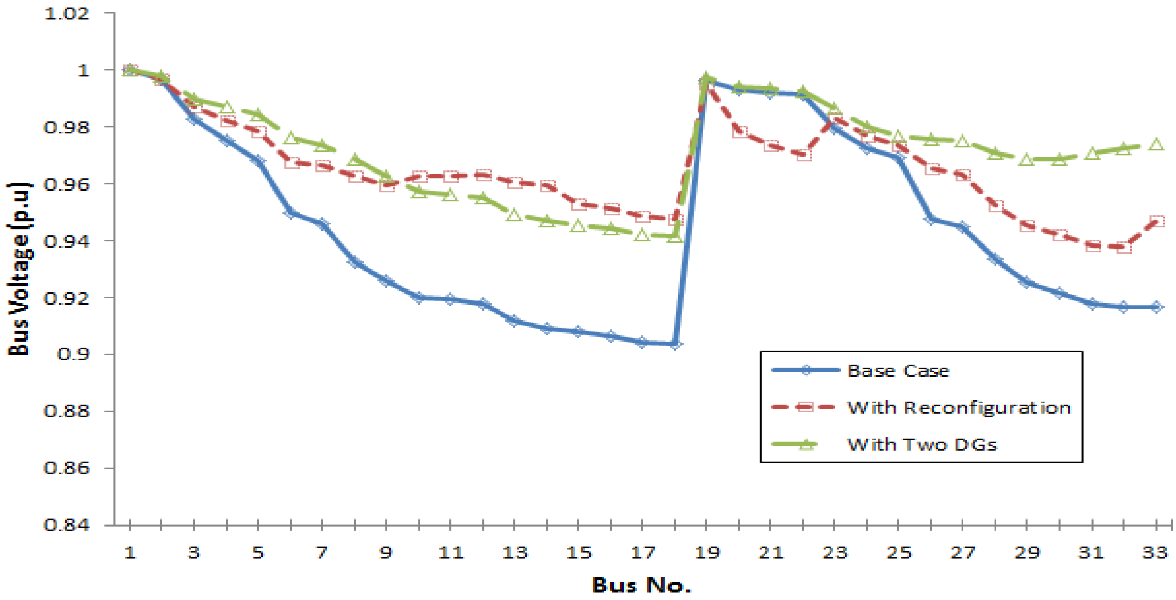

Figure 6.10: Bus voltage magnitude of IEEE 33 bus system with DGs

6.3.2. Generation Allocation of IEEE 69 Bus Distribution System

The effect one and two DGs in the network are shown and compared in Table 6.12 The variation in voltage sensitivity index and bus voltage magnitude are shown in Fig. 6.11 6.12 respectively.

Table 6.12: Distributed generation allocation on IEEE 69 bus system

	Without DG	**With One DG**	**With Two DGs**
DG Location	–	61	17,61
DG Size (kW)	–	1872.7	531.18,1781.5
Active power loss (kW)	224.9804	83.21	71.677
Reactive power loss (kVAr)	102.1560	40.531	35.942
Min Voltage (p.u)	0.9038	0.9683	0.97893
Min. Voltage Bus	65	27	65
Min. VSI	0.68354	0.87954	0.91861
Min. VSI Bus	65	27	65

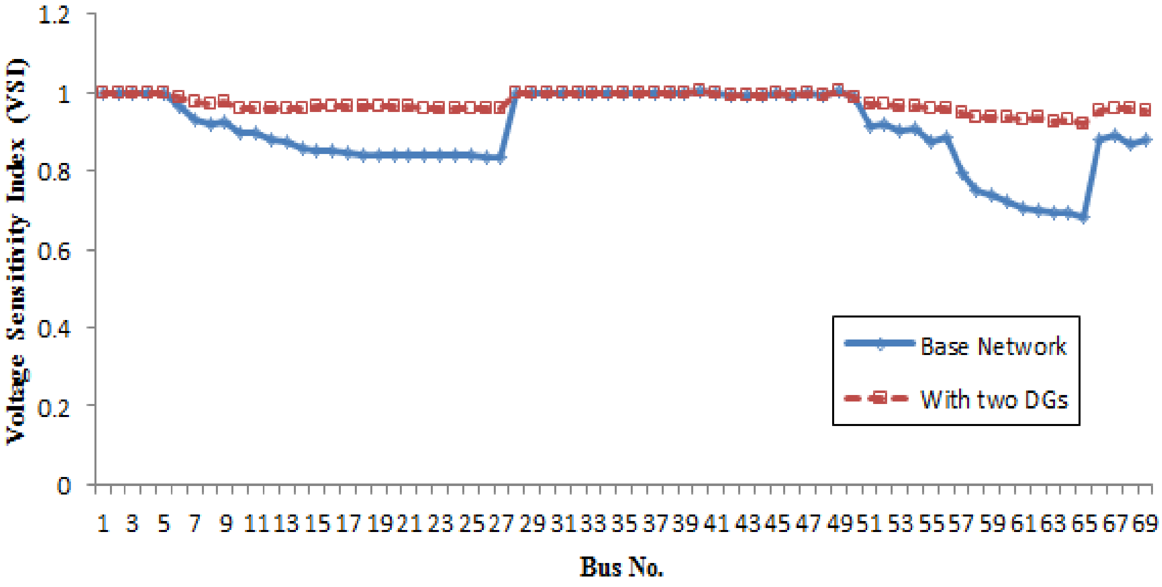

Figure 6.11: Voltage sensitivity index of IEEE 69 bus system with DGs

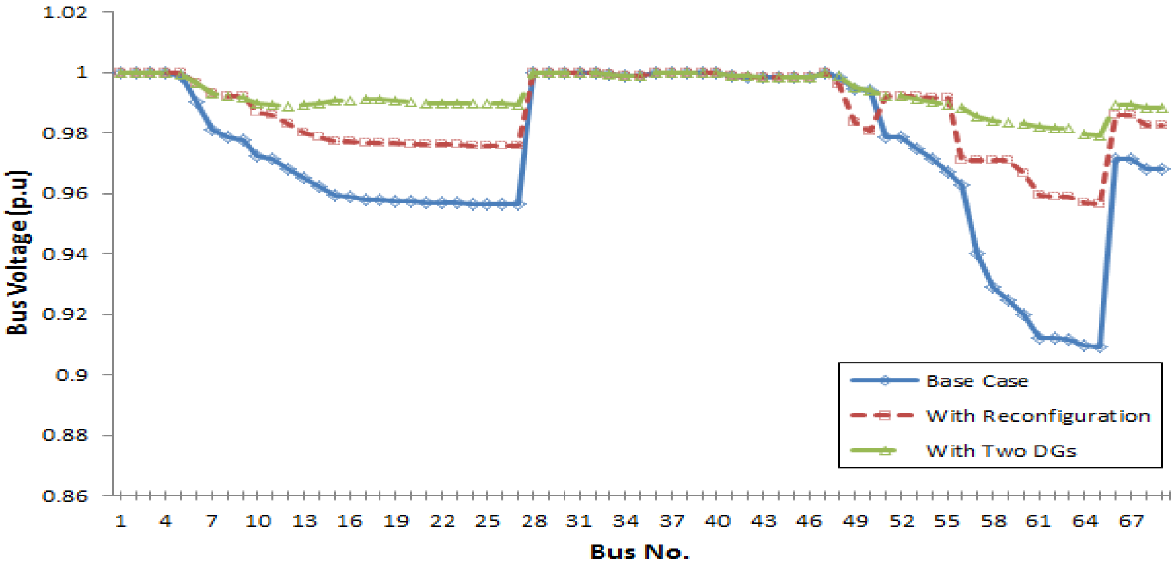

Figure 6.12: Bus voltage magnitude of IEEE 69 bus system with DGs

6.4. Contingency Analysis

In this section contingency analysis on radial distribution system is performed and the effect of network reconfiguration and distributed generation is analysed. For this analysis the cost of active power loss (C^{loss}) is taken S 5 \$/MW and cost of demand curtailment C^{d_curt} is taken as 250 \$/MW. The complete analysis has been divided in 3 different cases. The results of all the cases with discussion for both the test systems are described below.

6.4.1. IEEE 33 Bus Distribution System

Case 1: Contingency at base system

In this case contingency is applied to base network and revenue loss is calculated shown in the Table 6.13. At first, load curtailment for each contingency is calculated and the network losses and minimum bus voltage are calculated for the remaining network.

Table 6.13: Contingency analysis of base IEEE 33 bus system

Branch Cont.	Active Loss (kW)	Reactive Loss (kW)	Min. Voltage (p.u)	Min. Voltage Bus	Load Curt. (kW)	Revenue Loss $
0	210.6697	142.84	0.903841138	18	0	1.053349
1	0	0	1	1	3715	928.75
2	1.282011	1.1499	0.99423643	22	3255	813.7564
3	16.15627	11.016	0.981549284	25	2235	558.8308
4	17.59031	11.75	0.980947701	25	2115	528.838
5	18.35998	12.143	0.980665514	25	2055	513.8418

6	92.87927	61.555	0.938254552	33	1075	269.2144
7	105.6635	69.602	0.9343466	33	875	219.2783
8	120.8733	79.594	0.930386794	33	675	169.3544
9	125.6097	82.781	0.929283368	33	615	154.378
10	130.6964	86.235	0.928172678	33	555	139.4035
11	135.5394	89.54	0.927185751	33	510	128.1777
12	142.1983	94.11	0.925909906	33	450	113.211
13	149.449	99.114	0.924621879	33	390	98.24724
14	166.784	111.22	0.921898579	33	270	68.33392
15	174.3725	116.61	0.920824443	33	210	53.37186
16	183.3951	123.04	0.919632126	33	150	38.41698
17	193.2303	130.12	0.914614341	17	90	23.46615
18	207.4096	140.66	0.904126057	18	360	91.03705
19	207.9311	140.93	0.904055105	18	270	68.53966
20	208.5766	141.31	0.903984036	18	180	46.04288
21	209.4653	141.92	0.903912739	18	90	23.54733
22	171.116	120.01	0.908668634	18	930	233.3556
23	173.725	121.37	0.908195167	18	840	210.8686
24	188.5937	129.61	0.906038054	18	420	105.943
25	84.00684	59.33	0.927845205	18	920	230.42
26	87.39644	61.419	0.926712331	18	860	215.437
27	90.81998	63.53	0.92562416	18	800	200.4541
28	94.42988	65.764	0.924532213	18	740	185.4721
29	103.2743	71.317	0.922042364	18	620	155.5164
30	148.9951	101.31	0.912887281	18	420	105.745
31	167.728	113.71	0.909770902	18	270	68.33864
32	199.2793	135.02	0.905277641	18	60	15.9964

Case 2: Reconfiguration after contingency at base network

In this case network is reconfigured after the contingency and the best position of sectionalizer and tie line switches for each contingency is determined and tabulated in Table 6.14 with respective active power losses revenue losses. It is assumed that islanding operation of the network is not allowed, therefore contingency between bus 1 and 2 is not considered.

Table 6.14: Reconfiguration of IEEE 33 bus system after contingency

Con. No.	**Sectionalizer Position**					**Tie line position**					**Active Loss (kW)**	**Min. Voltage (p.u)**	**Min.Voltage Bus**	**Revenue Loss $**
2	1	0	1	1	0	1	0	1	1	0	883.1765	0.729342	25	4.42
3	1	1	1	1	1	0	0	1	0	0	201.1425	0.917144	4	1.01
4	1	1	1	1	1	0	0	1	0	0	183.56	0.925206	7	0.92
5	1	1	1	1	1	0	0	1	0	0	176.3296	0.928262	7	0.88
6	1	1	1	1	0	1	0	1	0	0	143.0037	0.938778	33	0.72
7	1	1	1	1	0	1	0	1	0	0	139.3297	0.937876	32	0.7
8	1	1	1	1	0	0	1	1	0	0	145.9624	0.935063	33	0.73
9	1	1	1	1	0	0	1	1	0	0	139.3297	0.937876	32	0.7
10	1	1	1	1	0	0	1	1	0	0	140.0572	0.937875	32	0.7
11	1	1	1	1	0	0	1	1	0	0	140.9821	0.937874	32	0.7
12	1	1	1	1	0	0	0	1	1	0	145.7943	0.937132	33	0.73
13	1	1	1	1	0	0	0	1	1	0	142.8708	0.937873	32	0.71
14	1	1	1	1	0	0	0	1	1	0	139.3297	0.937876	32	0.7
15	1	1	1	1	0	0	1	0	0	1	157.5749	0.918303	16	0.79
16	1	1	1	1	0	0	0	1	0	1	151.934	0.923327	17	0.76
17	1	1	1	1	0	0	0	1	0	1	147.3027	0.927543	18	0.74
18	1	1	0	0	0	1	1	1	0	1	259.947	0.90312	18	1.3
19	1	1	0	0	0	1	1	1	0	1	243.8665	0.906781	18	1.22
20	1	1	0	0	0	1	1	1	0	1	229.2695	0.910383	18	1.15
21	1	1	1	1	0	0	1	1	0	0	157.0458	0.933202	33	0.79
22	1	1	1	1	1	0	0	1	0	0	251.1906	0.898665	23	1.26
23	1	1	1	1	1	0	0	1	0	0	233.9222	0.904707	24	1.17
24	1	1	1	1	1	0	0	1	0	0	173.9401	0.921876	32	0.87
25	1	1	1	1	1	0	0	1	0	0	151.3171	0.936818	32	0.76
26	1	1	1	1	1	0	0	1	0	0	146.9353	0.938374	32	0.73
27	1	1	1	1	1	0	0	1	0	0	143.2059	0.93984	32	0.72
28	1	1	1	1	1	0	0	1	0	0	139.884	0.941297	32	0.7
29	1	1	1	1	0	0	0	1	0	1	257.505	0.828439	30	1.29
30	1	1	1	1	0	0	0	1	0	1	154.7863	0.906123	31	0.77
31	1	1	1	1	0	0	0	1	0	1	142.4049	0.923944	32	0.71
32	1	1	1	1	0	0	0	1	0	1	139.3297	0.937876	32	0.7

Case 3: Reconfiguration after contingency at network with Distributed Generation

In this case network having 2 DGs of size 851.58 kW and 1157.5 kW located at bus 13,and 30 respectively, is reconfigured after the contingency and the best position of sectionalizer and tie line switches for each contingency is identified and tabulated in Table 6.15 with respective active power losses revenue losses.

Table 6.15: Reconfiguration of IEEE 33 bus system after contingency

Con. No.	**Sectionalizer Position**					**Tie line Position**					**Active Loss (kW)**	**Min. Voltage (p.u)**	**Min. Voltage Bus**	**Revenue Loss $**
0	1	0	1	0	0	0	0	1	1	1	72.23261	0.972733	33	0.361163
2	1	0	1	1	0	1	0	1	1	0	361.0525	0.822178	25	1.805263
3	1	0	1	1	1	0	0	1	1	0	92.76659	0.944732	4	0.463833
4	1	0	1	1	1	0	0	1	1	0	82.17104	0.952422	7	0.410855
5	1	0	1	1	1	0	0	1	1	0	78.25271	0.955325	7	0.391264
6	1	0	1	1	0	1	0	1	1	0	74.01693	0.969738	33	0.370085
7	1	0	1	0	0	1	0	1	1	1	72.23261	0.972733	33	0.361163
8	1	0	1	1	0	0	1	1	1	0	70.93954	0.972406	33	0.354698
9	1	0	1	1	0	0	1	1	1	0	71.28806	0.973818	33	0.35644
10	1	0	1	1	0	0	1	1	1	0	72.03199	0.975213	33	0.36016
11	1	0	1	1	0	0	1	1	1	0	72.77193	0.976536	33	0.36386
12	1	1	1	1	0	0	1	0	1	0	74.26648	0.976668	32	0.371332
13	1	1	0	0	0	0	1	1	1	1	82.11912	0.970366	18	0.410596
14	1	1	0	0	0	0	1	1	1	1	77.95653	0.972729	33	0.389783
15	0	1	1	1	0	0	0	1	1	1	79.58852	0.958475	16	0.397943
16	0	1	1	1	0	0	0	1	1	1	77.15863	0.963154	17	0.385793
17	1	0	1	1	0	0	0	1	1	1	74.96912	0.967067	18	0.374846
18	1	0	0	0	0	1	1	1	1	1	107.2543	0.951292	19	0.536271
19	1	0	0	0	0	1	1	1	1	1	100.4221	0.957629	22	0.50211
20	1	0	0	0	0	1	1	1	1	1	94.78361	0.962218	18	0.473918
21	1	0	1	0	0	0	1	1	1	1	74.07745	0.972732	33	0.370387
22	1	0	1	1	1	0	0	1	1	0	110.8856	0.936983	23	0.554428
23	1	0	1	1	1	0	0	1	1	0	101.7305	0.942577	24	0.508652
24	1	0	1	1	1	0	0	1	1	0	75.92662	0.962049	32	0.379633
25	1	0	1	1	1	0	0	1	1	0	66.85444	0.967174	32	0.334272
26	1	0	1	1	1	0	0	1	1	0	65.45699	0.968624	32	0.327285
27	1	0	1	1	1	0	0	1	1	0	64.64673	0.969988	32	0.323234
28	1	0	1	1	1	0	0	1	1	0	64.20358	0.971345	32	0.321018

29	1	1	1	1	0	0	0	1	0	1	138.5095	0.942431	32	0.692547
30	0	0	1	1	0	1	1	0	1	1	88.99555	0.941296	31	0.444978
31	1	0	1	1	0	0	0	1	1	1	78.09962	0.950887	32	0.390498
32	1	0	1	1	0	0	0	1	1	1	71.28806	0.973818	33	0.35644

Discussion

On comparing the outcomes of case 1, 2 and 3 following points can be concluded:

1. The load curtailment of the network has been eliminated using reconfiguration. This reduces the system revenue loss and improves system reliability under the event of contingency.
2. Distributed generation has improved the system voltage from loose lower limit (0.9 pu) to above Strict lower limit (0.95 pu) of voltage in most of the contingencies. From the results, it also can be concluded that the line outage near to main feeder (i.e. 2) may violate system voltage limit even after using network reconfiguration and DGs.
3. Reconfiguration has reduced the active power losses but reconfiguration with DGs has reduced active power losses relatively more.

Table 6.16: Contingency analysis of base IEEE 33 bus system

	Case 1	**Case 2**			**Case 3**		
Con. NO.	**Revenue Loss$**	**Active Loss (kW)**	**Min. Voltage V/g**	**Revenue Loss$**	**Active Loss (kW)**	**Min. Voltage V/g**	**Revenue Loss $**
0	1.053349	139.3297	0.937876	0.69	72.23261	0.972733	0.361163
1	928.75	−−	−−	−−	−−	−−	−−
2	813.7564	883.1765	0.729342	4.42	361.0525	0.822178	1.805263
3	558.8308	201.1425	0.917144	1.01	92.76659	0.944732	0.463833
4	528.838	183.56	0.925206	0.92	82.17104	0.952422	0.410855
5	513.8418	176.3296	0.928262	0.88	78.25271	0.955325	0.391264
6	269.2144	143.0037	0.938778	0.72	74.01693	0.969738	0.370085
7	219.2783	139.3297	0.937876	0.7	72.23261	0.972733	0.361163
8	169.3544	145.9624	0.935063	0.73	70.93954	0.972406	0.354698
9	154.378	139.3297	0.937876	0.7	71.28806	0.973818	0.35644
10	139.4035	140.0572	0.937875	0.7	72.03199	0.975213	0.36016
11	128.1777	140.9821	0.937874	0.7	72.77193	0.976536	0.36386
12	113.211	145.7943	0.937132	0.73	74.26648	0.976668	0.371332
13	98.24724	142.8708	0.937873	0.71	82.11912	0.970366	0.410596
14	68.33392	139.3297	0.937876	0.7	77.95653	0.972729	0.389783
15	53.37186	157.5749	0.918303	0.79	79.58852	0.958475	0.397943
16	38.41698	151.934	0.923327	0.76	77.15863	0.963154	0.385793
17	23.46615	147.3027	0.927543	0.74	74.96912	0.967067	0.374846
18	91.03705	259.947	0.90312	1.3	107.2543	0.951292	0.536271

19	68.53966	243.8665	0.906781	1.22	100.4221	0.957629	0.50211
20	46.04288	229.2695	0.910383	1.15	94.78361	0.962218	0.473918
21	23.54733	157.0458	0.933202	0.79	74.07745	0.972732	0.370387
22	233.3556	251.1906	0.898665	1.26	110.8856	0.936983	0.554428
23	210.8686	233.9222	0.904707	1.17	101.7305	0.942577	0.508652
24	105.943	173.9401	0.921876	0.87	75.92662	0.962049	0.379633
25	230.42	151.3171	0.936818	0.76	66.85444	0.967174	0.334272
26	215.437	146.9353	0.938374	0.73	65.45699	0.968624	0.327285
27	200.4541	143.2059	0.93984	0.72	64.64673	0.969988	0.323234
28	185.4721	139.884	0.941297	0.7	64.20358	0.971345	0.321018
29	155.5164	257.505	0.828439	1.29	138.5095	0.942431	0.692547
30	105.745	154.7863	0.906123	0.77	88.99555	0.941296	0.444978
31	68.33864	142.4049	0.923944	0.71	78.09962	0.950887	0.390498
32	15.9964	139.3297	0.937876	0.7	71.28806	0.973818	0.35644

6.4.2. IEEE 69 Bus Distribution System

Case 1: Contingency at base case

In this case contingency is applied to base network and revenue loss is calculated shown in the Table 6.17. At first load curtailment for each contingency is calculated and the network losses and minimum bus voltage are calculated for the remaining network.

Table 6.17: Contingency analysis of base IEEE 69 Bus system

Branch Cont.	**Active Loss (kw)**	**Reactive Loss (kVAr)**	**Min.Voltage (p.u)**	**Min. Voltage Bus**	**Load Curt. (kW)**	**Revenue Loss $**
0	224.9804	102.156	0.909187	65	0	1.124902
1	0	0	1	1	3801.85	950.4625
2	0	0	1	1	3801.85	950.4625
3	0.155841	0.178954	0.998468	46	3524.75	881.1883
4	2.532321	5.993855	0.994274	50	2676.35	669.1002
5	2.532321	5.993855	0.994274	50	2676.35	669.1002
6	2.532475	5.994173	0.994274	50	2673.75	668.4502
7	2.547429	6.0057	0.994272	50	2633.35	658.3502
8	2.744475	6.121284	0.994267	50	2514.25	628.5762
9	176.4235	79.06273	0.91604	65	767.5	192.7571
10	177.5181	79.63671	0.915796	65	739.5	185.7626
11	185.4714	83.73877	0.91419	65	558.5	140.5524
12	196.1675	89.06854	0.912392	65	357.5	90.35584
13	196.6334	89.29651	0.912321	65	349.5	88.35817
14	197.1048	89.52659	0.91225	65	341.5	86.36052

15	197.1048	89.52659	0.91225	65	341.5	86.36052
16	199.8923	90.87034	0.911849	65	296	74.99946
17	203.8123	92.71694	0.911333	65	236	60.01906
18	208.1728	94.72523	0.910814	65	176	45.04086
19	208.1728	94.72523	0.910814	65	176	45.04086
20	208.2499	94.76037	0.910805	65	175	44.79125
21	218.5526	99.36151	0.909756	65	61	16.34276
22	219.0507	99.57995	0.90971	65	56	15.09525
23	219.0507	99.57995	0.90971	65	56	15.09525
24	221.9401	100.8408	0.909449	65	28	8.1097
25	221.9401	100.8408	0.909449	65	28	8.1097
26	223.4399	101.4911	0.909318	65	14	4.6172
27	224.9347	102.1205	0.909189	65	91.5	23.99967
28	224.9368	102.1252	0.909189	65	65.5	17.49968
29	224.9395	102.1312	0.909188	65	39.5	10.9997
30	224.9395	102.1312	0.909188	65	39.5	10.9997
31	224.9395	102.1312	0.909188	65	39.5	10.9997
32	224.9395	102.1312	0.909188	65	39.5	10.9997
33	224.9444	102.1363	0.909188	65	25.5	7.499722
34	224.968	102.1499	0.909187	65	6	2.62484
35	224.8482	101.9644	0.909191	65	185.6	47.52424
36	224.8503	101.9691	0.90919	65	159.6	41.02425
37	224.8529	101.9749	0.90919	65	133.6	34.52426
38	224.8529	101.9749	0.90919	65	133.6	34.52426
39	224.8568	101.983	0.909189	65	109.6	28.52428
40	224.863	101.9947	0.909189	65	85.6	22.52431
41	224.8634	101.9955	0.909189	65	84.4	22.22432
42	224.8634	101.9955	0.909189	65	84.4	22.22432
43	224.8658	101.9995	0.909189	65	78.4	20.72433
44	224.8658	101.9995	0.909189	65	78.4	20.72433
45	224.9035	102.0534	0.909188	65	39.2	10.92452
46	222.4693	96.05568	0.909227	65	848.4	213.2123
47	222.4693	96.05568	0.909227	65	848.4	213.2123
48	222.4875	96.09608	0.909224	65	769.4	193.4624
49	223.136	97.66301	0.909206	65	384.7	97.29068
50	222.7264	100.9668	0.909559	65	44.1	12.13863
51	224.7909	102.056	0.909218	65	3.6	2.023954
52	22.65995	14.33462	0.971633	27	1716.75	429.3008
53	22.73712	14.37596	0.971597	27	1712.4	428.2137
54	23.19805	14.62275	0.97138	27	1686	421.616
55	23.63353	14.85573	0.971183	27	1662	415.6182
56	23.63353	14.85573	0.971183	27	1662	415.6182
57	23.63353	14.85573	0.971183	27	1662	415.6182

58	23.63353	14.85573	0.971183	27	1662	415.6182
59	25.9371	16.03316	0.970358	27	1562	390.6297
60	25.9371	16.03316	0.970358	27	1562	390.6297
61	154.9379	72.30072	0.928884	61	318	80.27469
62	161.1259	74.93913	0.927222	62	286	72.30563
63	161.1259	74.93913	0.927222	62	286	72.30563
64	210.4425	95.95739	0.913424	64	59	15.80221
65	222.4491	100.9309	0.909515	65	36	10.11225
66	223.7071	101.5402	0.909351	65	18	5.618535
67	220.6121	100.1086	0.909698	65	56	15.10306
68	222.7669	101.1208	0.909443	65	28	8.113835

Case 2: Reconfiguration after contingency at base network
In the case network is reconfigured after the contingency and the best position of sectionalizer and tie line switches for each contingency is determined and tabulated in Table 6.18 with respective active power losses revenue losses. It is assumed that islanding operation of the network is not allowed. Therefore Cont. No. 1, 2, 27, 28, 29, 30, 31, 32, 33, 34, 50, 51, 65, 66, 67 and 68 are not considered.

Table 6.18: Reconfiguration of IEEE 69 Bus system after contingency

Cont. No.	**Sectionalizer Position**					**Tie line Position**					**Active Loss (kW)**	**Min. Voltage (p.u)**	**Revenue Loss $**
3	0	0	1	1	1	0	0	1	1	1	1021.071	0.679552	5.105357
4	1	1	0	0	1	1	0	1	1	0	106.4661	0.949528	0.53233
5	1	1	0	0	1	1	0	1	1	0	106.4661	0.949528	0.53233
6	1	1	0	0	1	1	0	1	1	0	106.2468	0.949641	0.531234
7	1	1	0	0	1	1	0	1	1	0	103.1046	0.951294	0.515523
8	1	1	0	0	1	1	0	1	1	0	95.09452	0.956042	0.475473
9	1	1	0	0	1	1	0	1	1	0	90.36601	0.956304	0.45183
10	1	1	0	0	1	1	0	1	1	0	89.01602	0.956303	0.44508
11	0	0	1	0	1	1	1	1	1	0	80.0855	0.956298	0.400428
12	0	0	1	0	1	1	1	1	1	0	75.40399	0.956293	0.37702
13	0	0	1	0	1	1	1	1	1	0	75.37521	0.956293	0.376876
14	0	0	1	0	1	1	1	1	1	0	75.35793	0.956292	0.37679
15	0	1	0	0	1	1	1	1	1	0	84.49396	0.956283	0.42247
16	0	1	0	0	1	1	1	1	1	0	83.84547	0.956283	0.419227
17	0	1	0	0	1	1	1	1	1	0	83.35287	0.956283	0.416764
18	0	1	0	0	1	1	1	1	1	0	83.23261	0.956283	0.416163
19	0	1	0	0	1	1	1	1	1	0	83.23261	0.956283	0.416163

20	0	1	0	0	1	1	1	1	1	0	83.23376	0.956283	0.416169
21	0	1	0	1	1	1	0	1	1	0	85.00017	0.953112	0.425001
22	0	1	0	1	1	1	0	1	1	0	84.82007	0.953411	0.4241
23	0	1	0	1	1	1	0	1	1	0	84.82007	0.953411	0.4241
24	0	1	0	1	1	1	0	1	1	0	83.9245	0.954979	0.419622
25	0	1	0	1	1	1	0	1	1	0	83.9245	0.954979	0.419622
26	0	1	0	1	1	1	0	1	1	0	83.55315	0.955641	0.417766
35	1	1	0	0	1	1	0	1	1	0	90.69403	0.956278	0.45347
36	1	1	0	0	1	1	0	1	1	0	89.41838	0.956279	0.447092
37	1	1	0	0	1	1	0	1	1	0	88.21699	0.95628	0.441085
38	1	1	0	0	1	1	0	1	1	0	88.21699	0.95628	0.441085
39	1	1	0	0	1	1	0	1	1	0	87.17565	0.95628	0.435878
40	1	1	0	0	1	1	0	1	1	0	86.19611	0.956281	0.430981
41	1	1	0	0	1	1	0	1	1	0	86.14602	0.956281	0.43073
42	1	1	0	0	1	1	0	1	1	0	86.14602	0.956281	0.43073
43	0	1	1	0	1	1	0	1	1	0	87.86812	0.956281	0.439341
44	0	1	1	0	1	1	0	1	1	0	87.86812	0.956281	0.439341
45	0	1	1	0	1	1	0	1	1	0	85.40728	0.956282	0.427036
46	0	0	1	1	1	1	1	1	0	0	194.6912	0.871471	0.973456
47	0	0	1	1	1	1	1	1	0	0	194.6912	0.871471	0.973456
48	0	1	0	0	1	1	0	1	1	1	428.6476	0.873887	2.143238
49	0	1	0	0	1	1	0	1	1	1	312.1355	0.891986	1.560678
52	0	1	0	0	1	1	0	1	1	1	84.63	0.955491	0.42315
53	0	1	0	0	1	1	0	1	1	1	84.50147	0.955558	0.422507
54	0	1	0	0	1	1	0	1	1	1	83.80001	0.955939	0.419
55	0	1	0	0	1	1	0	1	1	1	83.23261	0.956283	0.416163
56	0	1	0	0	1	1	0	1	1	1	83.23261	0.956283	0.416163
57	0	1	0	0	1	1	0	1	1	1	83.23261	0.956283	0.416163
58	0	1	0	0	1	1	0	1	1	1	83.23261	0.956283	0.416163
59	0	1	0	1	1	1	0	1	1	0	466.4002	0.811713	2.332001
60	0	1	0	1	1	1	0	1	1	0	466.4002	0.811713	2.332001
61	0	1	0	1	1	1	0	1	1	0	89.99736	0.949465	0.449987
62	0	1	0	1	1	1	0	1	1	0	88.05374	0.952446	0.440269
63	0	1	0	1	1	1	0	1	1	0	88.05374	0.952446	0.440269
64	0	1	0	1	1	1	0	1	1	0	82.44196	0.958649	0.41221

Case 3: Reconfiguration after contingency at network with DG

In this case network having 2 DGs of size 531.18 kW and 1781.5 kW located at bus 17,and 61 respectively is reconfigured after the contingency and the best position of sectionalizer and tie line switches for each contingency is determined and tabulated in table 6.19 with respective active power losses revenue losses.

Table 6.19: Reconfiguration of IEEE 69 Bus system with DG after contingency

Con. No.	**Sectionalizer Position**					**Tie line Position**					**Active Loss (kW)**	**Min.Voltage (p.u)**	**Min. Voltage Bus**	**Revenue Loss $**
0	0	0	0	0	1	1	1	1	1	0	32.27022	0.978133	65	0.161351
3	1	0	0	0	1	1	1	1	1	0	318.4334	0.856342	65	1.592167
4	1	0	0	0	1	1	1	1	1	0	44.37719	0.96964	55	0.221886
5	1	0	0	0	1	1	1	1	1	0	44.37719	0.96964	55	0.221886
6	1	0	0	0	1	1	1	1	1	0	44.22852	0.969771	55	0.221143
7	1	0	0	0	1	1	1	1	1	0	42.16771	0.97169	55	0.210839
8	1	0	0	0	1	1	1	1	1	0	37.26781	0.977127	69	0.186339
9	1	0	0	0	1	1	1	1	1	0	34.69283	0.978147	65	0.173464
10	1	0	0	0	1	1	1	1	1	0	34.04178	0.978146	65	0.170209
11	0	0	1	0	1	1	1	1	1	0	30.75377	0.978142	65	0.153769
12	0	0	1	0	1	1	1	1	1	0	30.97481	0.978136	65	0.154874
13	0	0	1	0	1	1	1	1	1	0	31.13399	0.978136	65	0.15567
14	0	0	1	0	1	1	1	1	1	0	31.30424	0.978136	65	0.156521
15	0	1	0	0	1	1	1	1	1	0	32.46133	0.978133	65	0.162307
16	0	1	0	0	1	1	1	1	1	0	32.75759	0.978133	65	0.163788
17	0	1	0	0	1	1	1	1	1	0	34.8015	0.978133	65	0.174007
18	0	1	0	0	1	1	1	1	1	0	33.60546	0.978133	65	0.168027
19	0	1	0	0	1	1	1	1	1	0	33.60546	0.978133	65	0.168027
20	0	1	0	0	1	1	1	1	1	0	33.58845	0.978133	65	0.167942
21	0	0	0	1	1	1	1	1	1	0	33.04504	0.97507	22	0.165225
22	0	0	0	1	1	1	1	1	1	0	32.9451	0.975359	23	0.164726
23	0	0	0	1	1	1	1	1	1	0	32.9451	0.975359	24	0.164726
24	0	0	0	1	1	1	1	1	1	0	32.50362	0.976875	25	0.162518
25	0	0	0	1	1	1	1	1	1	0	32.50362	0.976875	26	0.162518
26	0	0	0	1	1	1	1	1	1	0	32.36091	0.977514	27	0.161805
35	1	0	0	0	1	1	1	1	1	0	37.13387	0.978128	65	0.185669
36	1	0	0	0	1	1	1	1	1	0	36.22865	0.978128	65	0.181143
37	1	0	0	0	1	1	1	1	1	0	35.39542	0.978129	65	0.176977
38	1	0	0	0	1	1	1	1	1	0	35.39542	0.978129	65	0.176977
39	1	0	0	0	1	1	1	1	1	0	34.69191	0.97813	65	0.17346
40	1	0	0	0	1	1	1	1	1	0	34.04839	0.97813	65	0.170242
41	1	0	0	0	1	1	1	1	1	0	34.01511	0.97813	65	0.170076
42	1	0	0	0	1	1	1	1	1	0	34.01511	0.97813	65	0.170076
43	0	0	1	0	1	1	1	1	1	0	34.21375	0.978131	65	0.171069

44	0	0	1	0	1	1	1	1	1	0	34.21375	0.978131	65	0.171069
45	0	0	1	0	1	1	1	1	1	0	33.10855	0.978132	65	0.165543
46	0	0	0	0	1	1	1	1	1	1	162.1318	0.943735	47	0.810659
47	0	0	0	0	1	1	1	1	1	1	162.1318	0.943735	48	0.810659
48	0	0	0	0	1	1	1	1	1	1	149.5842	0.947999	49	0.747921
49	0	0	0	0	1	1	1	1	1	1	101.0669	0.963956	65	0.505334
52	0	0	0	0	1	1	1	1	1	1	32.67576	0.977374	65	0.163379
53	0	0	0	0	1	1	1	1	1	1	32.62709	0.977438	65	0.163135
54	0	0	0	0	1	1	1	1	1	1	32.4051	0.977803	65	0.162025
55	0	0	0	0	1	1	1	1	1	1	32.27022	0.978133	65	0.161351
56	0	0	0	0	1	1	1	1	1	1	32.27022	0.978133	65	0.161351
57	0	0	0	0	1	1	1	1	1	1	32.27022	0.978133	65	0.161351
58	0	0	0	0	1	1	1	1	1	1	32.27022	0.978133	65	0.161351
59	0	1	0	1	1	1	0	1	1	0	126.4643	0.961644	64	0.632321
60	0	1	0	1	1	1	0	1	1	0	126.4643	0.961644	64	0.632321
61	0	0	0	1	1	1	1	1	1	0	44.70919	0.965121	62	0.223546
62	0	0	0	1	1	1	1	1	1	0	42.14555	0.968245	63	0.210728
63	0	0	0	1	1	1	1	1	1	0	42.14555	0.968245	64	0.210728
64	0	0	0	1	1	1	1	1	1	0	32.46195	0.980409	64	0.16231

Discussion

On comparing the outcomes of case 1, 2 and 3 following points can be concluded:

1. The load curtailment of the network has been eliminated using reconfiguration. This reduces the system revenue loss and improves system reliability under the event of contingency.
2. Distributed generation has improved the system voltage from loose lower limit (0.9 pu) to above strict lower limit (0.95 pu) of voltage in most of the contingencies. From the results it also can be concluded that the line outage near to main feeder (i.e. 2) may violate system voltage limit even after using network reconfiguration and DGs.
3. Reconfiguration has reduced the active power losses but reconfiguration with DGs has reduced active power losses relatively more.

Table 6.20: Contingency analysis of base IEEE 69 bus system

	Case 1	**Case 2**			**Case 3**		
Con. NO.	**Revenue Loss $**	**Active Loss (kW)**	**Min. Voltage (p.u)**	**Revenue Loss $**	**Active Loss (kW)**	**Min. Voltage (p.u)**	**Revenue Loss $**
0	1.124902	83.23261	0.956283	0.416	32.27022	0.978133	0.161351
1	950.4625	−−	−−	−−	−−	−−	−−
2	950.4625	−−	−−	−−	−−	−−	−−
3	881.1883	1021.071	0.679552	5.105357	318.4334	0.856342	1.592167
4	669.1002	106.4661	0.949528	0.53233	44.37719	0.96964	0.221886
5	669.1002	106.4661	0.949528	0.53233	44.37719	0.96964	0.221886
6	668.4502	106.2468	0.949641	0.531234	44.22852	0.969771	0.221143
7	658.3502	103.1046	0.951294	0.515523	42.16771	0.97169	0.210839
8	628.5762	95.09452	0.956042	0.475473	37.26781	0.977127	0.186339
9	192.7571	90.36601	0.956304	0.45183	34.69283	0.978147	0.173464
10	185.7626	89.01602	0.956303	0.44508	34.04178	0.978146	0.170209
11	140.5524	80.0855	0.956298	0.400428	30.75377	0.978142	0.153769
12	90.35584	75.40399	0.956293	0.37702	30.97481	0.978136	0.154874
13	88.35817	75.37521	0.956293	0.376876	31.13399	0.978136	0.15567
14	86.36052	75.35793	0.956292	0.37679	31.30424	0.978136	0.156521
15	86.36052	84.49396	0.956283	0.42247	32.46133	0.978133	0.162307
16	74.99946	83.84547	0.956283	0.419227	32.75759	0.978133	0.163788
17	60.01906	83.35287	0.956283	0.416764	34.8015	0.978133	0.174007
18	45.04086	83.23261	0.956283	0.416163	33.60546	0.978133	0.168027
19	45.04086	83.23261	0.956283	0.416163	33.60546	0.978133	0.168027
20	44.79125	83.23376	0.956283	0.416169	33.58845	0.978133	0.167942
21	16.34276	85.00017	0.953112	0.425001	33.04504	0.97507	0.165225
22	15.09525	84.82007	0.953411	0.4241	32.9451	0.975359	0.164726
23	15.09525	84.82007	0.953411	0.4241	32.9451	0.975359	0.164726
24	8.1097	83.9245	0.954979	0.419622	32.50362	0.976875	0.162518
25	8.1097	83.9245	0.954979	0.419622	32.50362	0.976875	0.162518
26	4.6172	83.55315	0.955641	0.417766	32.36091	0.977514	0.161805
27	23.99967	−−	−−	−−	−−	−−	−−
28	17.49968	−−	−−	−−	−−	−−	−−
29	10.9997	−−	−−	−−	−−	−−	−−
30	10.9997	−−	−−	−−	−−	−−	−−
31	10.9997	−−	−−	−−	−−	−−	−−
32	10.9997	−−	−−	−−	−−	−−	−−
33	7.499722	−−	−−	−−	−−	−−	−−
34	2.62484	−−	−−	−−	−−	−−	−−
35	47.52424	90.69403	0.956278	0.45347	37.13387	0.978128	0.185669
36	41.02425	89.41838	0.956279	0.447092	36.22865	0.978128	0.181143
37	34.52426	88.21699	0.95628	0.441085	35.39542	0.978129	0.176977
38	34.52426	88.21699	0.95628	0.441085	35.39542	0.978129	0.176977

39	28.52428	87.17565	0.95628	0.435878	34.69191	0.97813	0.17346
40	22.52431	86.19611	0.956281	0.430981	34.04839	0.97813	0.170242
41	22.22432	86.14602	0.956281	0.43073	34.01511	0.97813	0.170076
42	22.22432	86.14602	0.956281	0.43073	34.01511	0.97813	0.170076
43	20.72433	87.86812	0.956281	0.439341	34.21375	0.978131	0.171069
44	20.72433	87.86812	0.956281	0.439341	34.21375	0.978131	0.171069
45	10.92452	85.40728	0.956282	0.427036	33.10855	0.978132	0.165543
46	213.2123	194.6912	0.871471	0.973456	162.1318	0.943735	0.810659
47	213.2123	194.6912	0.871471	0.973456	162.1318	0.943735	0.810659
48	193.4624	428.6476	0.873887	2.143238	149.5842	0.947999	0.747921
48	193.4624	428.6476	0.873887	2.143238	149.5842	0.947999	0.747921
49	97.29068	312.1355	0.891986	1.560678	101.0669	0.963956	0.505334
50	12.13863	−−	−−	−−	−−	−−	−−
51	2.023954	−−	−−	−−	−−−−	−−	−−
52	429.3008	84.63	0.955491	0.42315	32.67576	0.977374	0.163379
53	428.2137	84.50147	0.955558	0.422507	32.62709	0.977438	0.163135
54	421.616	83.80001	0.955939	0.419	32.4051	0.977803	0.162025
55	415.6182	83.23261	0.956283	0.416163	32.27022	0.978133	0.161351
56	415.6182	83.23261	0.956283	0.416163	32.27022	0.978133	0.161351
57	415.6182	83.23261	0.956283	0.416163	32.27022	0.978133	0.161351
58	415.6182	83.23261	0.956283	0.416163	32.27022	0.978133	0.161351
59	390.6297	466.4002	0.811713	2.332001	126.4643	0.961644	0.632321
60	390.6297	466.4002	0.811713	2.332001	126.4643	0.961644	0.632321
61	80.27469	89.99736	0.949465	0.449987	44.70919	0.965121	0.223546
62	72.30563	88.05374	0.952446	0.440269	42.14555	0.968245	0.210728
63	72.30563	88.05374	0.952446	0.440269	42.14555	0.968245	0.210728
64	15.80221	82.44196	0.958649	0.41221	32.46195	0.980409	0.16231
65	10.11225	−−	−−	−−	−−	−−	−−
66	5.618535	−−	−−	−−	−−	−−	−−
67	15.10306	−−	−−	−−	−−	−−	−−
68	8.113835	−−	−−	−−	−−	−−	−−

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

7.1. Conclusion

In this work, effect of (N-1) contingency condition on IEEE 33 and 69 bus distribution system considering network reconfiguration and distributed generation has been investigated. An exhaustive analysis along with evaluation of distribution system has been made for minimization of loss of revenue due to certain contingencies. The work depicts the advantages of reconfiguration and distributed generation resulting in improvement of the system voltage stability of the under contingency condition and reduction in system power losses and load curtailment. The optimal location and size of DGs are obtained using genetic algorithm. The proposed work can be a valuable tool to optimally reconfigure the system by evaluating all possible contingencies of the network in presence of DG.

7.2. Future Scope

The following areas are identified for future work:

- Utilize meta heuristic approach for network reconfiguration of a distribution system with large number of switches so that it can be incorporated in contingency analysis.
- Contingency analysis of distribution with different load models.
- Contingency analysis of distribution with different generation models.
- Contingency analysis of distribution system with the possibility of islanded operation.

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APPENDIX

A.1. Line and Bus Data of IEEE 33 Bus System

Table 7.1: IEEE 33 Bus system Line Data

Branch No.	**Sending End Bus**	**Receiving End Bus**	**Branch Resistance (Ω)**	**Branch Reactance (Ω)**
1	1	2	0.0922	0.047
2	2	3	0.493	0.2511
3	3	4	0.366	0.1864
4	4	5	0.3811	0.1941
5	5	6	0.819	0.707
6	6	7	0.1872	0.6188
7	7	8	1.7114	1.2351
8	8	9	1.03	0.74
9	9	10	1.04	0.74
10	10	11	0.1966	0.065
11	11	12	0.3744	0.1238
12	12	13	1.468	1.155
13	13	14	0.5416	0.7129
14	14	15	0.591	0.526
15	15	16	0.7463	0.545
16	16	17	1.289	1.721
17	17	18	0.732	0.574
18	2	19	0.164	0.1565
19	19	20	1.5042	1.3554
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3083
23	23	24	0.898	0.7091
24	24	25	0.896	0.7011
25	6	26	0.203	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.059	0.9337
28	28	29	0.8042	0.7006
29	29	30	0.5075	0.2585
30	30	31	0.9744	0.963
31	31	32	0.3105	0.3619
32	32	33	0.341	0.5302

Table 7.2: IEEE 33 Bus system Bus Data

Bus Number	Bus Type	Specified Voltage (p.u)	Specified Angle (p.u)	Active Power Load (KW)	Reactive Power Load (KVAr)
1	Slack	1	0	0	0
2	PQ	1	0	100	60
3	PQ	1	0	90	40
4	PQ	1	0	120	80
5	PQ	1	0	60	30
6	PQ	1	0	60	20
7	PQ	1	0	200	100
8	PQ	1	0	200	100
9	PQ	1	0	60	20
10	PQ	1	0	60	20
11	PQ	1	0	45	30
12	PQ	1	0	60	35
13	PQ	1	0	60	35
14	PQ	1	0	120	80
15	PQ	1	0	60	10
16	PQ	1	0	60	20
17	PQ	1	0	60	20
18	PQ	1	0	90	40
19	PQ	1	0	90	40
20	PQ	1	0	90	40
21	PQ	1	0	90	40
22	PQ	1	0	90	40
23	PQ	1	0	90	50
24	PQ	1	0	420	200
25	PQ	1	0	420	200
26	PQ	1	0	60	25
27	PQ	1	0	60	20
28	PQ	1	0	60	20
29	PQ	1	0	120	70
30	PQ	1	0	200	600
31	PQ	1	0	150	70
32	PQ	1	0	210	100
33	PQ	1	0	60	40

A.2. Line and Bus Data of IEEE 69 Bus System

Table 7.3: IEEE 69 Bus system Line Data

Branch No.	**Sending End Bus**	**Receiving End Bus**	**Branch Resistance** (Ω)	**Branch Reactance** (Ω)
1	1	2	0.0005	0.0012
2	2	3	0.0005	0.0012
3	3	4	0.0015	0.0036
4	4	5	0.0251	0.0294
5	5	6	0.366	0.1864
6	6	7	0.3811	0.1941
7	7	8	0.0922	0.047
8	8	9	0.0493	0.0251
9	9	10	0.819	0.2707
10	10	11	0.1872	0.0619
11	11	12	0.7114	0.2351
12	12	13	1.03	0.34
13	13	14	1.044	0.345
14	14	15	1.058	0.3496
15	15	16	0.1966	0.065
16	16	17	0.3744	0.1238
17	17	18	0.0047	0.0016
18	18	19	0.3276	0.1083
19	19	20	0.2106	0.069
20	20	21	0.3416	0.1129
21	21	22	0.014	0.0046
22	22	23	0.1591	0.0526
23	23	24	0.3463	0.1145
24	24	25	0.7488	0.2475
25	25	26	0.3089	0.1021
26	26	27	0.1732	0.0572
27	3	28	0.0044	0.0108
28	28	29	0.064	0.1565
29	29	30	0.3978	0.1315
30	30	31	0.0702	0.0232
31	31	32	0.351	0.116
32	32	33	0.839	0.2816
33	33	34	1.708	0.5646
34	34	35	1.474	0.4873
35	3	36	0.0044	0.0108
36	36	37	0.064	0.1565
37	37	38	0.1053	0.123
38	38	39	0.0304	0.0355

39	39	40	0.0018	0.0021
40	40	41	0.7283	0.8509
41	41	42	0.31	0.3623
42	42	43	0.041	0.0478
43	43	44	0.0092	0.0116
44	44	45	0.1089	0.1373
45	45	46	0.0009	0.0012
46	4	47	0.0034	0.0084
47	47	48	0.0851	0.2083
48	48	49	0.2898	0.7091
49	49	50	0.0822	0.2011
50	8	51	0.0928	0.0473
51	51	52	0.3319	0.1114
52	9	53	0.174	0.0886
53	53	54	0.203	0.1034
54	54	55	0.2842	0.1447
55	55	56	0.2813	0.1433
56	56	57	1.59	0.5337
57	57	58	0.7837	0.263
58	58	59	0.3042	0.1006
59	59	60	0.3861	0.1172
60	60	61	0.5075	0.2585
61	61	62	0.0974	0.0496
62	62	63	0.145	0.0738
63	63	64	0.7105	0.3619
64	64	65	1.041	0.5302
65	11	66	0.2012	0.0611
66	66	67	0.0047	0.0014
67	12	68	0.7394	0.2444
68	68	69	0.0047	0.0016

Table 7.4: IEEE 69 Bus system Bus Data

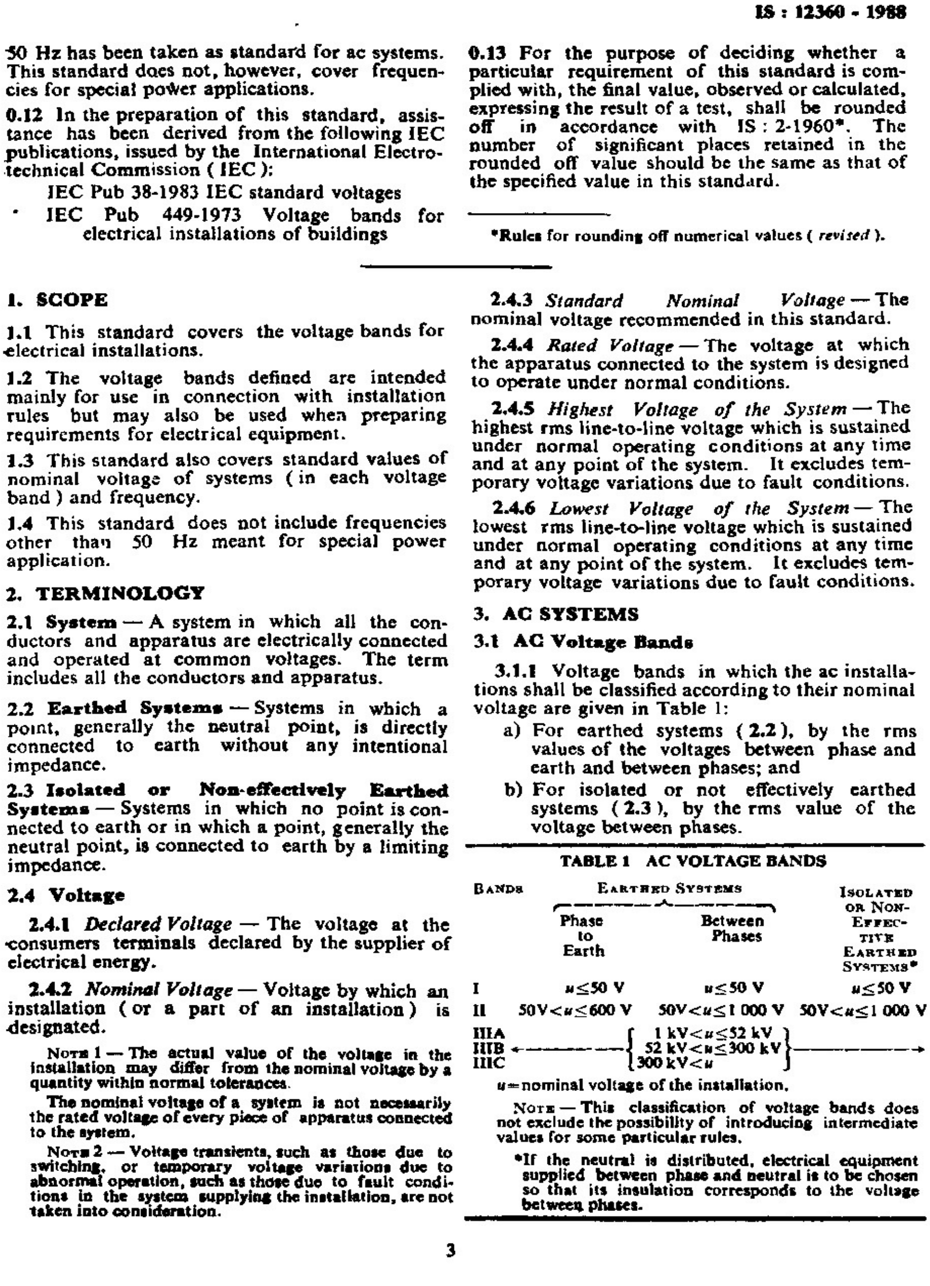
Bus Number	**Bus Type**	**Specified Voltage (p.u)**	**Specified Angle (p.u)**	**Active Power Load (KW)**	**Reactive Power Load (KVAr)**
1	Slack	1	0	0	0
2	PQ	1	0	0	0
3	PQ	1	0	0	0
4	PQ	1	0	0	0
5	PQ	1	0	0	0
6	PQ	1	0	2.6	2.2

7	PQ	1	0	40.4	30
8	PQ	1	0	75	54
9	PQ	1	0	30	22
10	PQ	1	0	28	19
11	PQ	1	0	145	104
12	PQ	1	0	145	104
13	PQ	1	0	8	5.5
14	PQ	1	0	8	5.5
15	PQ	1	0	0	0
16	PQ	1	0	45.5	30
17	PQ	1	0	60	35
18	PQ	1	0	60	35
19	PQ	1	0	0	0
20	PQ	1	0	1	0.6
21	PQ	1	0	114	81
22	PQ	1	0	5	3.5
23	PQ	1	0	0	0
24	PQ	1	0	28	20
25	PQ	1	0	0	0
26	PQ	1	0	14	10
27	PQ	1	0	14	10
28	PQ	1	0	26	18.6
29	PQ	1	0	26	18.6
30	PQ	1	0	0	0
31	PQ	1	0	0	0
32	PQ	1	0	0	0
33	PQ	1	0	14	10
34	PQ	1	0	19.5	14
35	PQ	1	0	6	4
36	PQ	1	0	26	18.55
37	PQ	1	0	26	18.55
38	PQ	1	0	0	0
39	PQ	1	0	24	17
40	PQ	1	0	24	17
41	PQ	1	0	1.2	1
42	PQ	1	0	0	0
43	PQ	1	0	6	4.3
44	PQ	1	0	0	0
45	PQ	1	0	39.2	26.3
46	PQ	1	0	39.2	26.3
47	PQ	1	0	0	0
48	PQ	1	0	79	56.4
49	PQ	1	0	384.7	274.5

50	PQ	1	0	384.7	274.5
51	PQ	1	0	40.5	28.3
52	PQ	1	0	3.6	2.7
53	PQ	1	0	4.35	3.5
54	PQ	1	0	26.4	19
55	PQ	1	0	24	17.2
56	PQ	1	0	0	0
57	PQ	1	0	0	0
58	PQ	1	0	0	0
59	PQ	1	0	100	72
60	PQ	1	0	0	0
61	PQ	1	0	1244	888
62	PQ	1	0	32	23
63	PQ	1	0	0	0
64	PQ	1	0	227	162
65	PQ	1	0	59	42
66	PQ	1	0	18	13
67	PQ	1	0	18	13
68	PQ	1	0	28	20
69	PQ	1	0	28	20

A.3. IS 12360:1988

Voltage Bands for Electrical Installations Including Preferred Voltages and Frequency.



IS : 12360 - 1988

50 Hz has been taken as standard for ac systems. This standard does not, however, cover frequencies for special power applications.

0.12 In the preparation of this standard, assistance has been derived from the following IEC publications, issued by the International Electrotechnical Commission (IEC):

IEC Pub 38-1983 IEC standard voltages

IEC Pub 449-1973 Voltage bands for electrical installations of buildings

0.13 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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*Rules for rounding off numerical values (*revised*).

1. SCOPE

1.1 This standard covers the voltage bands for electrical installations.

1.2 The voltage bands defined are intended mainly for use in connection with installation rules but may also be used when preparing requirements for electrical equipment.

1.3 This standard also covers standard values of nominal voltage of systems (in each voltage band) and frequency.

1.4 This standard does not include frequencies other than 50 Hz meant for special power application.

2. TERMINOLOGY

2.1 System — A system in which all the conductors and apparatus are electrically connected and operated at common voltages. The term includes all the conductors and apparatus.

2.2 Earthed Systems — Systems in which a point, generally the neutral point, is directly connected to earth without any intentional impedance.

2.3 Isolated or Non-effectively Earthed Systems — Systems in which no point is connected to earth or in which a point, generally the neutral point, is connected to earth by a limiting impedance.

2.4 Voltage

2.4.1 *Declared Voltage* — The voltage at the consumers terminals declared by the supplier of electrical energy.

2.4.2 *Nominal Voltage* — Voltage by which an installation (or a part of an installation) is designated.

NOTE 1 — The actual value of the voltage in the installation may differ from the nominal voltage by a quantity within normal tolerances.

The nominal voltage of a system is not necessarily the rated voltage of every piece of apparatus connected to the system.

NOTE 2 — Voltage transients, such as those due to switching, or temporary voltage variations due to abnormal operation, such as those due to fault conditions in the system supplying the installation, are not taken into consideration.

2.4.3 *Standard Nominal Voltage* — The nominal voltage recommended in this standard.

2.4.4 *Rated Voltage* — The voltage at which the apparatus connected to the system is designed to operate under normal conditions.

2.4.5 *Highest Voltage of the System* — The highest rms line-to-line voltage which is sustained under normal operating conditions at any time and at any point of the system. It excludes temporary voltage variations due to fault conditions.

2.4.6 *Lowest Voltage of the System* — The lowest rms line-to-line voltage which is sustained under normal operating conditions at any time and at any point of the system. It excludes temporary voltage variations due to fault conditions.

3. AC SYSTEMS

3.1 AC Voltage Bands

3.1.1 Voltage bands in which the ac installations shall be classified according to their nominal voltage are given in Table 1:

a) For earthed systems (**2.2**), by the rms values of the voltages between phase and earth and between phases; and

b) For isolated or not effectively earthed systems (**2.3**), by the rms value of the voltage between phases.

TABLE 1 AC VOLTAGE BANDS

BANDS	EARTHED SYSTEMS		ISOLATED OR NON-EFFECTIVE EARTHED SYSTEMS*
	Phase to Earth	Between Phases	
I	$u \leq 50$ V	$u \leq 50$ V	$u \leq 50$ V
II	$50 \text{V} < u \leq 600$ V	$50 \text{V} < u \leq 1\,000$ V	$50 \text{V} < u \leq 1\,000$ V
IIIA	←	$1 \text{ kV} < u \leq 52$ kV	→
IIIB	←	$52 \text{ kV} < u \leq 300$ kV	→
IIIC	←	$300 \text{ kV} < u$	→

u = nominal voltage of the installation.

NOTE — This classification of voltage bands does not exclude the possibility of introducing intermediate values for some particular rules.

*If the neutral is distributed, electrical equipment supplied between phase and neutral is to be chosen so that its insulation corresponds to the voltage between phases.

3

3.1.2 *AC System Voltage* — The preferred values of ac nominal system voltages shall be as given in Table 2.

TABLE 2 AC SYSTEM VOLTAGES

AC Voltage Band		Preferred, Nominal AC System Voltage	Highest System Voltage	Lowest System Voltage
I		Not specified	—	—
II*	*Three phase* —	415 V (Voltage to neutral — 240 V)	457 V	374 V
	Single phase —	240 V	264 V	216 V
III	*Three phase*	3·3 kV	3·6 kV	3·0 kV
		6·6 kV	7·2 kV	6·0 kV
		11 kV	12 kV	10 kV
IIIA		33 kV	36 kV	30 kV
		66 kV	72·5 kV	60 kV
IIIB		132 kV	145 kV	120 kV
		220 kV	245 kV	200 kV
IIIC		400 kV	420 kV	380 kV

NOTE 1 — This standard recognises that 110 kV system is already in existence though it is not a preferred system voltage.

NOTE 2 — The values are line-to-line *rms* values.

*The historical development of the standard value for AC system voltages in Band II is given in Appendix A.

3.1.3 *Tolerance on Declared Voltage* — The voltage at any point of the system under normal conditions shall not depart from the declared voltage by more than the values given below:

Band I	Not specified
Band II	± 6 percent
Band IIIA	$^{+6}_{-9}$ percent
Band IIIB and IIIC	± 12·5 percent

NOTE — It should be noted that the highest and the lowest system voltages given in Table 2 are meant for guidance to designers.

4. STANDARD SYSTEM FREQUENCY

4.1 The standard system frequency shall be 50 Hz.

4.2 The limits within which the frequency is to be maintained is ± 3 percent.

4.3 For frequencies higher than 50 Hz for special power applications, reference may be made to the relavant Indian Standard.

5. DC SYSTEM

5.1 DC Voltage System

5.1.1 DC voltage bands in which the installations shall be classified according to their nominal voltage are given in Table 3.

TABLE 3 DC VOLTAGE BANDS

(*Clause* 5.1.1)

Bands	Earthed Systems		Isolated or Not Effectively Earthed Systems* Between Poles
	Pole to Earth	Between Poles	
I	$u \leq 120$ V	$u \leq 120$ V	$u \leq 120$ V
II	120 V $< u \leq$ 900 V	120V $< u \leq$ 1 500 V	120 V $< u \leq$ 1 500 V

u = nominal voltage of the installation (volts).

NOTE 1 — The values of this table relate to ripple-free *dc*.

NOTE 2 — This classification of voltage bands does not exclude the possibility of introducing intermediate limits for some particular rules.

NOTE 3 — Higher voltages for dc applications are under consideration.

*If a middle wire is distributed, electrical equipment supplied between poles and middle wire is to be chosen so that its insulation corresponds to the voltage between the poles.

a) For earthed systems (**2.2**), by the values of the voltages between pole and earth and between poles; and

3.1.2 *AC System Voltage* — The preferred values of ac nominal system voltages shall be as given in Table 2.

TABLE 2 AC SYSTEM VOLTAGES

AC Voltage Band		Preferred, Nominal AC System Voltage	Highest System Voltage	Lowest System Voltage
I		Not specified	—	—
II*	*Three phase* —	415 V (Voltage to neutral — 240 V)	457 V	374 V
	Single phase —	240 V	264 V	216 V
III	*Three phase*	3·3 kV	3·6 kV	3·0 kV
		6·6 kV	7·2 kV	6·0 kV
IIIA		11 kV	12 kV	10 kV
		33 kV	36 kV	30 kV
		66 kV	72·5 kV	60 kV
IIIB		132 kV	145 kV	120 kV
		220 kV	245 kV	200 kV
IIIC		400 kV	420 kV	380 kV

Note 1 — This standard recognises that 110 kV system is already in existence though it is not a preferred system voltage.

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II	120 V $< u \leq 900$ V	120V $< u \leq 1\,500$ V	120 V $< u \leq 1\,500$ V

u=nominal voltage of the installation (volts).

Note 1 — The values of this table relate to ripple-free *dc*.

Note 2 — This classification of voltage bands does not exclude the possibility of introducing intermediate limits for some particular rules.

Note 3 — Higher voltages for dc applications are under consideration.

*If a middle wire is distributed, electrical equipment supplied between poles and middle wire is to be chosen so that its insulation corresponds to the voltage between the poles.

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radial Distribution

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