

**OPTIMAL PLACEMENT AND SIZING OF DG IN
UNBALANCED RADIAL DISTRIBUTION NETWORKS
USING CULTURAL ALGORITHM**

A Dissertation submitted in fulfillment of the requirements for the Degree
of

MASTER OF ENGINEERING
in
Power Systems

Submitted by

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DECLARATION

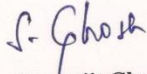
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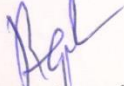

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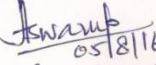
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NOMENCLATURE

Z_{abcn}	Impedance matrix
Z_{jk}	Branch impedance
R_{jk}	Branch resistance
Y_a	Admittance in phase a
Y_b	Admittance in phase b
Y_c	Admittance in phase c
V_a	Bus voltage in phase a
V_b	Bus voltage in phase b
V_c	Bus voltage in phase c
V_{\min}	Minimum voltage
V_{\max}	Maximum voltage
I_a	Branch current in phase a
I_b	Branch current in phase b
I_c	Branch current in phase c
I_d	Load current
P_d	Active power load
Q_d	Reactive Power load
P_{loss}	Active power loss
Q_{loss}	Reactive power loss
P_G	Active Power generated
Q_G	Reactive Power generated
SL	Apparent power loss in a branch
K	Voltage ratio
br	Branch number
$\theta_{I\text{-br}}$	Phase angle of branch current

ABBREVIATIONS

DG	Distributed Generation
RDN	Radial Distribution Network
URDN	Unbalanced Radial Distribution Network
CA	Cultural Algorithm
PSO	Particle Swarm Optimization
ABC	Artificial Bee Colony
KVL	Kirchhoff's voltage law
KCL	Kirchhoff's current law
VSI	Voltage sensitivity index
LSI	Loss sensitivity index
LMP	Locational marginal pricing
PARCA	Parallel co-operating cultural algorithm

ABSTRACT

Distribution system in our country has radial configuration. Generally, we have three phase four wire line model, where single phase and three phase power can be utilized. Practically, domestic loads consume single phase power. The power consumption capability is not same in each phase. This irregular arrangement of loads makes the system unbalanced. Distribution system has low voltage and high current profile, consequently line current and power losses are different in each phase. The complete power flow for such unbalanced radial distribution network has been computed by backward/forward sweep technique.

The main objective of this thesis is reduction of power losses. DG technology has been introduced for providing supplement power to the branches. This power injection process is used for loss reduction. The siting of the DG in unbalanced radial distribution network has been computed by loss sensitivity index and the size of the DG was estimated by Cultural Algorithm technique.

The influence of different DGs on the power losses have been demonstrated in this thesis work. The improvement in the voltage profile after DG placement has been graphically represented for different cases.

Chapter 1

INTRODUCTION

Whenever we talk about electricity the first thing comes in our mind that how, such a bulky power is available to us. Power systems have three pillars, first, the generation that converts mechanical energy into electrical energy, second, the transmission that moves the bulk power and third, the distribution that divides the power and provides it to the individual consumer. After travelling such a long path, degradation in the power quality has been observed. To improve the power quality several techniques have been introduced in all the sub-systems. Our main focus is on the distribution system in which distributed generation has a vital role in loss minimization and voltage improvement. The paradigm of the distribution system and its reorganization is represented in this report.

1.1 Distribution network

In India, mainly A.C. distribution systems are used. Distribution network begins where transmission ends i.e. at 66/33 kV. The distribution schemes are mainly classified into Primary and Secondary. Primary scheme of distribution network works on high voltage e.g. 2.2 kV, 3.3 kV, 11kV etc. whereas secondary scheme of distribution network works on low voltage for 440 V (3-phase) and 230 V (single phase). A distribution system starts from the substation and involves the conductor lines, line poles, transformers and other electrical instruments to deliver electrical energy to consumers at certain voltage extent. Loads are classified on the basis of the consumers and their demands (i.e. residential, commercial and industrial). Every distribution system has similar arrangement of equipment. A typical distribution system consists of following units.

- 1) Substation –It is a high-voltage facility, which manages different equipment, circuits or lines present inside and outside of the system. The main application of a substation is to change the A.C. voltage and the current from one level to another. Some basic functions of a common substation are
 - Adjustment of the voltage level to maintain the voltage regulation.
 - Interaction with the power from transmission to distribution.

- Protection of the system from lightning and switching surges.
 - Measurement of the electrical qualities.
- 2) Feeder circuit –The interconnection between the distribution substation and the primary circuit is called as feeder circuit. The conductors from the substation go through the circuit breaker and underground cables. Several feeder circuits can move away from the substation in different directions to provide power to the customer.
 - 3) Switches – Switches present in the distribution system are strategically placed. Power flow can be cut-out or redirect using switches. Even maintenance or repairing is possible because of the switches. Most of the switches present in the system are circuit breaker type of switches, mono pole break switches, multi pole switches and pad controller.
 - 4) Protection gears – Distribution system has variety of protective arrangements. It has protective relays, circuit breakers, lightning arresters, isolators and fuses. All of these have separate capabilities of protecting the system. Usually circuit breaker isolates the faulty region after relay gets energized. It protects the healthy region from faulty region. Fuses cut-out the part that can harm the system .Lightning arresters can ground the electrical energy of the lightning.
 - 5) Distribution transformers –This is the most important part of the system also known as service transformers. It step downs the voltage at different level. For primary distribution system, three phase transformers are used and voltage can step down up to 2.2 kV, but 11kV is very common for industrial application. For secondary distribution three phase transformer of delta star connection is preferred to get the three- phase voltage of 440V and single phase voltage of 230V.
 - 6) Services –The wire extended from the secondary of the distribution transformer to the consumer’s location is called as services. Overhead wires as well as underground cables can be used as service wire.

1.2 Distribution configuration

Distribution system has variety of configurations that depends on the arrangement of the conductors, bus bars and load. For any distribution network, at least one substation or source of power must be present. Some commonly used configurations are

- a) Radial type distribution network (RDN) – In this system the power is taken from the substation to the consumers using conductors of lateral arrangement. It is the typical model for distribution scheme, which requires less installation price. Unlike other schemes it doesn't have any alternate path to provide power, that's why a single fault can cause great failure in the system. Radial distribution as shown in Fig. 1.1 has variety of structures.

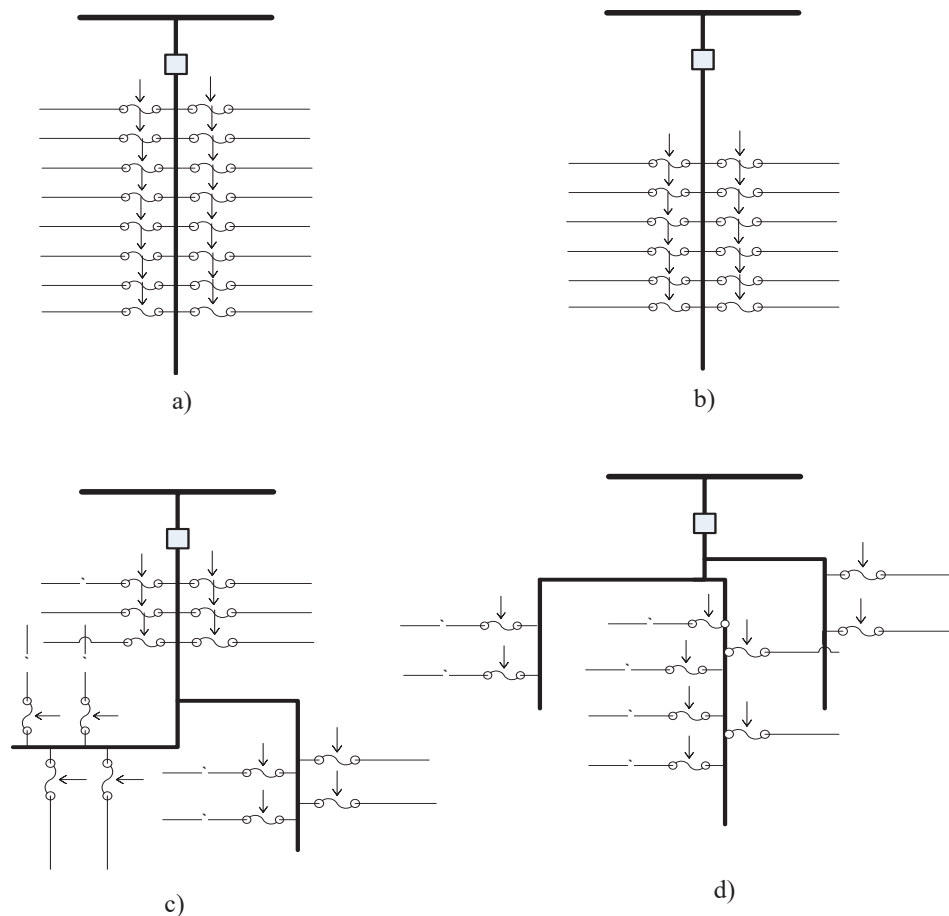


Fig. 1.1:RDN a)Single main line b)Express feeder c) Branched mainline d)Very branched mainline

- Single mainline system – These are the systems in which substation is close to the loads.
- Express feeder – This is the arrangement in which substation is far away from loads.
- Branched mainline – In this arrangement mainline from the substation is bifurcated.
- Very branched mainline – This is the complex form of the branched mainline arrangement where branches are again divided into sub-branches.

b) Loop distribution system – This the system in which more than one distribution path runs from the distribution substation involving multiple distribution transformers and load centers, which further returns to the same substation as shown in Fig. 1.2. This is also known as ring type of distribution system in which alternate path is present to provide power back up in system outage condition. This is more expensive than radial type of distribution system.

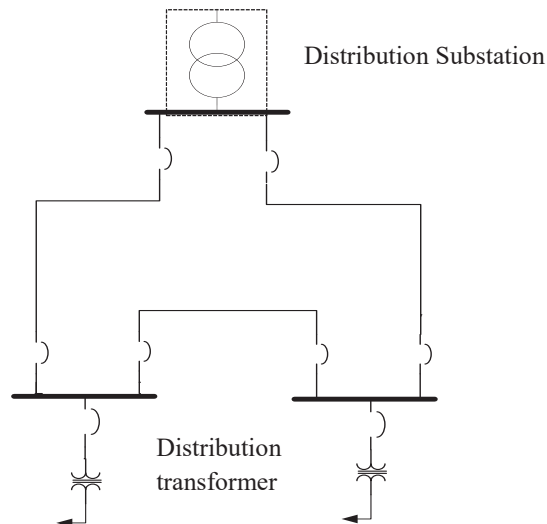


Figure 1.2: Single loop distribution system

c) Interconnected system – The interconnected system is a very flexible type of distribution system in which power is supplied from two or more distribution substations as shown in Fig 1.3. This arrangement makes the system much reliable .Such arrangement could be used to extent the network.

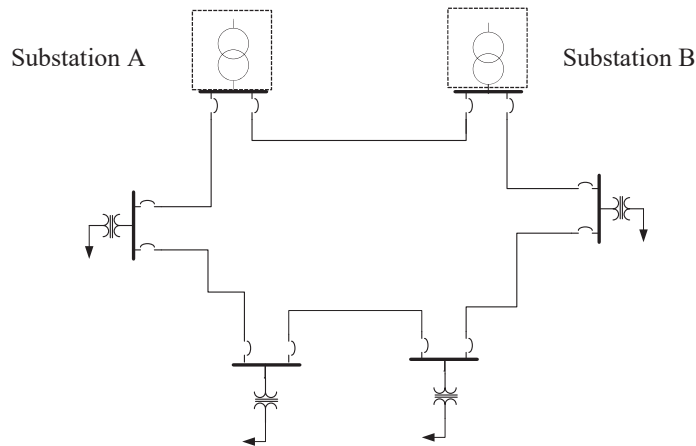


Figure 1.3: Multi substation interconnected system

1.3 Distributed Generation (DG)

Distributed generation represents micro to medium level generation or energy storage technology, which helps to supply alternative power and improves the power system characteristics. Usually the DG technologies used in the distribution network are free from the centralized power generation. Due to its independent nature it, is often referred as on site generation system. It is quite clear that distributed generation has certain power rating, but less than centralized power generation system. The power rating is also termed as size of DG. As per IEEE (US) 1547 standard, single or aggregate DG units should have capacity less than or equal to 10 MW.

1.3.1 Impact of the DG on network parameters

Installation of the DG in RDN can bring positive as well as negative effects on the network parameters. The site and the characteristics of a particular generation unit can affect the reliability and the economics of the power systems. Some of the common impacts after DG placement are

- a) Impact on regulation of voltage - It helps to increase the voltage level of the bus. The load at bus and the size of the DG have important effect on the voltage drop in the network. It has been observed that heavy load with DG has excessive voltage drop below the standard level .For light load, voltage drop is less, but bus voltage could be high. Due to poor voltage drop, power reversal takes place in the system. Hence, it has been advised that DG should not supply more than 20% of the load current.

- b) Impact on Power and its quality - Two possibilities that occur in DG placement are 1) voltage fluctuation and 2) harmonic distortion .Depending on the size of the DG, voltage can be increased or decreased. DG can produce negative current, which reduces the losses, but up to some extent. This current can affect the protection devices and may occur as overcurrent fault. Current fluctuation is very common for wind energy sources. The change in current leads to voltage disturbance. Harmonics occurs due to non-linear loads present in the system. DG with convertor circuit is the main cause for a harmonics, which comes in the picture in the form of overheat, distortion and interference.
- c) Impact on ferroresonance - A ferroresonance phenomenon occurs between magnetization reactance of the transformer and the capacitance of the cable. The DG in the system suffers from harmonics and over voltage, which enhances the fault condition of the system. DG with higher power rating gets easily influenced by ferroresonance.
- d) Impact on distribution protection devices- DG contributes current to the feeder circuit. This current contribution increases the fault level and in some cases it changes the current flow direction. The DG fault current affects the system by undesirable protection trips. The faulty current depends on the size, nature and the location of the DG.

1.4 Overview of the thesis

The main goal of this thesis is to settle the distributed generator (DG) of a specific power quantity and quality. The efficient value can be determined by comparing the net loss of the distribution model. The node location and the amount of power generated by DG are computed by two different techniques. Location can be analyzed by loss sensitivity expression, whereas the quantity of distributed generation (DG) has been evaluated by a new and magnificent meta-heuristic approach called as Cultural algorithm (CA). This thesis is divided into five following chapters:-

Chapter 1 describes about different structures and components of the distribution system. It also represents the distributed generation (DG) technology and its impact on the network parameters.

Chapter 2 represents previously done research works by the expertise people and shares the knowledge of modern techniques, which makes the power distribution more efficient and reliable.

Chapter 3 elaborates the three phase model of RDN with the power flow technique used in radial type configuration of unbalanced distribution network. The optimization process for achieving the perfect DG size has been discussed in this section.

Chapter 4 presents the favorable outcomes after applying the proposed algorithm on different bus system.

Chapter 5 presents the conclusion and the possible modifications of the thesis.

Chapter 2

TECHNICAL REVIEW

Gautam and Mithulanathan [1] presented new methodologies on settlement of Distributed Generator technology for a prime load flow, which is made on wholesale electricity scenario. Distributed generation (DG) placement and size are computed for different objectives like social welfare expansion and profit extension. Location for DG settlement is modeled from location marginal cost price. Overall method was tested on modified IEEE 14 bus.

Khushalani *et al.* [2] programmed a multi-phase unbalanced power distribution solution, which includes multiple DG handling capability. Program can adjust DG working mechanism from fixed voltage to constant operating power factor mode. Shipboard power system and its load arrangement had been also explained in this paper. IEEE standard 37 node system had been used to demonstrate the radial network. Ice breaker ship system was taken as an example to elaborate the shipboard power system.

Syaffi *et al.* [3] presented three-phase Distributed Generation for unbalanced RDN and analyzed its effect on the system. DG has been modeled as generator with voltage bus (PV node) and apparent power injection (PQ node) node. The distribution power flow evaluation has been modeled on Newton Raphson method which is tested on 37 node RDN. This load flow was compared with radial distribution analysis package (RDAP).

Ghosh *et al.* [4] explained a technique, which decides finest sizing and placement of distributed generation. Newton Raphson (NR) load flow was performed on 6, 14 and 30 RDS bus data. Reduction of the losses and the cost of DGs were the main objectives of this project. Weight factor concept had been introduced to maintain balance between its objectives.

Shukla *et al.* [5] highlighted on multi-site distribution generation circumstance in order to lower down the power losses of the balanced distribution network using the genetic algorithm (GA) formulation. The sensitivity of power and the alteration in the real power supply was analyzed to select an effective node for DG settlement. The concept of energy saving was also introduced in this method.

Safari et al. [6] presented the effect of distributed generators (DG) on radial branch losses. Evaluation was established on combination of GA and PSO also called as HGAPSO. The main focus was on achieving appropriate DG setting for distribution network. The superiority of this process was explained with the help of a numerical example and its quality had been compared with Genetic algorithm (GA). Proposed method was tested on IEEE-34 node system

Elnasher et al. [7] proposed a unique technique to recognize the site and the node position of the distributed generation in a large mesh connected system. Proposed method had visual optimization approach in which planner could set the sizing and the sitting of the DG by using appropriate weight factor. Some parameters like losses, voltage and short circuit current level had been used in the algorithm for prediction of the optimum power rating and the perfect location of the DG. This method was tested on IEEE-24 RDS.

Charles et al [8] presented different categories of DG system and analyzed the loss reduction and voltage improvement in IEEE-57 bus system. Loss sensitivity factor had been used to find the best locations of the nodes for placement. Multi DG units had been placed at different bus locations using GA-IPSO approach. GA determined the size and IPSO sets the initial particle.

Taher and Karimi [9] investigated network reconfiguration of balanced and unbalanced RDN. This method has an efficient approach of simultaneous use of network reconfiguration as well as Distributed generation (DG) allocation. A Multi-objective approach has been implemented to resolve distribution network problems like power losses, voltage profile, voltage unbalance and current unbalance. Genetic algorithm (GA) was used to get optimum solution. Proposed work was implemented on 33 and 69 bus balanced radial type of distribution model and it was also implemented on 25 bus unbalanced radial type of distribution model.

Dharata et al. [10] proposed a method to evaluate the voltage fluctuation problem in URDN. It includes uncertainty in power supply and DG. The formulation is based on mixed –integer nonlinear programming (MNLP) which had two stages. Monte Carlo simulation studies were compared with proposed method to check its robustness. Above formulation was implemented and tested on IEEE 123 bus URDN.

Othman et al. [11] redefined the big bang and big crunch algorithm for getting appropriate node locations and the power range of the DGs for multiple DG placement on three phase unbalanced

distribution network. Declared method was tested on 33 and 37 bus feeder and its outputs were related with traditional methods. Loss minimization was the primary objective of this above algorithm.

Dahal and Salehfar [12] developed a program for unbalanced distribution model in which the favorable location and the estimation of the DGs had been identified by “Particle swarm optimization (PSO)”. The complete program was based on MATLAB coding and open DSS simulation, which was implemented on IEEE 123 bus system. The obtained results from the program have been compared with repeated load flow solution, using different categories of the DG system.

Subrahmanyam and Radhakrishna [13] presented quick solving method, which analyses the existence of the capacitor in unbalanced distribution model. The node position and the power rating of the capacitor can be identified by this method. Two major objectives of this formulation includes energy cost and total capacitor installation charges. Overall loss and saving had been calculated for 25 and 37 bus system.

Ravichandrudu *et al.* [14] presented Artificial Bee colony (ABC) method to find the size of the capacitor for proper placement at certain location in unbalanced RDN. Objectives of this project involve the energy utilization cost, capacitor market price and installation expenditure. Function had been considered as fit when the net investment cost was less and the saving was more. This method was applied on 25-bus and 37-bus URDN.

Vulasala *et al.* [15] put an outstanding effort on the network reconfiguration to decrease the branch loss and to enhance the voltage margin in three-phase unbalanced RDN. GA had been performed to get the finest possible solution from reconfiguration of distribution network to decrease the total loss. The power flow formulation was inspired from forward/backward sweep algorithm. Proposed method was implemented on 19 and 25 bus URDN.

Cheng and Shirmohammadi [16] presented load flow solution for three phase primary distribution system. This load flow was based on real time reference with detail explanation on distributed generation and unbalanced loads. The concept of distribution automation and its components like shunt capacitors, voltage regulator and tap controller had been explained with real time value.

Ghosh and Das [17] proposed an easy and well organized way to perform power flow studies on RDN. It involves concept of Kirchoff's voltage and current law. Computationally, the proposed method was evaluated on 29, 33 as well as 69 bus system. The efficacy of this process was proved using various conditions.

Chakrobarty and Das [18] derived a mathematical equation of "Voltage Sensitivity Index (VSI)" to identify the critical nodes for which the chances of voltage collapse are more in any distribution network. It has been illustrated on IEEE 69 bus network of radial configuration.

Teng and Chang [19] proposed a unique load flow for three phase unbalanced radial network. This method was based on classic approach of Newton Raphson (NR) load flow in which branch voltage was taken as state variable. Lower- upper triangular (LU) factorization of Jacobian matrix has reduced the computation time of load flow analysis.

Ciric *et al.* [20] developed a new method to perform load flow analysis on four wire unbalanced radial distribution network. Proposed method had involved the neutral wire and evaluated the ground current effect on the radial network. The backward/forward power flow technique had been applied for quick convergence. This method had been explained using low voltage and medium voltage feeder circuit.

Rajan *et al.* [21] propounded an easy process to resolve three-phase URDN using basic algebraic iterative formulation of line voltage. It stores all the records in matrices. It includes the fundamentals of network theory. Three phase mathematical models with consideration of mutual coupling effect amongst branches have been developed to explain the load flow. This procedure was tried by numerous of distribution models.

Subrahmanyam and Radhakrishna [22] presented a simple load flow technique for three phase URDN using common principles of circuit and network theory. Three phase four line configuration was used in which mutual coupling between phases were involved in the mathematical modeling. Above technique was applied on different unbalanced distribution network of radial configuration.

Mahmoud and Akher [23] represented an efficient method to demonstrate three-phase URDN using backward and forward sweep load flow technique. A new transformer model had been

introduced in the system. Proposed method had given better solution for singularity matrix conversion of admittance co-matrices, formed due to transformer configuration. Several models of loads and shunt capacitors were also placed randomly connected at different phase. This method was implemented on IEEE 4 bus and 34 bus system.

Prakash and Sydulu [24] introduced an efficient power flow method on the basis of primitive and topological impedance. This power flow used the fundamental of primitive impedance of the lines and only diagonal data of the Load Flow matrix were calculated and saved in one-dimensional array to achieve the load flow solution for distribution networks. Unlike other load flow no Lower –Upper (LU) decomposition of bus matrix took place ,which made it more durable and time effective. The major advantage of this load flow was that it could be extended to weakly-meshed distribution feeder.

Hong [25] suggested about locational marginal pricing (LMP) model for distribution system to make the system more economic and operational. Loss sensitivity index plays an important role for calculating LMP. Loss sensitivity index was applied for three phase unbalanced distribution system and tested on IEEE-8500 node model.

Samal and Ganguly [26] modified the backward/forward sweep technique for three phase load flow analysis. The branch current value has been rearranged into three matrices namely A, B and C, which has reduced the length of the calculation. Mutual coupling effect had been also considered in the three phase line model. This modified technique had been compared with the original technique.

Zad et al [27] projected on reactive power maintenance problems in medium voltage range distribution systems .Voltage sensitivity was evaluated to identify the weak voltage nodes and then the reactive type of DGs were employed to advance the bus voltages of the network The size limitation of the DG was based on PSO algorithm.

Yang and Le [28] propounded an exclusive method for power flow analysis of URDN. Analysis was based on loop frame instead of bus frame .Each bus, except slack bus was combined with fictitious link of current source. Proposed method was applicable for both fundamental and harmonic load flow study. A current injection technique had been used to build the coefficient matrix and to calculate shunt capacitor harmonic current.

Digalakis and Margaritis [29] suggested a multi population cultural algorithm to sort out generator scheduling problem also known as parallel co-operating cultural algorithm (PARCA). Proposed method has several selection mechanism, operators and communication methods. It included several combinations of generators, which could be renewable as well as non-renewable. These combinations were mathematically formulated in particular time interval.

Chapter 3

PROBLEM FORMULATION

3.1 Three phase line component

Unbalanced Radial Distribution Network (URDN) includes either 2-phase or 3-phase network arrangement with unequal load distribution in each phase. This unequal arrangement draws irregular current in each phase and makes unsymmetrical voltage at each node. Three phase lines have self-impedance and mutual impedance, which is mathematically represented by Carson (4x4) impedance matrix [19] as shown in Fig. 3.1.

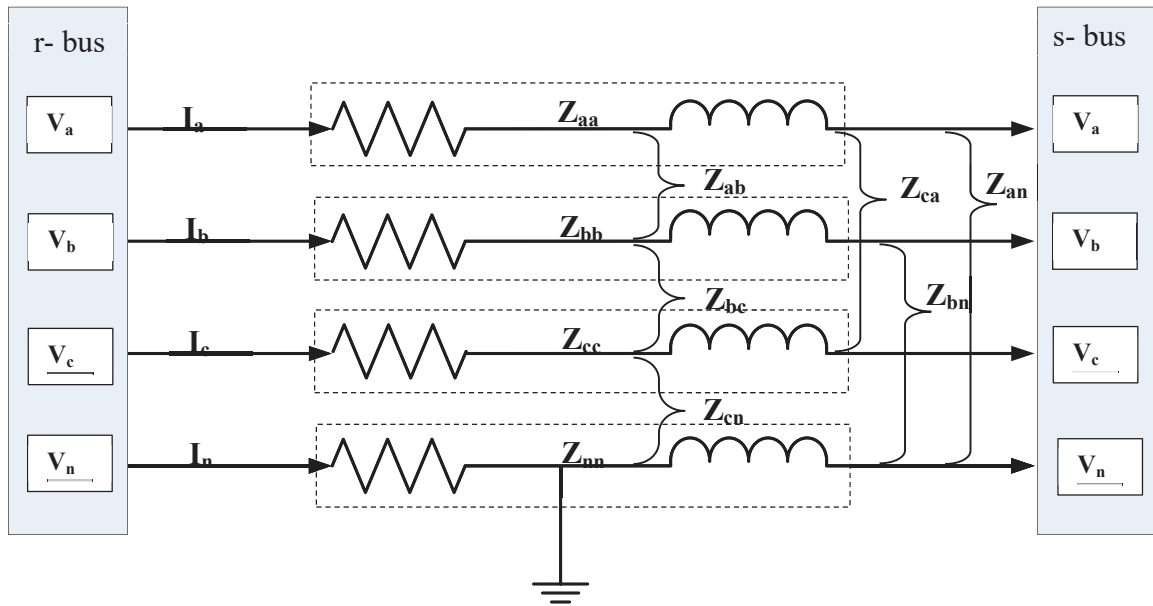


Fig 3.1.: Three phase four wire model

$$[Z_{abcn}^{rs}] = \begin{bmatrix} Z_{aa}^{rs} & Z_{ab}^{rs} & Z_{ac}^{rs} & Z_{an}^{rs} \\ Z_{ba}^{rs} & Z_{bb}^{rs} & Z_{bc}^{rs} & Z_{bn}^{rs} \\ Z_{ca}^{rs} & Z_{cb}^{rs} & Z_{cc}^{rs} & Z_{cn}^{rs} \\ Z_{na}^{rs} & Z_{nb}^{rs} & Z_{nc}^{rs} & Z_{nn}^{rs} \end{bmatrix} \quad (3.1)$$

This matrix has reduced to 3x3 matrix by kron's reduction, which includes the effect of ground or neutral wire and it is represented as per phase impedance matrix as shown in Eq. (3.2)

$$[Z_{abcn}^{new}] = \begin{bmatrix} Z_{aa-n}^{rs} & Z_{ab-n}^{rs} & Z_{ac-n}^{rs} \\ Z_{ba-n}^{rs} & Z_{bb-n}^{rs} & Z_{bc-n}^{rs} \\ Z_{ca-n}^{rs} & Z_{cb-n}^{rs} & Z_{cc-n}^{rs} \end{bmatrix} \quad (3.2)$$

The relationship between bus Voltages and branch currents is given by Eq.(3.3)

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} V_{ar} \\ V_{br} \\ V_{cr} \end{bmatrix} - \begin{bmatrix} Z_{aa-n}^{rs} & Z_{ab-n}^{rs} & Z_{ac-n}^{rs} \\ Z_{ba-n}^{rs} & Z_{bb-n}^{rs} & Z_{bc-n}^{rs} \\ Z_{ca-n}^{rs} & Z_{cb-n}^{rs} & Z_{cc-n}^{rs} \end{bmatrix} \begin{bmatrix} I_{a(rs)} \\ I_{b(rs)} \\ I_{c(rs)} \end{bmatrix} \quad (3.3)$$

3.2 Node component

All distribution systems have some series and shunt components [31]. The line components like line conductors, transformers, voltage regulators etc. are categorized as series components and the loads, capacitor banks, DGs etc. are the shunt components. To define particular load, it is necessary to understand the shunt components. Three phase distribution system has basically delta and star (wye) connected loads as shown in Fig. 3.2, but loads are characterized as constant complex power loads, constant current loads and constant impedance (or admittance) loads. There are mainly two arrangements of loads mentioned below

- 1) Spot static loads – These loads are located at the node. It can be single phase or multiphase with delta or star (wye) connection.
- 2) Distributed loads – These are located at the mid of the line, uniformly distributed in the system. Like spot loads, it can be single and multiphase with delta or star (wye) connection

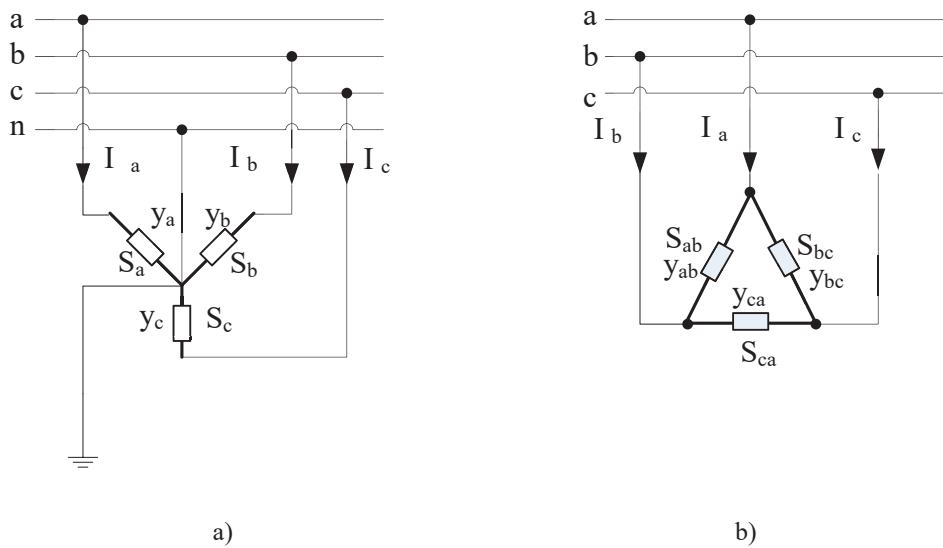


Fig 3.2: a) Star load connection and b) delta load connection

On the basis of the load classification mentioned above, other components like DG, capacitors and other type of loads are arranged in RDN as shown in Fig.3.3

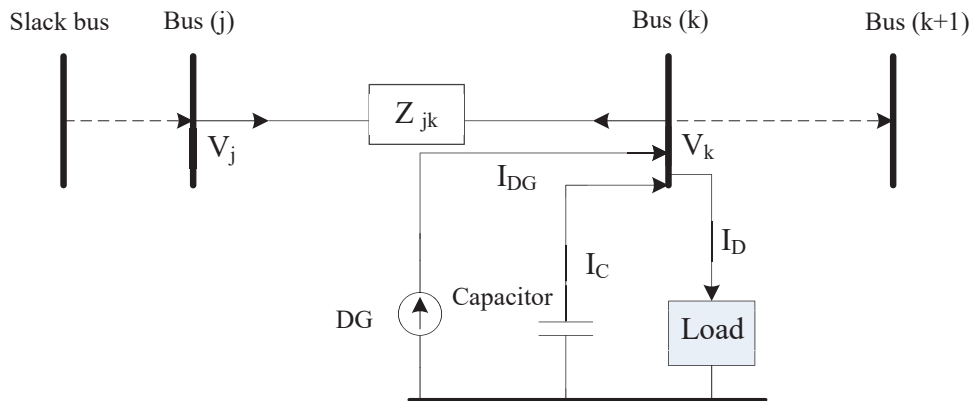


Fig.3.3: Different node components

The direction and the value of the current depend on the nature of the component present at the node. Basically, loads intake the current whereas DGs and capacitors have the tendency to supply power. The DG behaves like a constant power load and the capacitor like a constant impedance load but the current direction as shown in the Fig. 3.3 is opposite to the network current which makes it behave like an energy source. The current equations for various type of spot static load are represented in the Table 3.1. The matrix T is a transformation matrix which converts phase current into line current

$$T = \begin{bmatrix} 1 & 0 & -1 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \quad (3.4)$$

The load current from each node can be easily calculated from the formulas given below. During power flow analysis it is necessary to calculate each load current. The current at each phase, will be different in magnitude and phase angle. The Eq. (3.5) is derived form of constant complex power load.

Table 3.1: Current equations for different load configuration

Connection	Constant power	Constant current	Constant admittance
star (wye) with grounded	$\begin{bmatrix} I_a^k \\ I_b^k \\ I_c^k \end{bmatrix} = \begin{bmatrix} \left(\frac{S_a}{V_a^k - V_n^k} \right)^* \\ \left(\frac{S_b}{V_b^k - V_n^k} \right)^* \\ \left(\frac{S_c}{V_c^k - V_n^k} \right)^* \end{bmatrix}$	$\begin{bmatrix} I_a^k \\ I_b^k \\ I_c^k \end{bmatrix} = \begin{bmatrix} I_a^{rated} \\ I_b^{rated} \\ I_c^{rated} \end{bmatrix}$	$\begin{bmatrix} I_a^k \\ I_b^k \\ I_c^k \end{bmatrix} = \begin{bmatrix} y_a^{rated} V_a^k \\ y_b^{rated} V_b^k \\ y_c^{rated} V_c^k \end{bmatrix}$
Delta	$\begin{bmatrix} I_a^k \\ I_b^k \\ I_c^k \end{bmatrix} = T \begin{bmatrix} \left(\frac{S_{ab}}{V_a^k - V_b^k} \right)^* \\ \left(\frac{S_{bc}}{V_b^k - V_c^k} \right)^* \\ \left(\frac{S_{ca}}{V_c^k - V_a^k} \right)^* \end{bmatrix}$	$\begin{bmatrix} I_a^k \\ I_b^k \\ I_c^k \end{bmatrix} = T \begin{bmatrix} I_a^{rated} \\ I_b^{rated} \\ I_c^{rated} \end{bmatrix}$	$\begin{bmatrix} I_a^k \\ I_b^k \\ I_c^k \end{bmatrix} = T \begin{bmatrix} y_{ab}^{rated} (V_a^k - V_b^k) \\ y_{bc}^{rated} (V_b^k - V_c^k) \\ y_{ca}^{rated} (V_c^k - V_a^k) \end{bmatrix}$

The branch current is obtained from load current. The updated branch current matrix is obtained by addition of branch current and load current connected beyond the bus in each phase.

$$I_d^a(i) = \frac{P_d^a(i) - jQ_d^a(i)}{(V^a(i))^*} \quad (3.5(a))$$

$$I_d^b(i) = \frac{P_d^b(i) - jQ_d^b(i)}{(V^b(i))^*} \quad (3.5(b))$$

$$I_d^c(i) = \frac{P_d^c(i) - jQ_d^c(i)}{(V^c(i))^*} \quad (3.5(c))$$

Where

I_d =Load current

V =Bus voltage

i = Bus number

P_d =Active load

Q_d =Reactive load

3.3 Objective and constraints

In Radial distribution network, feeders laterally go out of the substation and linked with the transformer of the distribution networks. Such arrangement has a major disadvantage that in case of failure of any feeder, power will not be delivered to the consumer as there is no alternate path to provide power to the consumers. In other words there will no power and darkness until transformer is replaced or repaired. Hence it is necessary to operate system in optimum way.

Distribution system has many transformers due to which it has high R/X ratio; consequently losses are more in distribution lines as compared to transmission lines. To minimize the losses and to improve the bus voltage, Distributed Generation (DG) is used. To place the DG of optimum size it is necessary to take care of the branch losses. DG could increase the losses if its power rating (size) is not suitable for a particular bus. Therefore the size of the DG must be in such a way that it should reduce the losses as well as it must satisfy the constraints.

3.3.1 Objective functions

The chief objective is to minimize the active and reactive power losses. The equation for losses in each branch is given by [22]

$$S_{ij}^a = P_{ij}^a + jQ_{ij}^a = (V_i^a - V_j^a) \cdot (I_{ij}^a)^* \quad (3.6 (a))$$

$$S_{ij}^b = P_{ij}^b + jQ_{ij}^b = (V_i^b - V_j^b) \cdot (I_{ij}^b)^* \quad (3.6 (b))$$

$$S_{ij}^c = P_{ij}^c + jQ_{ij}^c = (V_i^c - V_j^c) \cdot (I_{ij}^c)^* \quad (3.6 (c))$$

$$\text{Minimize } f = \sum_{j=1}^{br} S_j^{abc} \quad (3.7)$$

Where

i =Sending end bus

j =Receiving end bus

ij = branch number

S =Apparent power loss

P =Active power loss

Q =Reactive power loss

br =number of branches

3.3.2 Constraints

The load flow for the radial distribution will be feasible only if the constraints are satisfied

a. Voltage restriction

The bus voltage at each phase must be within the limit. A small change in voltage can bring a great change in current as the relation is shown in Eq. (3.5). Reactive power will be also effected by the voltage change.

$$V_{i(min)}^n \leq V_i^n \leq V_{i(max)}^n \quad \text{Where } i \in \{1,2,3,\dots,N\} \quad (3.8)$$

Where

$V_{i(min)}$ = Minimum voltage

$V_{i(max)}$ = Maximum voltage

V_i = Voltage at i^{th} bus

n = Phase

N = Number of bus

b. Branch current constraint

Current magnitude in each branch must lie within a certain limit. Overcurrent could exceed the power loss in the network

$$I_j^{(abc)} \leq I_j^{(max)} \quad \text{Where } j \in \{1,2,3,\dots,br\} \quad (3.9)$$

Where

I_j^{abc} = Branch current

I_j^{max} = Maximum tolerable branch current

br = Branch number

c. Power flow

The active and the reactive power generated at each bus are equal to the sum of the power load and the losses in the branch. The Eqs. (3.10) and (3.11) represents the net active and reactive power generated at each bus.

$$\sum P_{Gi}^n = \sum P_D^n + \sum P_{Loss}^n \quad \text{Where } i \in \{1,2,3,\dots,N\} \quad (3.10)$$

$$\sum Q_{Gi}^n = \sum Q_D^n + \sum Q_{Loss}^n \quad (3.11)$$

Where

P_G = Active power generated

Q_G = Reactive power generated

P_D = Active load

Q_D = Reactive load

P_{Loss} =Branch active power loss

Q_{Loss} =Branch reactive power loss

n =Phase

3.4 Load flow study

Power system's load flow study represents mathematical analysis of electric power, flowing in an interconnected network. Load flow study is represented by a single line diagram in which all the parameters are in per unit. The main focus of every load flow is to find different parameters like bus voltage, voltage angle, active power and reactive power. The load flow analysis is a steady state operation. There are several load flow techniques like Newton Raphson, Gauss Siedal and Fast Decoupled method, but Backward/Forward sweep is preferred over these methods due to its fast convergence rate.

3.5 Backward/ forward sweep

Backward and forward sweep load flow technique [17] is based on Kirchoff's network laws of current and voltage. First the load current is calculated from the load data and then it is propagated in backward direction by adding the load current with the branch current one by one with respect to each bus or load present in the system. Once the branch current is updated, voltage is calculated by Kirchoff's voltage law. Unlike balanced radial distribution system, it has mutual coupling effect between the lines; hence impedance matrix has 3x3 dimension matrix which includes self as well as mutual impedance. Backward/forward sweep is an iterative method, its voltage and current value changes with each iteration. Once the voltage difference is less than convergence factor, iteration stops. The voltage at each bus and the current in each branch are different in each phase only in case of unbalanced radial distribution system.

3.5.1 Presumptions

1) System is unbalanced, hence it is un-transposed and loads are not equal in each phase. It can be represented in single line diagram model but specification of load and impedance in each phase is required.

- 2) System has positive sequence network and working independent from the grid system.
- 3) No shunt capacitance and no charging current flowing in the network.
- 4) Loads are considered as constant power load.
- 5) Each value of the Impedance is in per phase and depends on the length and the type of the conductor.

3.6 Load flow algorithm

1. Collect the line data that includes impedance matrix, sending end node, receiving end node and branch number. Collect the load data which includes power rating of each load at receiving end node of the bus system
2. Get the base voltage and base MVA and convert all parameters in per unit value.
3. Set the maximum number of iterations and the convergence factor i.e. $\epsilon=0.00001$
4. Initialize the line voltage and phase angle at each bus i.e. $V_a=1\angle 0^\circ$, $V_b=1\angle -120^\circ$ and $V_c=1\angle 120^\circ$.
5. Calculate the load current at each bus present in each phase using equation 1.

$$I_d^n(i) = \frac{P_d^n(i) - jQ_d^n(i)}{(V^n(i))^*} \quad (3.12)$$

Where

i = bus number

I_d =Load current

P_d =Active power load

Q_d =Reactive power load

V =Bus voltage

n = Phase

6. Update the branch current value by adding the branch current and the load current connected to the specific bus. This concept is known as backward sweep of current which is based on Kirchoff's current law. Eq. 3.13(a) represents the end bus current and Eq. 3.13(b) represents the updated load current.

$$I_{br}^n(k) = I_d^n(RE(k)) \quad (3.13(a))$$

$$I_d^n(SE(k)) = I_d^n(SE(k)) + I_{br}^n(k) \quad (3.13(b))$$

Where

I_{br} =Branch current

I_d =Load current

k = Branch number

SE =Sending end node

RE =Receiving end node

n =Phase

7. Update the line voltage at each bus using forward sweep technique .Like Kirchhoff's voltage law the voltage drop in each branch is subtracted to get bus voltage in each phase. The general equation for line voltage is given below

$$V_j^n = V_i^n - [Z_{abcn}][I_{br}^n] \quad (3.14)$$

Where

i =Sending end bus

j =Receiving end bus

I_{br} =Branch current matrix

n =Phase

Z_{abcn} = Impedance matrix

8. Compare the voltage magnitude difference of each bus in each phase with the convergence factor “ ϵ ”. If the maximum difference is less than “ ϵ ”, stop the iteration and get the voltage, if it does not satisfy the condition then repeat and increase the iteration.

$$\max |V_n^i - V_n^{i+1}| < \epsilon \quad (3.15)$$

Where

i =Iteration

n =Phase

9. After getting the voltage and the current value branch losses are calculated by the Eq. (3.16)

$$SL_{ij}^n = PL_{ij}^n + jQL_{ij}^n = (V_i^n - V_j^n) \cdot (I_{ij}^n)^* \quad (3.16)$$

Where

SL =Apparent loss

PL =Active loss

QL =Reactive loss

n =Phase

i =Sending end bus

j =Receiving end bus

ij =Branch number

3.7 Selection of the Distributed Generation (DG)

Distributed Generation (DG) is a modern methodology that provides small scale technology to produce electricity near to the consumer. Distributed Generation (DG) technology could be in the form of generator or in the form of storage device. In many cases DGs can be beneficial as it provides low cost electricity and high power reliability. Renewable and non-renewable sources of energy can be used as DG, depending upon the power necessity. There have been several researches in the area of DG technology, its location and sizing, economic and financial analysis coupled with DG integration, etc. It is difficult for researchers, policy makers, and academicians to study all the related materials. Several matters related to the DG technology and its integration are presented. It is must for a researcher to understand the main issue of the large effect of the distributed generation (DG) in the power system.

Radial distribution system is a large chain of radial feeders. Each branch suffers from active and reactive power losses. These losses reduce the bus voltage magnitude in each phase which gives poor voltage at the end buses of the radial network. To overcome from such problems DGs are implemented at certain bus locations. DGs are nothing but the source of power, connected with the bus bar to supply current in the network and to reduce the active and reactive losses in the system. DGs can be widely used in distribution systems, as losses are comparatively more with respect to the transmission systems and length of the distribution systems is much less as compared to the transmission system, so even less power DG can be used to compensate power loss.

There are several ways to classify the Distributed Generation (DG), but mainly they are classified into four types as per their power generation characteristics.

DG-I: This type of DG has the tendency to deliver only active power, which supplies power to the system using converters and inverters. However, as per the power demand, sometimes these supply reactive power as well. PV, micro-turbines, fuel cells are some of the examples for such type of DG.

DG-II: This type of DG can deliver reactive power component. Synchronous compensators such as DSTATCOM, SVC are few examples, which can adjust the power factor up to zero.

DG-III: Such DG is capable of generating apparent power. These DG units are mainly focused on synchronous generators because synchronous generators have the capability of producing both active and reactive power component. Power factor can be controlled by the excitation. Cogeneration, gas turbine, small captive power plants etc. are few examples related to such DG

DG-IV: This type of DG supplies active power and consumes reactive power. Induction type of generators used in the wind farms can be classified under this category. Doubly fed induction generators are mostly used for such purpose.

3.8 DG allocation and Sizing

Every Distributed Generation (DG) has a specific power supplying capability. DGs are available with wide power range and size in the market, but all DGs are not suitable for loss compensation. In unbalanced radial distribution system, single phase DG of different power rating is preferred for individual phase over the three phase balanced DG. The proper placement of DG at certain bus bar makes it feasible to supply more power to fulfill the demand. The power injected through the bus is distributed to the branches and the loads connected to the bus, just like the current source at a particular node divides current in each branch connected to it. When the power injected at the bus exceeds the load demand, overcurrent may occur which could increase the losses. The size of the DG is dependent on the location as well. The bus number for which the placement of DG gives minimum losses are said to be the best location. Hence, selection of the right DG and its suitable location is a crucial process and requires an algorithm to get an optimum solution.

3.8.1 DG allocation

The process of finding the bus location for which DG placement gives minimum losses without breaking any constraint is called as DG allocation. The size of DG depends on the location of the bus in the radial distribution system. All the buses except slack bus are suitable for DG placement. Factors affecting the location of the DG are

1. Number of buses /nodes present in the RDN.

2. Power rating of the loads linked with the bus/node.
3. Number of branches linked with the bus/node.
4. Losses in the branches associated with a particular bus/node.
5. Power rating and the class of the DG.

3.8.2 Conventional approach for DG allocation

The conventional approach is based on the hit and trial method in which a particular size of DG is placed one by one at each bus/node. For unbalanced radial distribution system this is applied for each phase. For each placement the overall losses are calculated, the location for which the net loss is minimum can be considered as the best location. Due to mutual coupling, DG placement at any phase will affect the losses in other two phases. This method is not efficient as it takes too much iteration to get the perfect node.

3.8.3 Loss Sensitivity index (LSI) for DG allocation

For large bus network it is not feasible to try conventional approach to identify the best location for DG placement. Hence a mathematical technique is applied to get the best location in a very simple and non-iterative way. Loss sensitivity is a mathematical approach in which the receiving end nodes of the high loss sensitive branches are selected. These nodes are the best locations for the DG placement. Loss has inverse relation with the bus voltage and direct relation with the branch current. In three phase network due to mutual coupling, neighbor branch current also contributes itself to increase the loss. In other words, loss sensitivity can be defined as change in the branch loss by change in the branch current. The expression [25] represents loss sensitivity index for three phase network. Eq.3.17 represents the mathematical formula.

$$\begin{aligned} \frac{dP_{loss-br}}{d|I_{n-\phi}|} = & 2 \cdot K_{br-n} |I_{br-a}| \cdot R_{br-\phi a} \cdot \cos(\theta_{I-br-a} - \theta_{I-n-\phi}) \\ & + 2 \cdot K_{br-n} |I_{br-b}| \cdot R_{br-\phi b} \cdot \cos(\theta_{I-br-b} - \theta_{I-n-\phi}) \\ & + 2 \cdot K_{br-n} |I_{br-c}| \cdot R_{br-\phi c} \cdot \cos(\theta_{I-br-c} - \theta_{I-n-\phi}) \end{aligned} \quad (3.17)$$

Where

K=Voltage ratio

I=Current

br =Branch number

n=bus number

\emptyset = Phase (a, b & c)

R=Resistance

The loss sensitivity index (LSI) evaluates the highly loss effected receiving end nodes and then in decreasing order top three nodes are selected which tell about the locations, good for the DG and the capacitor placement in the radial distribution network. In unbalanced radial distribution system, it is necessary to calculate the LSI for each phase. LSI could represent different results for different phase due to unbalance nature of the network.

3.8.4 DG sizing

Once the locations of the buses are available the next big challenge is to select the size of the Distributed Generation (DG).The size basically means the power rating of the DG up to which the DG unit can generate. The parameters on which the sizing of the DG depends for unbalanced radial network are

1. The bus location and the phase where DG is going to be placed.
2. Losses and its nature (Active loss or Reactive loss)
3. Short circuit current level of the bus
4. Bus Voltage tolerance level.

Unlike the location, it is not easy to predict the exact size of the DG for a bus. There are infinite possibilities of DGs for a single bus/node. To calculate the range of the DG for which the load flow is feasible, depends on the objective function. The main aim of this work is to minimize the losses. An optimization function is necessary to give the minimum and the maximum value of the DG for which the losses are reduced. Beyond the limit it might increase the losses drastically. Optimization techniques used in several other research papers are mainly based on the meta-heuristic and computational techniques. Some commonly used techniques are Genetic algorithm (GA), Particle Swarm Optimization (PSO), Bacterial Foraging etc. In this dissertation a new meta-heuristic technique called as Cultural algorithm is applied, which helps to evaluate the optimum size of the DG.

3.9 Cultural Algorithm

Cultural algorithm (CA) [30] is an evolutionary computational technique which withdraws the domain knowledge during the evolution and further extracts new knowledge from the specific domain knowledge. It can be defined as ‘*priori*’ base algorithm in which knowledge related to a specific task is already known. In this method complex scheduling operations can be optimized using several combinations. Any operation under cultural algorithm must have a task for which machines are operated for a particular schedule to achieve a certain objective.

Cultural algorithm is a model based on the sociological and archeological studies which tries to change itself with modern cultural evolution. This cultural evolution can be seen as inheritance operation at two levels:

1. Micro evolutionary level-This is the information which is genetically obtained by the off springs from their parents by inheritance.
2. Macro evolutionary level-This is the knowledge acquired by one from the generations and the society.

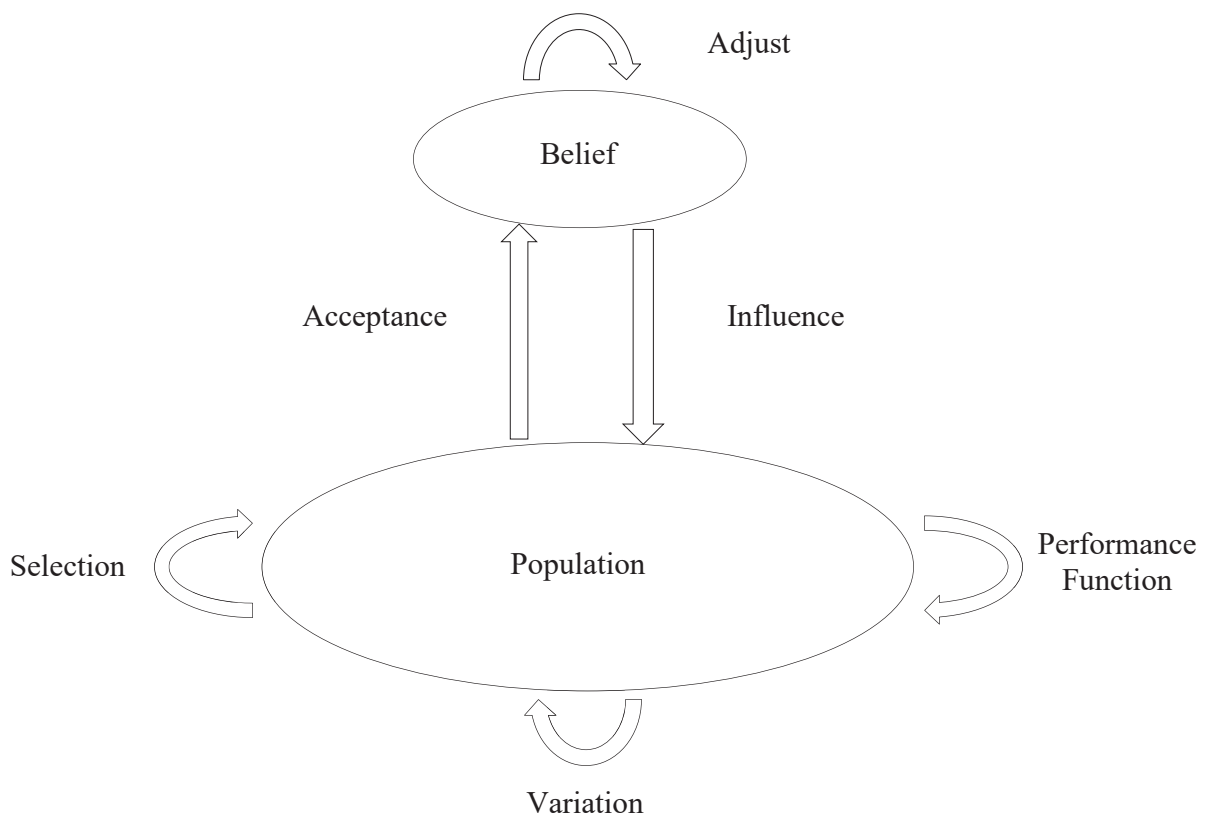
Cultural algorithm (CA) is based on ideological phenomena in which population has a belief. This belief is nothing, but the knowledge which is encrypted and stored; further this knowledge from the individual can be interpreted. The knowledge utilized by individual members is coded in such a way that it could be accepted by the member of society.

Cultural algorithm (CA) has two operating spaces. First, the population space where each individual member has specific feature which identifies its fitness. Second space represents the belief space where knowledge modifies itself through generations. New population is generated due to the modification of the knowledge in which the ancestors can be replaced by their descendants. In order to interconnect the two spaces, it is must to have communication links between them which would alert and send the information in the two spaces. Two important communication functions are *influence* and *acceptance* which affects the two spaces.

Most of the Cultural Algorithm (CA) has the same arrangement and obeys the traditional procedure mentioned below. The Fig. 3.4 explains it in a better way

1. Access the Population (its size, type etc.)

2. Initialize the belief space
3. Evaluate the individuals of the population.
4. Examine each individual of the population by comparing it with the belief space.
5. Apply the changes in the population as per the belief space.
6. Check the performance of each individual after the modification.
7. Repeat the procedure from step 3 until the favorable outcome is obtained.



3.4 Block diagram for Cultural Algorithm

3.10 Cultural Algorithm for DG sizing

Cultural algorithm is an evolutionary approach which helps to identify the optimal size of the Distributed generation (DG). The main challenge is to implement the load flow on cultural algorithm technique. We can consider the DG as a machine and the bus locations as a set of tasks. There are two spaces present in the algorithm as mentioned in section 3.8. The different

size (power rating) and the type of the DG, comes under the population space. On the other hand the objective function defines the Belief space. The communication links shown in the Fig.3.4 represents the constraints and the restrictions for which the size of the DG might change. To initialize the population, the maximum and the minimum limit of the DG size must be mentioned. The range and the type of DG are at micro-evolutionary level. There are infinite possibilities between any two numbers; hence certain feasible range will be required to determine the new population. The performance of the individual DG is tested and compared with the last individual. The range for which the load flow shows better outcome, is selected otherwise, several variations takes place to narrow the population range. The objective function (belief) also adjusts itself to get the best output.

In the load flow, the main objective is loss minimization for which different type and size of the DG are utilized. The sizing of the DG also depends on the type of the DG. There are four types of DG as explained in 3.6. In this thesis first three types of DGs are tested. The selection of the type and the size of the DG are at macro-evolutionary level. The range of the DG for which the load flow gives feasible solution depends on the branch losses. It has been observed that active power DG has better loss reduction capability than reactive power DG. The size of the DG decides the cost of the system, it is not necessary that DG with higher power rating will be more reliable or cost efficient. The choice of the DG also differs due to the environment in which it is used. Availability of the sources and fuel decides the existence of the DG.

The load flow for unbalanced radial distribution network has many ups and downs. The losses in each branch are not same hence; identifying the perfect DG for each phase is a very long process. To avoid long iteration, three phase DGs are preferred over individual single phase DG. In case, when LSI represents three different bus locations at each phase, single phase DG are preferred. The complete load flow with allocation and sizing of DG is explained in the flowchart in Fig.3.5. The complete algorithm is only for a particular type of DG.

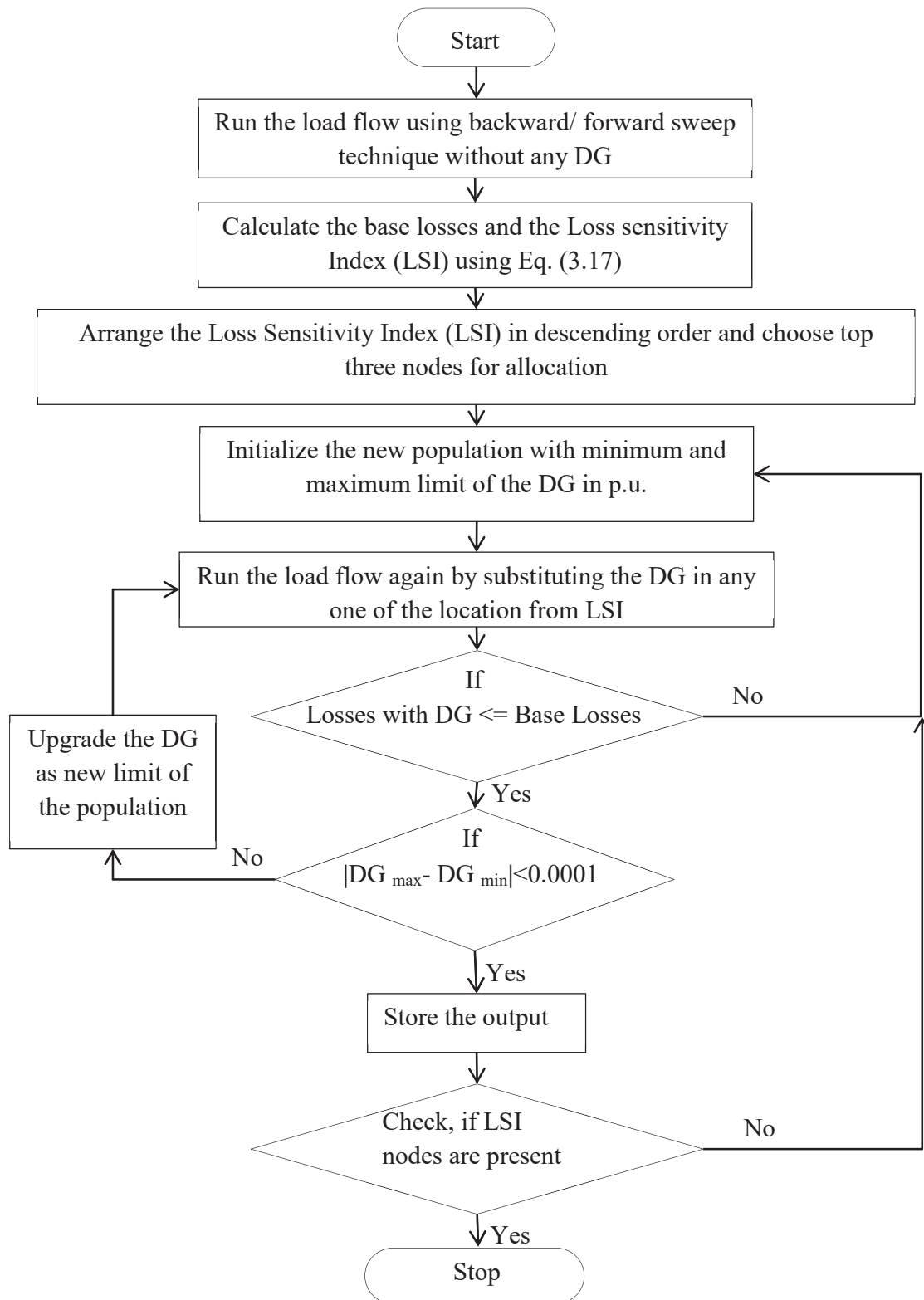


Fig. 3.5 Flowchart for DG siting and sizing

3.11 Combinations for DG

There are three types of DG and three possible ways to substitute them. Here we can say that there are nine possible combinations for getting feasible solutions. The main intention of an operator is to get the best solution, which can be achieved by direct comparison of the results. In this work net losses will be the reference of comparison. The size and the type of the DG for which total system loss is least will be considered as the best DG. The overall analysis is based on single DG placement. For multiple DG placements, the more number of combinations are possible; consequently the complexity will be more.

Chapter-4

RESULTS

4.1 Test networks

The overall thesis is based on three phase unbalanced distribution system of radial configuration. The complete power flow analysis, DG adjustment and its related algorithm have been implemented on 19 node and 25 node URDNs. The crucial parameters of both the networks have been presented and compared with different possible arrangements of the DG. The complete line data and load data related to the bus system are given in the Appendix-A section. The bus arrangement of 19-node system and 25-node system are shown in Fig 4.1 and Fig. 4.2 respectively. In each case branches are represented as “b” and nodes as a number

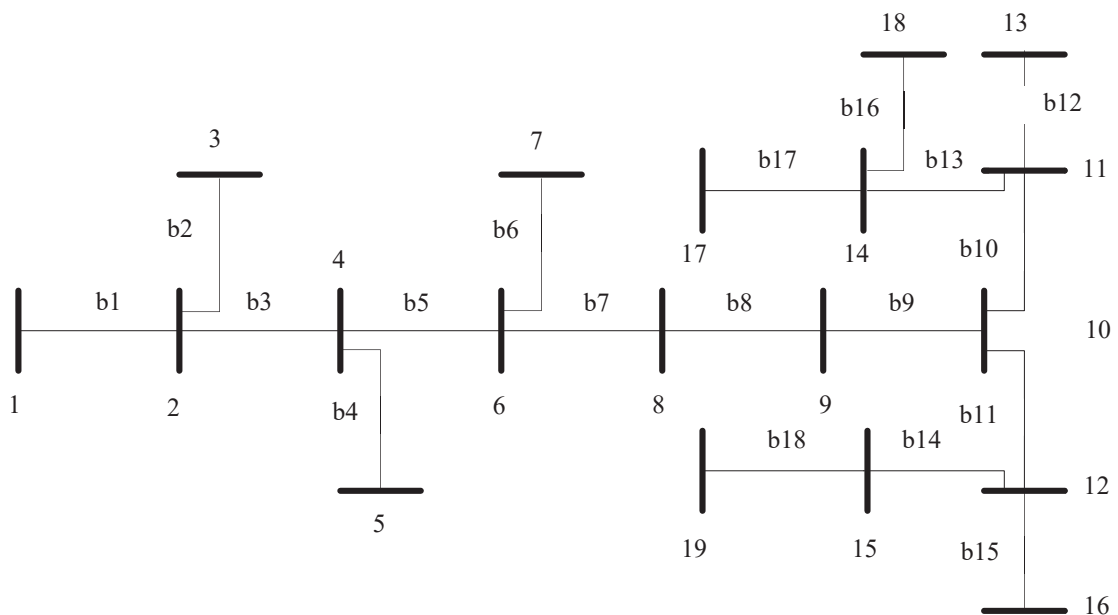


Fig. 4.1: 19 bus URDN(Unbalanced radial distribution network)

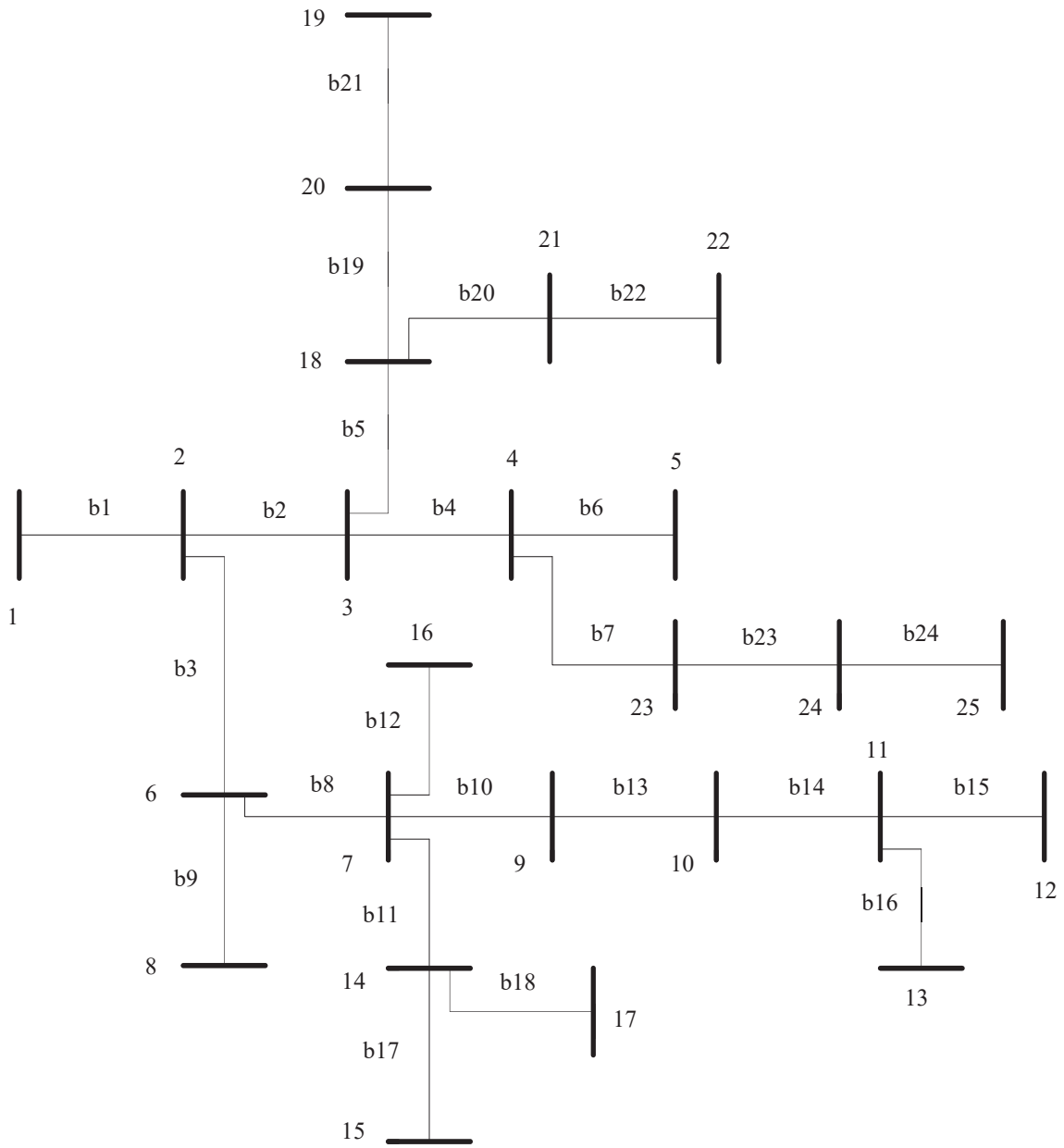


Fig 4.2: 25 bus URDN (Unbalanced radial distribution network)

4.2 Bus systems

4.2.1 Location identification

The best locations for the DG in the bus systems are evaluated by two techniques. Three top priority order nodes from each technique have been taken to estimate the best location for DG placement. Considering all the phases the nodes suitable for specific bus system are mentioned in Table 4.1

Table 4.1: Identification of nodes using different methods

Techniques	19-node	25-node
Identification of the nodes using conventional method	10,11,12	7,9,14
Identification of the nodes using Loss sensitivity index (LSI)	2,10,9	2,6,7

The best location for 19 bus system is node number 10 and for 25 bus system it is node number 7

4.2.2 Power estimation of the DG (sizing)

The selection of the DG has been done by cultural algorithm evolutionary technique (mentioned in 3.8). Three types of generators have been used to analyze the quantity of power. The Table 4.2 represents the different size and the type of generation system suitable for the best node selected from LSI.

Table 4.2: Different size of DG at the best location

Networks	DG –I (kW)	DG –II (kVAr)	DG – III (kVA)
19 bus	85.2	41.6	94.8
25 bus	699	525	874.2

4.3 Loss compensation

There are three different categories of the DG for which the loss minimizing capability is different. The different size and the type of DGs (shown in Table 4.2) have been evaluated to estimate the net power loss compensation, which is presented in Table 4.3

- **Influence of DG on net loss for 19 bus URDS**

Table 4.3: Loss reduction under different categories of DG in 19 bus URDN

		Without using DG		Using DG -I		Using DG -II		Using DG -III	
		Active Power Loss (kW)	Reactive Power Loss (kVAr)	Active Power Loss (kW)	Reactive Power Loss (kVAr)	Active Power Loss (kW)	Reactive Power Loss (kVAr)	Active Power Loss (kW)	Reactive Power Loss (kVAr)
19 bus	a	4.4544	1.9407	1.2055	0.5239	3.6639	1.6104	0.4898	0.2240
	b	4.4540	1.8967	1.1026	0.4829	3.6272	1.5455	0.3623	0.1680
	c	4.5645	1.9591	1.1587	0.4847	3.7485	1.5937	0.4250	0.1575

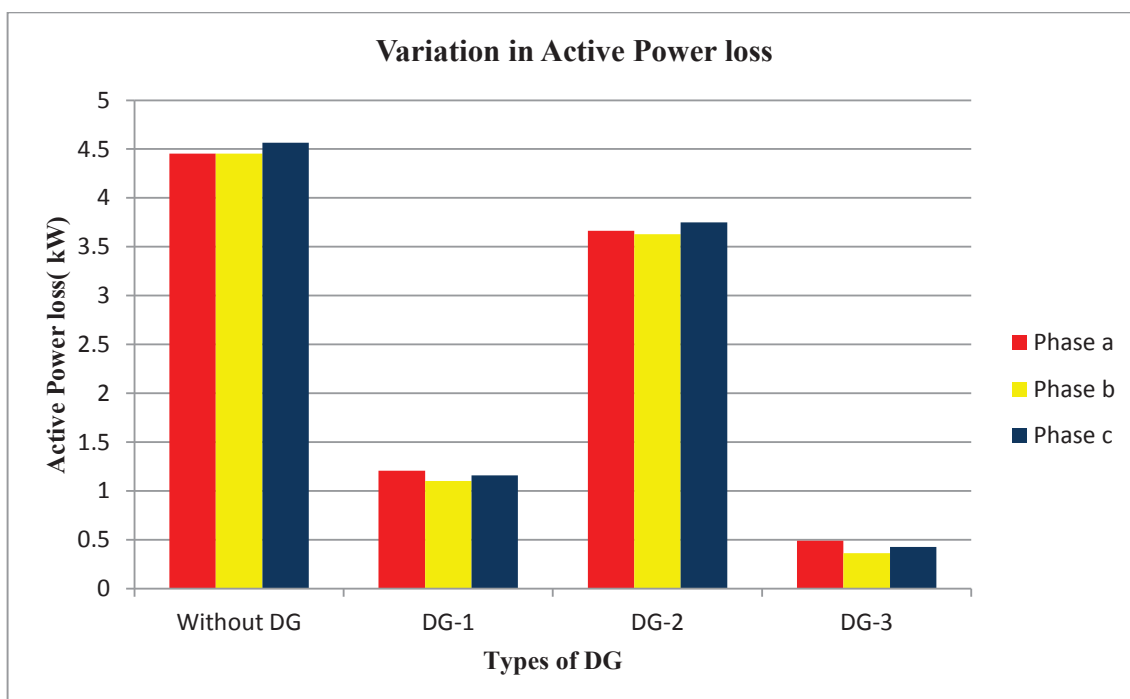


Fig.4.3: Variation in Active Power loss after using different types of DG in 19 bus URDN

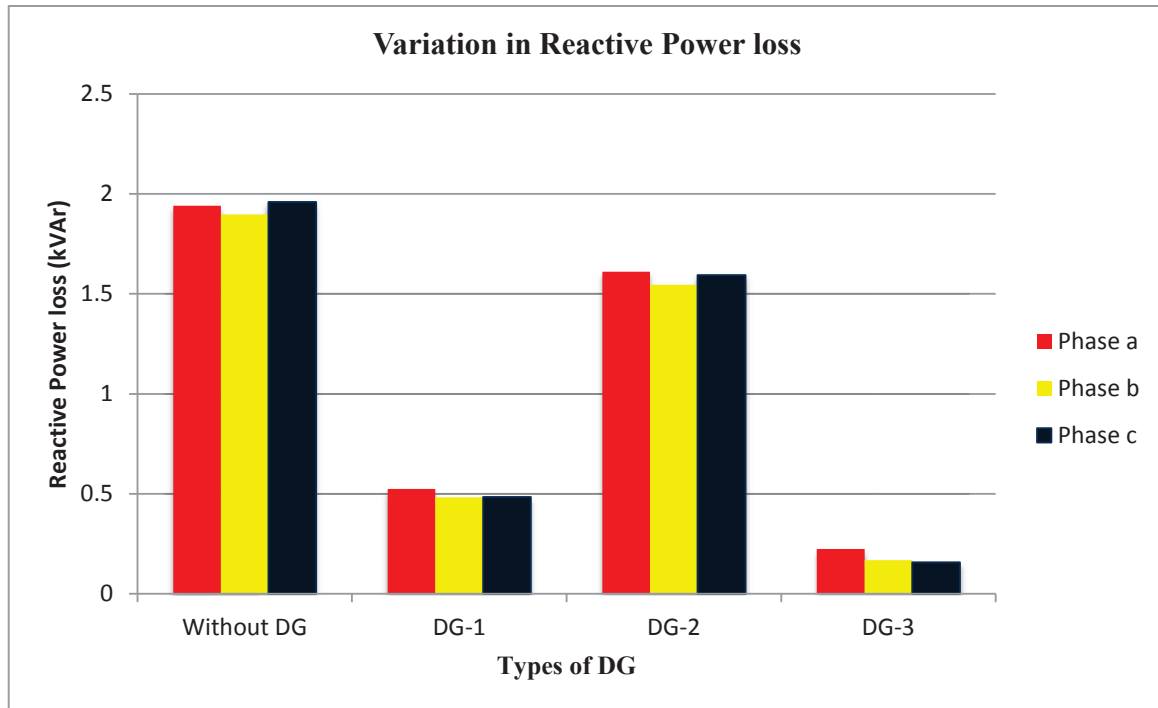


Fig 4.4: Variation in Reactive Power loss after using different types of DG in 19 bus URDN

- **Influence of DG on net loss for 25 bus URDS**

Table 4.4: Loss reduction under different categories of DG in 25 bus URDN

		Without using DG		Using Type -1 DG		Using Type -2 DG		Using Type-3 DG	
		Active Power Loss (kW)	Reactive Power Loss (kVAr)	Active Power Loss (kW)	Reactive Power Loss (kVAr)	Active Power Loss (kW)	Reactive Power Loss (kVAr)	Active Power Loss (kW)	Reactive Power Loss (kVAr)
25 bus	a	52.8149	58.2919	27.7597	29.7892	38.5230	42.0444	14.9697	15.1330
	b	55.4443	53.2953	29.1833	27.4608	40.3225	38.4077	15.5162	13.9279
	c	41.8621	55.6918	22.2912	28.6667	30.5251	40.0685	12.0604	14.3339

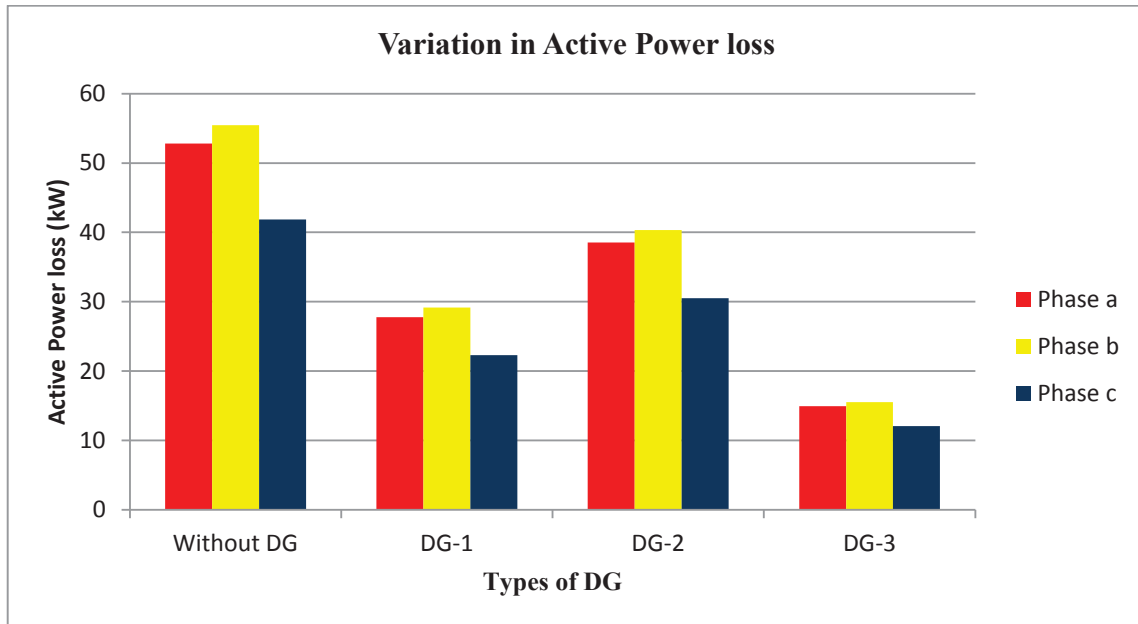


Fig.4.5: Variation in Active Power loss after using different types of DG in 25 bus URDN

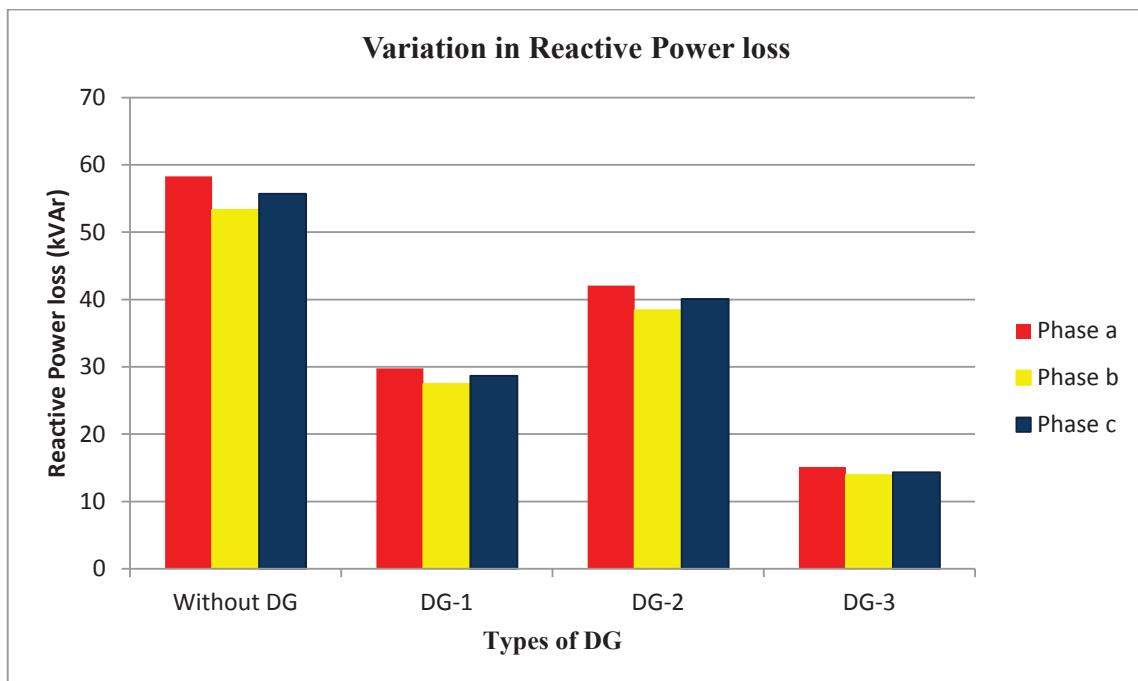


Fig.4.6: Variation in Reactive Power loss after using different types of DG in 25bus URDN

4.4 Voltage improvement

The voltage level rises with the addition of the DG. Like loss compensation analysis there are different categories of the DG. For each category voltage has different magnitude. The end node of each bus system has the lowest voltage level; hence the end node voltage of each network has been described in each case of DG placement in Table 4.5 and Table 4.6

Table 4.5: Minimum bus voltage after DG placement in 19 bus URDN

	Least bus voltage in p. u for 19 bus URDN		
	$ V_a $	$ V_b $	$ V_c $
Without DG	0.951592	0.949758	0.950466
With DG-I	0.988389	0.986737	0.987435
With DG-II	0.959460	0.957674	0.958362
With DG-III	0.995953	0.994339	0.995020

Table 4.6: Minimum bus voltage after DG placement in 25 bus URDN

	Least bus voltage in p. u. for 25 bus URDN		
	$ V_a $	$ V_b $	$ V_c $
Without DG	0.952020	0.954690	0.961166
With DG-I	0.961964	0.964885	0.968008
With DG-II	0.962337	0.963778	0.970738
With DG-III	0.972137	0.973850	0.977492

- Voltage variation in 19 bus URDN

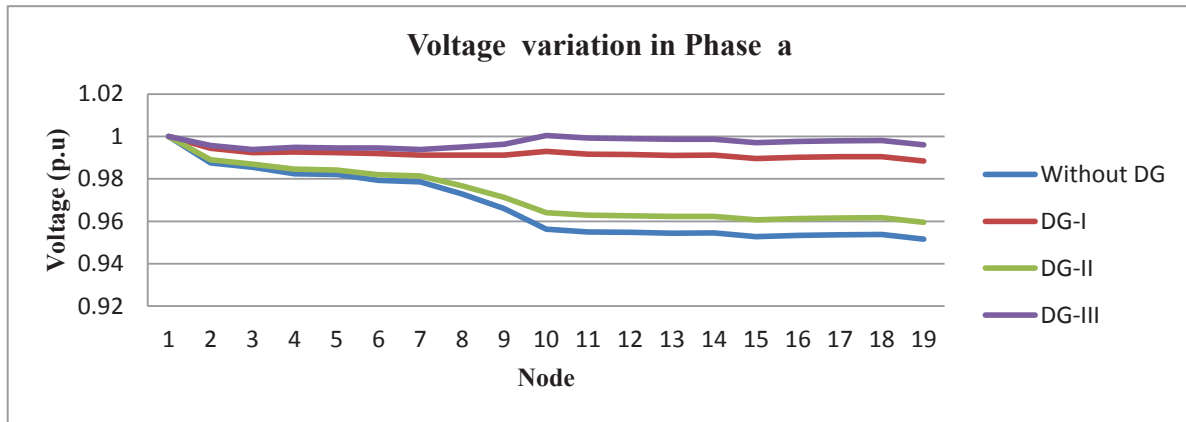


Fig 4.7: Improvement of voltage in phase a for 19 bus URDN

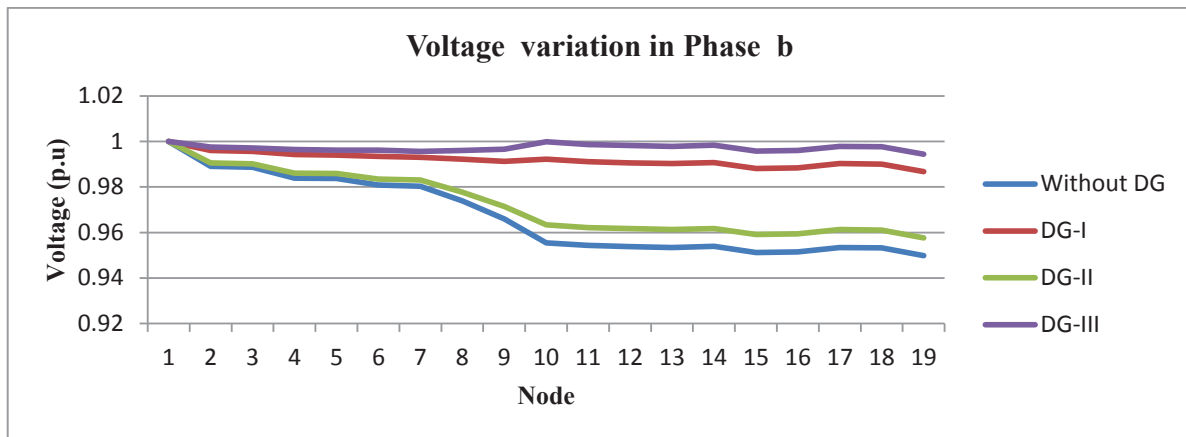


Fig. 4.8.: Improvement of voltage in phase b for 19 bus URDN

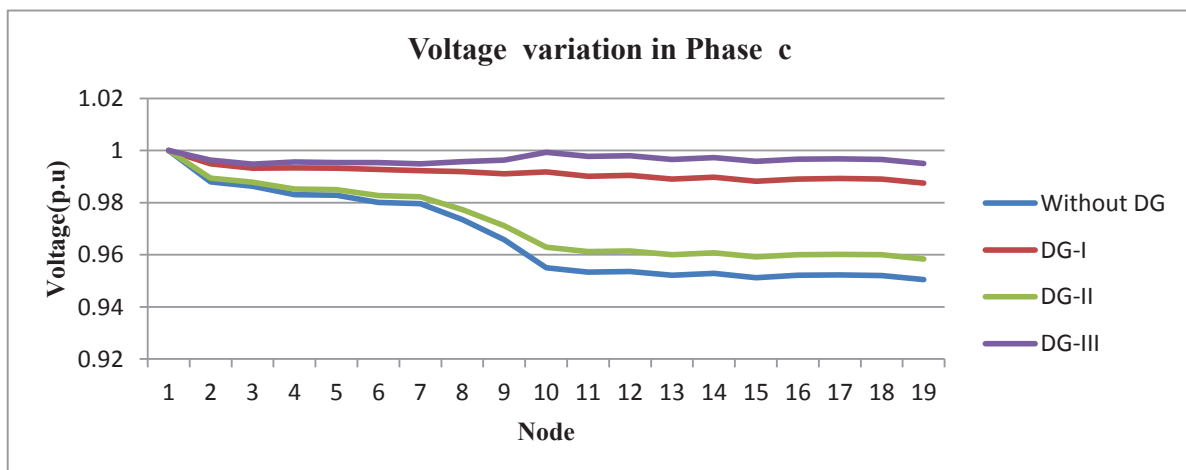


Fig.4.9: Improvement of voltage in phase c for 19 bus URDN

- Voltage variation in 25 bus URDN

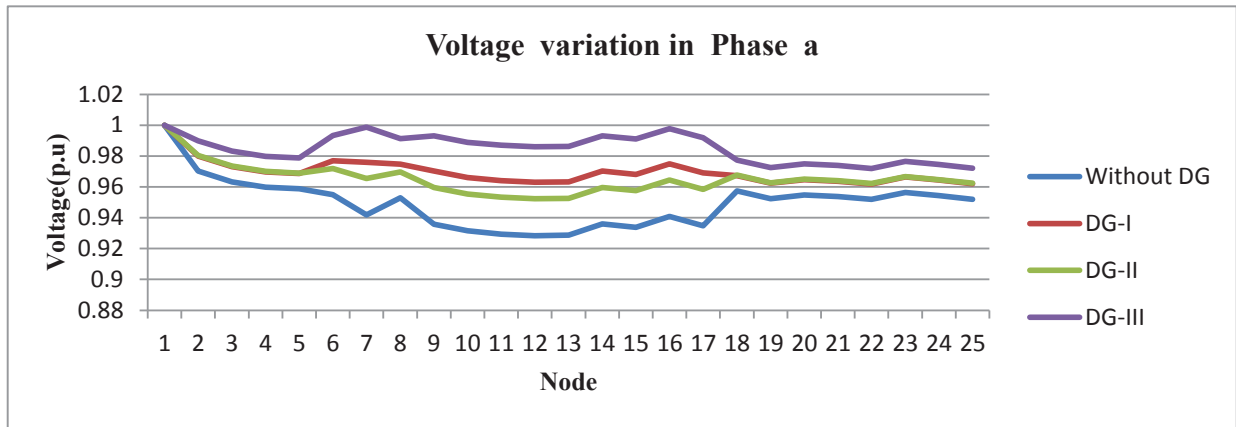


Fig.4.10: Improvement of voltage in phase a for 25 bus URDN

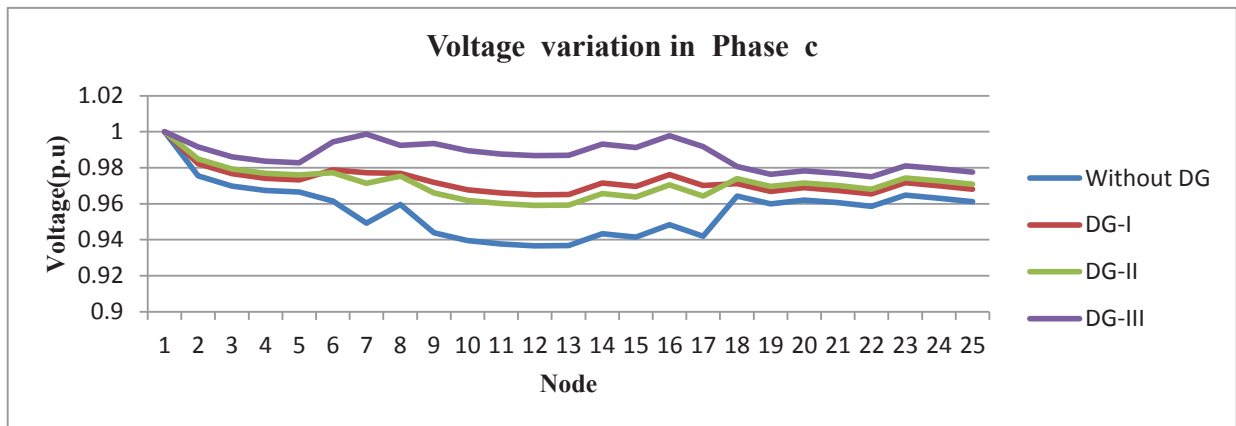


Fig 4.11: Improvement of voltage in phase b for 25 bus URDN

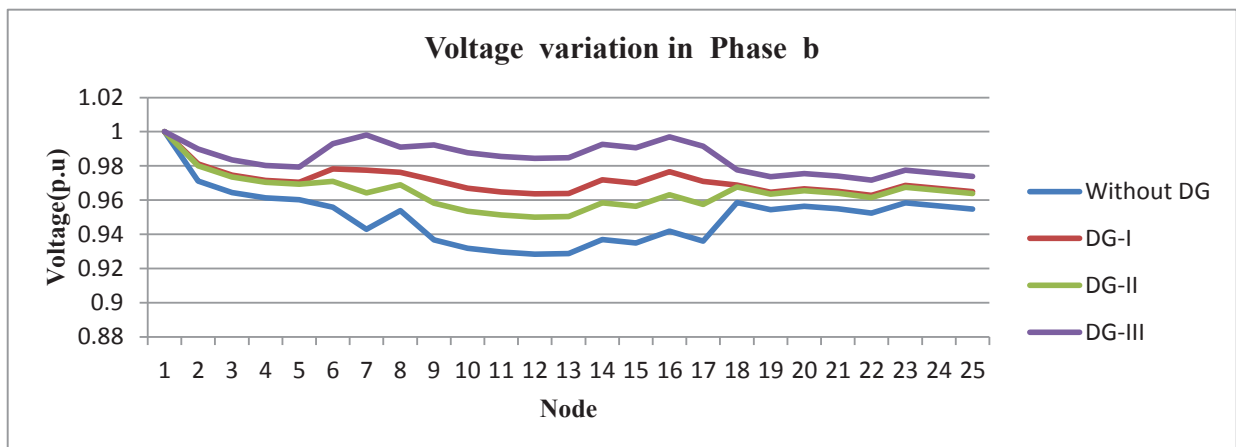


Fig 4.12: Improvement of voltage in phase c for 25 bus URDN

Chapter 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

This thesis has demonstrated the loss minimization phenomena using distributed generators. The overall operation has been executed on 19 node and 25 node URDNs. The load flow is based on backward/forward sweep technique in which position of node was determined by a mathematical approach known as loss sensitivity index (LSI). The node at which distributed generator shows best performance is said to be the perfect location for DG placement. The sizing of DG has been done by a new computational technique known as Cultural algorithm (CA). Three types of DG have been analyzed and compared using this algorithm. The synchronous generator type of DG (DG-III) has shown the best performance in loss reduction for both the URDNs.

5.2 Future Scope

Following modifications can be done

- Presently, this work has been limited up to single DG placement but, further modification could make for multi DG placement.
- Three phase as well as single phase DG placement analysis with hybrid combination of capacitor could make it more efficient.
- Cost analysis of DG could make it more economic and reliable.

LIST OF PUBLICATIONS

1. Rohit Nandi and Smarajit Ghosh, “Literature Survey on Loss Reduction Methods for Three Phase Unbalanced Radial Distribution Network”, Communicated to International Journal of Scientific Research and Education.

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APPENDIX –A

Table A.1 Load data and Line parameters of 19 bus URDN [15]

Branch	Sending end	Receiving end	Conductor type	Length (Km)	Receiving end load kVA					
					Phase A		Phase B		Phase C	
1	1	2	1	3	10.38	5.01	5.19	2.52	10.38	5.01
2	2	3	1	5	11.01	5.34	5.19	2.52	9.72	4.71
3	2	4	1	1.5	4.05	1.95	5.67	2.76	6.48	3.15
4	4	5	1	1.5	6.48	3.15	5.19	2.52	4.53	2.19
5	4	6	1	1	4.2	2.04	3.09	1.5	2.91	1.41
6	6	7	1	2	9.72	4.71	8.1	3.93	8.1	3.93
7	6	8	1	2.5	7.44	3.6	5.34	2.58	3.39	1.65
8	8	9	1	3	12.3	5.97	14.91	7.23	13.29	6.42
9	9	10	1	5	3.39	1.65	4.2	2.04	2.58	1.26
10	10	11	1	1.5	7.44	3.6	7.44	3.6	11.01	5.34
11	10	12	1	1.5	9.72	4.71	8.1	3.93	8.1	3.93
12	11	13	1	5	4.38	2.13	5.34	2.58	6.48	3.15
13	11	14	1	1	3.09	1.5	3.09	1.5	4.05	1.95
14	12	15	1	5	4.38	2.13	4.86	2.34	6.96	3.36
15	12	16	1	6	7.77	3.78	10.38	5.01	7.77	3.78
16	14	17	1	3.5	6.48	3.15	4.86	2.34	4.86	2.34
17	14	18	1	4	5.34	2.58	5.34	2.58	5.52	2.67
18	15	19	1	4	8.76	4.23	10.05	4.86	7.14	3.45

(Base voltage 11 kV, Base MVA=1)

Table A.2 Impedance (ohm/km) matrix of 19 bus URDN [15]

	a	b	c
a	1.5609+j0.67155	0.5203+j0.22385	0.5203+j0.22385
b	0.5203+j0.22385	1.5609+j0.67155	0.5203+j0.22385
c	0.5203+j0.22385	0.5203+j0.22385	1.5609+j0.67155

Table A.3 Load data and Line parameters of 25 bus URDN [15]

Branch	Sending end	Receiving end	Conductor type	Length (ft)	Receiving end load kVA					
					Phase A		Phase B		Phase C	
1	1	2	1	1000	0	0	0	0	0	0
2	2	3	1	500	35	25	40	30	45	32
3	2	6	2	500	40	30	45	32	35	25
4	3	4	1	500	50	40	60	45	50	35
5	3	18	2	500	40	30	40	30	40	30
6	4	5	2	500	40	30	40	30	40	30
7	4	23	2	400	60	45	50	40	50	35
8	6	7	2	500	0	0	0	0	0	0
9	6	8	2	1000	40	30	40	30	40	30
10	7	9	2	500	60	45	50	40	50	35
11	7	14	2	500	50	35	50	40	60	45
12	7	16	2	500	40	30	40	30	40	30
13	9	10	2	500	35	25	40	30	45	32
14	10	11	2	300	45	32	35	25	40	30
15	11	12	3	200	50	35	60	45	50	40
16	11	13	3	200	35	25	45	32	40	30
17	14	15	2	300	133.3	100	133.3	100	133.3	100
18	14	17	3	300	40	30	35	25	45	32
19	18	20	2	500	35	25	40	30	45	32
20	18	21	3	400	40	30	35	25	45	32
21	20	19	3	400	60	45	50	35	50	40
22	21	22	3	400	50	35	60	45	50	40
23	23	24	2	400	35	25	45	32	40	30
24	24	25	3	400	60	45	50	30	50	35

(Base voltage 4.16 kV, Base MVA=30)

Table A.4 Impedance (ohm/mile) matrix of 25 bus URDN [15]

Type		a	b	c
1	a	0.3686+j0.6852	0.0169+j0.1515	0.0155+j0.1098
	b	0.0169+j0.1515	0.3757+j0.6715	0.0188+j0.2072
	c	0.0155+j0.1098	0.0188+j0.2072	0.3723+j0.6782
2	a	0.9775+j0.8717	0.0167+j0.1697	0.0152+j0.1264
	b	0.0167+j0.1697	0.9844+j0.8654	0.0186+j0.2275
	c	0.0152+j0.1264	0.0186+j0.2275	0.9810+j0.8648
3	a	1.9280+j1.4194	0.0161+j0.1183	0.0161+j0.1183
	b	0.0161+j0.1183	1.9308+j1.4215	0.0161+j0.1183
	c	0.0161+j0.1183	0.0161+j0.1183	1.9337+j1.4236