

# **LOSS MINIMIZATION BY ALLOCATING DG IN RADIAL DISTRIBUTION NETWORK USING BFOA**

A Dissertation submitted in fulfillment of the requirements for the Degree

of

**MASTER OF ENGINEERING**

*In*

**Power Systems**

*Submitted by*

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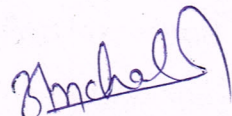
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## DECLARATION

I hereby certify that the work which is presented in dissertation entitled “**Loss Minimization by Allocating DG in Radial Distribution Network using BFOA**” in the partial fulfillment of the requirement for the degree of **Master of Engineering in Power Systems**, Submitted in Electrical and Instrumentation Engineering department, Thapar University, Patiala is an authentic work carried out under the guidance of **Dr. Smarajit Ghosh**, Professor EIED, Thapar University. It refers others researcher’s work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, either in part or in full to any other degree to any other university or institute except as reported in text and references.

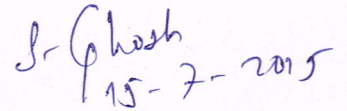
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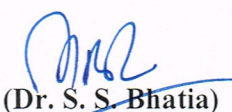
  
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The paucity of words does not compromise to thank my parents, whose blessings have brought me this far in life.

(AANCHAL JAGGA)

***DEDICATED TO MY PARENTS***

## **ABSTRACT**

The requirement of reliable and energy is increasing day by day. There is a need to set-up new infrastructure like more generating stations, install new transmission lines and utility to meet the demand. But installing of these is very time consuming and costly. Also more policies are build up for the liberalization of the electricity market as more companies are emerging to enter the market. In addition technical advancement in small-scale generation units popularly known as distributed generation enhances its role in today's market. The usage of DG helps to decrease the losses and improves the voltage profile. It also provide grid reinforcement and more reliable supply to the consumer. To optimize the losses the size of DG must be strategically placed. Various methods are presented to optimize the size of DG at a location. In this thesis work, loss sensitivity factor to select the location and bacterial foraging optimization technique is to obtain the optimal size to minimize the losses. The given method is tested on 69-node in RDN.

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# CHAPTER-1

## INTRODUCTION

### 1.1 BACKGROUND

Because of the regular rising need for electrical power generation and its reliability of supply, research work for innovative work are being done in this field. A large number of new structures, transmission lines and utility restructuring needs to be build up to lower the losses. But adding of new centralized generation have its own complexities for long distance power transmission constraint restriction due to the capacity limits of the lines, this have created increased interest in distributed power generation. Distributed generation (DG) devices if strategically placed in power systems it helps in grid reinforcement and reduction of power losses. Also the on-peak operating costs and voltage profiles are improved. This helps in increasing the efficiency and reliability of the system [1].

### 1.2 DEFINATION OF DISTRIBUTED GENERATION

Various definitions of DG are presented below:

*DPCA (Distributed Power Coalition of America)*

Distributed power generation is any small-scale power generation technology that provides electric power at a site closer to customers than central station generation. A distributed power unit can be connected to the distribution system directly or to the consumer.

*CIGRE (International Conference on High Voltage Electric Systems)*

Distributed generation upto the range of 100MW generally connected to the distribution network. These may or may not connected to the system centrally therefore not necessary they are centrally dispatched.

*IEA (International Energy Agency)*

Distributed generation is generating plant serving a customer on-site, or providing support to a distribution network, and connected to the grid at distribution level voltages. The

technologies normally include engines, small (including micro) turbines, fuel cells and photovoltaic.

As conclusion, DG is considered as a unit which may or may not be planned, or connected to the central grid system. It is allocated to the system to reduce the losses and improve the voltage profile. Addition of a DG to a network increases the reliability of the whole system.

### **1.3 ADVANTAGES FOR DISTRIBUTED GENERATORS**

- a) Load centres being far-off places much energy is dissipated in transmitting and distributing the energy. Hence new DGs are installed to compensate these losses. These dgs are set-up near the electric utility. Thus it reduces losses in the system.
- b) Setting up of new DGs decreases the dependency of consumers on the main grid. Thus making the system more reliable.
- c) DGs if strategically placed helps in reducing the losses and improving the voltage profile. Since losses are reduced efficiency of the system improves.
- d) As the efficiency of the system increases cost to the end consumer decreases. Hence decreasing the overall cost and improves reliability.

This thesis presents a distribution generation (DG) allocation strategy to improve node voltage and power loss of radial distribution systems using bacterial foraging. The objective is to minimize active power losses while keep the voltage profiles in the network within specified limit.

### **1.4 TYPES OF DG**

Various types of DGs are

Type1:

DGs that are capable of injecting or suppling the active power only are categorized in this type.

These are generally DC power sources that are integrated to the main grid using inverters or converters. Maximum range of DGs under this category is less than 500MW. Examples are fuel cells, photovoltaic cells and microturbines.

Type 2:

DGs that supply only reactive power fall under this category. Examples are synchronous compensator, gas turbines.

Type3:

DGs that supply or inject both real and reactive power . Co-generation is primarily used these types of DG. Examples are DG units which are based on synchronous machine.

Type4:

DGs that supply real power but consume reactive power are categorized in this type. Example are induction generators used in wind farms[2].

## 1.5 LITERATURE REVIEW

This literature survey presents the definition of DG and various methods such as network reconfiguration, DG allocation to minimize the losses. Influence of a DG in a distribution network is also studied.

**Civanlar *et al.*** [3] presented a method to decrease the losses by feeder reconfiguration. Losses could be decreased by altering the on/off states of the sectional and tie-line switches. The proposed method suggested a methodology to vary the states of the switches that could reduce the losses. This filtering mechanism significantly reduces reducing the computational time.

**Nara *et al.*** [4]used the genetic algorithm to reduce the losses for distribution system reconfiguration. The authors proposed GA is based on the principle of the survival of fittest. GA could be applied to both ill-structured optimization problems and continuous optimization.

**Fan *et al.*** [5] suggested that in order to reduce the losses by network reconfiguration, single loop optimization technique could be used. This methodology solved a linear programming problem by simplex method. The author described a heuristic approach for optimizing the switch plan to reach the optimal configuration.

**Barker and Mellow** [6] considered the impact of distributed generation in power system that could drastically affect power flow and voltage at customers-end and utility equipment. The benefits of distributed generation include reduction in losses, reliability, voltage support and improved power quality. The factors that determined system impacts included not only the size, but also the dynamic characteristics of the generator and various else parameters.

**Kim et al.** [7] presented a fuzzy-GA method for reducing the losses. The objective function to reduce the power losses was achieved by placing the DG at optimized location. Fuzzy evaluates the multi-objective function that was the reason to convert the objective function and its constraints in terms of number and size of DG that were evaluated as multi-objective function.

**Losi and Russo** [8] proposed an object oriented algorithm based on Newton-Raphson technique. This type of tactic added flexibility to the system. In the proposed technique used a set the convergence criteria emphasis during mapping the electrical parameters to the mathematical parameters.

**Acharya et al.** [9] presented the analytical approach to shrink the losses with help of DG. This paper also described the effect on losses with respect to size and location. The comparison between exhaustive load-flow and loss sensitivity method was analysed. In that method the exact loss formula was considered in order to compute the whole methodology.

**Beroni et al.** [10] presented the particle swarm optimization(PSO) algorithm on the given test system. The proposed algorithm was applied to radial distribution network to improve the voltage profile. It also gave additional benefits like loss reduction and THD. They inferred that PSO gave better results when compared to GA in terms of solution quality and calculation complexities.

**Sagar and Prasad** [11] studied the impact of DG in RDN. The author distinguished the DG from the conventional generating units as DGs would experience more derated states. The inference were drawn from the reliability indices, load point indices and performance indices calculated through the proposed analytical technique.

**Mouti and El-Hawary** [12] compared the three techniques named as modified artificial bee colony(MABC), ABC and the analytical methodology on various bus systems. On comparison modified ABC algorithm approach gave the optimal solution in the least computation time and yield high quality solution among all.

**Ochoa et al.**[13] presented a technique to evaluate the maximum capacity of any new variable distributed generation. That technique is based on a multi-period AC optimal power flow for, connected in distribution system in presence of active network management (ANM) strategies. ANM strategies embedded coordinated the voltage control, adaptive power factor and energy reduction into the OPF.

**Shukla et al.** [14] presented a multi-location distribution generation problem in order to trim down active power losses of radial distribution system using the genetic algorithm based solution. The loss sensitivity, to change active power injection, was used in order to select an optimal node for DG placement.

**Dent et al.** [15] explained the impact of the size of DG to a RDN. In that method, the voltage step constraints had been integrated with the OPF method to examine the capacity of network to allocate the DG unit.

**Khodr et al.** [16] presented a probabilistic approach in order to aid the engineers of system planning in the selection of location of distributed generator, considering hourly load changes or daily load cycle. The location selected was according to their load magnitude, and used to calculate best probability distribution.

**Singh and Goswami** [17] suggested a new methodology which was based on nodal pricing to allocate DG unit for optimized results for loss reduction and voltage profile improvement. The method was carried out for time variant and time invariant loads, as well, by incorporating single and multiple DG units in an existing Indian rural distribution network.

**Koutroumpetis and Safigianni** [18] gave a suitably modified and optimized scheme by intriguing a real network with already installed DG unit. The method was used to determine the optimally placing the multiple DG units in a pre-determined bus as well as the other buses without changing their network structures.

**Akorede et al.** [19] proposed a valuable method to guide the electric utility distribution companies to determine the optimal position and size of DG unit used in the distribution system. This proposed approach considered system constraints and maximized the system profit of the distribution companies and loading margins.

**Moradi and Abedini** [20] proposed a novel genetic algorithm (GA) and PSO in order to find out the optimal size and location of DG units in a RDN. The main advantage of this method was homogeneous solution with negligible value for variances and also optimized the system at the same time.

**Naik et al.** [21] presented the analytical method to shrink the losses in RDN. This enhance the economy of the utility to decrease as well as improve the voltage profile.

**Mistry and Roy**[22] applied a PSO technique with constriction factor to determine the optimal sizes and locations of multiple DG units. A pre-determined load growth was considered as constraints with voltage regulation for five year.

**Karimyan et al.** [23] proposed a long term scheduling technique for optimal sizing and siting of DG unit for decreasing the power losses and improving the voltage profile of RDN. Particle swarm optimization (PSO) and an effective analytical method had been used to obtain reliable solution.

**Devi and Geetanjali**, [24] presented an optimization technique based the principle of bacyerial foraging. The bacterial foraging optimization to reduce the overall losses of a radial distribution system. These papers also considered the effect of distributed generation unit in distribution system. A modified bacterial foraging algorithm had been used to obtain the test result. It was proved that modified BFOA is more convenient and effective than other algorithm.

## **1.6 PURPOSE AND CONTRIBUTION OF THIS THESIS WORK**

The purpose of thesis work is to analyze the method to reduce the loss in RDN by placing the DG of suitable size. To obtain the above purpose following steps are taken:

- a) A load-flow program wisely used for an RDN.
- b) The methodology that effectively favors the location where a DG placed would result in minimizing the losses.

## **1.7 ORGANIZATION OF THESIS**

Chapter 1 presents a little background and definitions of DG. Also it presents the already work done in this field.

Chapter 2 shows the load-flow, which forms the life-line of RDN as it computes the voltage at the nodes, real and reactive losses for the base as well as for the proposed methods.

Chapter 3 proposed the algorithm for siting and sizing of DG.

Chapter 4 shows the problem formulation that contains the objective function along with its constraints.

Chapter 6 presents the result computed from the above methodologies.

## **CHAPTER-2**

### **LOAD-FLOW ANALYSIS**

#### **2.1 POWER FLOW ANALYSIS**

##### **2.1.1 INTRODUCTION**

In power system load-flow has become the life line of any RDN because it yields the electrical performance and power-flow in terms of real and reactive power losses and voltages at different nodes of the system under operating steady state. An efficient load-flow study becomes very effective for optimal conductor selection during planning of the system and also for the stability analysis of the system [25]. The load-flow is important for the analysis of distribution system, to investigate the issues related from planning, design to the operation and control. Many classical methods such as Gauss-Seidel, Newton Raphson are used to carry out the load-flow of transmission system.

In this thesis work, load-flow is applied on a distribution network. These systems are structurally weakly meshed but are operated with considering radial nature and because of the ease of computation in radial system the network has simplicity in design and cost. These networks have high R/X ratio on the other hand, the transmission system is loop in nature whereas the transmission networks have high X/R ratio.

If some quantities are known, for example the amount of power generated and consumed at different locations then with the help of load-flow analysis other unknown quantities are known. Voltage is the most important quantity of all of these quantities are the voltages at locations throughout the system. It contain both a magnitude and a time element or phase angle. The current flowing through every link can computed if the voltages are known. Thus once we have performed load-flow analysis we may determine how it flows in the distribution system. A power flow study basically uses simplified notation like per-unit and single line diagram (SLD) unlike traditional circuit analysis. Power flow focuses on different form of AC power (i.e.: reactive or active power) rather than voltage and current. Power flow analysis helps in planning of future expansion of the system and also determines the best operating condition.

### 2.1.2 BUS CLASSIFICATION

A bus is a node at which connects lines, loads and generators. In a power system, four quantities are specified which are voltage, phase angle, active and reactive power. To run a load flow 2 quantities must be specified 2 are required to be determined through the solution of equation. Depending on the quantities that have been specified, the buses are classified into 3 categories. For load-flow studies it is assumed that the loads are constant and they are defined by their real and reactive power consumption. The main objective of the load-flow is to find the voltage magnitude of each bus and its angle when the powers are generated and loads are pre-specified. The buses are classified as:

i) Load Buses (P, Q specified)

In these buses load is connected and therefore the generated real power  $P_{Gi}$  and reactive power  $Q_{Gi}$  are considered as zero. The load drawn by these buses are defined by real power  $P_{Li}$  and reactive power  $-Q_{Li}$  in which the negative sign signifies for the power flowing out of the bus. This is why these buses are called as P-Q bus. The objective of the load-flow is to find the bus voltage magnitude  $V$  and its angle  $\delta$ .

ii) Voltage Controlled Buses (P,V specified)

The buses that have generators are connected to them are known as voltage controlled buses. Hence the power generation in such type of buses are controlled through a prime mover while the terminal voltage which is controlled through the generator excitation. Here the input power constant is kept constant through turbine-governor control and to keep the bus voltage constant automatic voltage regulator is used, constant  $P_{Gi}$  and  $|V_i|$  are specified for these buses.

iii) Slack or Swing Bus (V, $\delta$  specified)

Generally this bus is referred as the reference thus numbered "1" for the load-flow studies. This bus also sets the angular reference for all the other buses. Since it is the angle

difference between two voltage sources that dictates the real and reactive power flow between them, the particular angle of the slack bus is not important. However, it sets the reference against and the angles of all other bus voltages are measured. For this reason the angle of this bus is usually chosen as  $0^\circ$ . Furthermore it is assumed that the magnitude of the voltage of this bus is known [26].

## 2.2 LOAD-FLOW TECHNIQUE

The load technique proposed by Ghosh and Das [27] is used in this thesis work.

Initially, the voltage for all the buses is assumed to be unity.

The branch number (LN1), sending-end(m1) and receiving-end (m2) node of the bus is known. For branch 1, the receiving-end node voltage can be given by:

$$V(2) = V(1) - I(1)Z(1) \quad (2.1)$$

Similarly for branch 2,

$$V(3) = V(2) - I(2)Z(2) \quad (2.2)$$

If branch current  $I(1)$  is known  $V(2)$  can be computed from Eq. (2.1).

Similarly, if  $I(2)$  is known  $V(3)$  can be computed from Eq. (2.2), and so on.

In general,

$$V(m2) = V(m1) - I(jj)Z(jj) \quad (2.3)$$

$m2 = \text{Voltage at the receiving end}(jj)$

$m1 = \text{Voltage at the sending end}(jj)$

where  $jj$  is the branch number.

Equation (2.3) can be evaluated for all the branches,  $jj = 1, 2, \dots, LN1$

where :  $LN1 = N_B - 1 = \text{number of branches}$

$N_B = \text{no. of nodes.}$

Current through branch 1 is equivalent to the sum of the branch of branch 2 and load current of node2.

$$I(1) = I(2) + IL(2) \quad (2.4)$$

Similarly,

$$I(2) = I(3) + IL(3) \quad (2.5)$$

For  $i=2$ , The current through branch 2 is equal to the sum of the load currents of all the nodes beyond branch 2 plus the sum of the charging currents of all the nodes beyond branch 2.

Therefore, if it is possible to identify the nodes beyond all the branches, it is possible to compute all the branch currents.

Load current of each node is calculated as

$$IL(i) = \frac{PL(i) - jQL(i)}{V^*(i)} \quad i=2,3,\dots, NB \quad (2.5)$$

Initially, a flat voltage of all the nodes is assumed and load currents of all the nodes are computed using Eq. (2.4) and (2.5). The branch current is equivalent to the load current itself for terminal buses as there are no branches beyond that. Terminal buses can be easily found out by analyzing the sending-end buses, the bus will be a terminal bus, which doesn't exist in the array  $m1$ .

When the load current and branch currents are computed, voltages are updated at the respective nodes and the convergence criteria is met.

After the obtaining value of  $V$ , real and reactive power losses are obtained.

Real power losses are calculated by

$$P_L = |I(jj)|^2 R(jj) \quad (2.6)$$

Reactive power losses are given by

$$Q_L = |I(jj)|^2 X(jj) \quad (2.7)$$

## CHAPTER 3

### SITING AND SIZING OF DG

#### 3.1 SITING OF DG

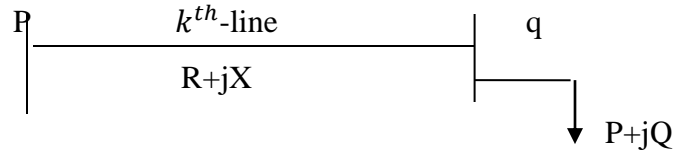
It is one of the crucial factor to minimize the losses. So the technique for the identification of node to place the DG must be wisely chosen.

In this thesis work, loss sensitivity factor method is considered to find the sensitive nodes proposed in [28]

##### 3.1.1 LOSS SENSITIVITY FACTOR

Major lead to use this method is this reduce the search space.

A distribution line with load P and Q is considered.



Real power are given as

$$P[q] = \frac{(P^2[q] + Q^2[q])R[k]}{(V[q])^2} \quad (3.1)$$

Similarly for reactive power

$$Q[q] = \frac{(P^2[q] + Q^2[q])X[k]}{(V[q])^2} \quad (3.2)$$

Real power supplied beyond the node q: P[q]

Reactive power supplied beyond the node q: Q[q]

Loss sensitivity factor is computed

$$\frac{\partial P_{loss}}{\partial Q} = 2 * \frac{Q^2[q] * R[k]}{(V[q])^2} \quad (3.3)$$

$$\frac{\partial Q_{loss}}{\partial Q} = 2 * \frac{Q^2[q] * X[k]}{(V[q])^2} \quad (3.4)$$

For DG allocation, Eq (3.3) is computed, evaluated and arranged in the descending node.

Node with the highest priority or say the topmost node is allocated with DG.

### **3.1.2 ALGORITHM OF LSF:**

Step1: Calculate the loss sensitivity factor.

Step2: Arrange it in descending order.

Step3: Node with the highest priority is allocated with DG.

Step4: Select the node and the size of DG can be calculated at that node.

Step5: Store that size DG that gives the minimum losses.

### **3.2 SIZING OF DG**

The optimization of the DG size is computed through this system. Foremost advantage is less computational time.

The method was proposed by [24].

#### **3.2.1 BACTERIAL FORAGING**

Passino evolved BFOA to find the optimal rating of FACTS devices in 2002. BFO algorithm constitutes the computational chemo taxis, where bacteria used to contender solution for any given optimization problem takes steps towards the foraging site to achieve an area with high-nutrient content (analogous to higher fitness value). BFOA aims at replication of the individual and group behavior of the E. Coli bacteria as a scattered optimization process. This is because of E. Coli i.e. a microorganism which searches its food faster than others to get minimum real power loss, minimization of total cost, improvement in voltage stability, voltage profile improvement. In this thesis work BFOA is used for optimization of DG placement

The rationale behind selecting the Bacterial Foraging Algorithm is due to the following reasons.

1. This algorithm does not get affected by the non linearity or the size of the system.
2. This algorithm has proved to be more satisfactory in many areas and converged to better and optimal solution, where most of the analytical methods failed to converge.
3. This algorithm has less computational load, less computational time required and has global convergence.
4. This algorithm can handle much more number of the objectives.

5. This method provides bacteria with a lot of nutrient and also keeps the population size constant.

Basic step involved in BFOA :

- i. Chemotaxis
- ii. Swarming
- iii. Reproduction
- iv. Elimination
  - i. Chemotaxis:

It is chiefly based on the natural foraging behavior of bacteria which helps to seize the required nutrients. Chemotaxis is the phenomenon where the bacteria, in the presence of chemical attractants and repellents, create the movement patterns. It can swim for a period of time in the same direction or it can tumble and fluctuate between these two modes of operation for the entire lifetime.

Movement of chemotaxis is given as:

$$\theta^i(j + 1, k, l) = \theta^i(j, k, l) + C(i) \frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}} \quad (3.5)$$

where

$\theta^i$ : location of  $i^{th}$  bacterium

$C(i)$ : Movement length

$\Delta(i)$ : Direction random vector

$j$ : is representing  $j^{th}$  chemotaxis

$k$ : is representing  $k^{th}$  reproduction

$l$ : is representing  $l^{th}$  elimination and dispersal.

- ii. Swarming

When a set of E. coli cells are placed in the central of a semisolid agar with single nutrient chemo-effectors, they move away from the middle in a traveling loop of cells by moving up the nutrient gradient produced by utilization of the nutrient by the set. This basically provides the direction to the parameters of the objective function to move.

### iii. Reproduction

The bacteria with worst fitness values ultimately die when each of the healthier bacteria i.e. bacteria with low yielding value of the objective function, which split themselves into two bacteria, which are then placed in the same location. This keeps the swarm size constant.

### iv. Elimination

As per E.Colli's bacteria events can occur such that all the bacteria in a region are killed or a group is dispersed into a new part of the environment. For example, a momentous local rise or fall of temperature can mutate or even kill a group of bacteria currently in a region with a high concentration of nutrient gradients. Events can take place in such a trend that all the bacteria in a region are eliminated or mutated in a group that dispersed into a new location. Over long periods of time, such examples could be seen in our environment from our intestines to hot springs and underground environments. To simulate this phenomenon in BFOA some bacteria are liquidated at random with a very small probability and the new replacements are initialized randomly over the search space. Elimination and dispersal events have the effect of possibly destroying chemotactic progress, but they also have the effect of assisting in chemotaxis, since dispersal may place the bacteria near good food sources.

## 3.2.2 ALGORITHM

Step 1: Initialize the parameters  $S$ ,  $N_c$ ,  $N_s$ ,  $N_{re}$ ,  $N_{ed}$  where

No. of bacterium:  $S$

No. of chemotactic steps:  $N_c$

No. of maximum steps:  $N_s$

No. of reproduction steps:  $N_{re}$

Ned: No. of elimination dispersal steps:  $N_{ed}$

Step 2: Elimination-Dispersal loop:  $l = l + 1$

Step 3: Reproduction loop:  $k = k + 1$

Step 4: Chemo taxis loop:  $j = j + 1$

(i) For  $i = 1, 2, \dots, S$  a chemo tactic step for bacteria  $i$  are taken as follows:

(ii) Compute objective function  $J(i, j, k, l)$  as:

$$\begin{aligned}
J_{cc}(\theta, P(j, k, l)) &= \sum_{i=1}^S J_{cc}(\theta, \theta^i(j, k, l)) + \\
&\sum_{i=1}^S [d_{\text{attractant}} \exp(\omega_{\text{attractant}} \sum_{m=1}^p (\theta_m - \theta_m^i)^2)] + \\
&\sum_{i=1}^S [-h_{\text{repellent}} \exp(\omega_{\text{repellent}} \sum_{m=1}^p (\theta_m - \theta_m^i)^2)]
\end{aligned} \tag{3.6}$$

where

$d_{\text{attractant}}$  : depth of attractant released by cell(0.1)

$\omega_{\text{attractant}}$ :width of attractant signal(0.2)

$h_{\text{replelent}}$ : height of repellent effect(0.1)

$\omega_{\text{repellent}}$ : width of repellent(1.0)

(iii) Update  $J(i, j + 1, k, l) = J(i, j, k, l) + J_{cc}(\theta'(j, k, l), P(J, K, L))$

(iv) Save the computed value in  $J_{\text{last}} = J(i, j, k, l)$  to find out the better results.

(v) Tumbling: create a random vector with each element  $\Delta(i) \in \mathbb{R}$  with each element  $\Delta_m$   $m = 1, 2, \dots, p$  random number on  $[-1, 1]$ . Where  $\mathbb{R}$  is a real number.

(vi) Move let

$$\theta^i(j + 1, k, l) = \theta^i(j, k, l) + C(i) \frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}} \tag{3.7}$$

This results in a step of size  $C(i)$  in a direction of the tumble for bacterium  $i$

(vii) Compute  $J(i, j+1, k, l)$ . Evaluate the objective function, if the value is minimum then proceed to the next step else go to step (iii)

(viii) Swim.

(a) Let  $m=0$  (counter for swim length)

(b) While  $m < N_s$

Let  $m=m+1$

If  $J(i, j+1, k, l) < J_{\text{last}}$  (if there is improvement), let  $J_{\text{last}} = J(i, j+1, k, l)$

Let the new position is given by

$$\theta^i(j + 1, k, l) = \theta^i(j + 1, k, l) + C(i) \frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}} \tag{3.8}$$

and use this  $\theta^i(j + 1, k, l)$  to evaluate the new  $J(i, j+1, k, l)$ .

Else, let  $m=N_S$ . End of while statement

(ix) Go to next bacterium ( $i+1$ ) if  $i \neq S$ .

Step 5: If  $j < N_c$  go to step 3. In this case, continue chemo taxis, since the life of the bacteria is not over.

Step 6: Reproduction

- a) For the given  $k$  and  $l$ , and for each  $i=1,2,\dots,S$ , let  $J_{health}^i = \sum_{j=1}^{N_c} J(i,j,k,l)$  be the health of bacterium  $i$ . Arrange the values of  $J_{health}^i$  and its chemotactic parameter  $C(i)$  in order of descending order.
- b) Step 7: If  $k < N_{re}$ , go to step 2. In this case we have not reached the number of specified reproduction steps.

Step 8: Elimination.

For  $i=1,2,\dots,S$  with probability  $P_{ed}$ , eliminate the bacterium by discard the worst values of bacterium. . If  $l < N_{ed}$ , then go to step 1, otherwise end.

## CHAPTER 4

### PROBLEM FORMULATION

#### 4.1 ASSUMPTIONS

- i) Three-phase distribution networks are balanced and can be represented in equivalent single-line diagram.
- ii) Distribution feeders are of medium level voltage so there is no shunt capacitance effect and no charging current flowing through the distribution network.
- iii) The loads are modeled as constant power.

#### 4.2 OBJECTIVE FUNCTION

Real power losses are evaluated based on the exact loss formula given by Acharya[9].

$$P_L = \sum_{i=1}^N \sum_{j=1}^N [\alpha_{ij}(P_i P_j + Q_i Q_j) + \beta_{ij}(Q_i P_j - P_i Q_j)] \quad (4.1)$$

where

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

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

$V_i \angle \delta_i$  the complex voltage at the bus  $i$  th

$r_{ij} + j\beta_{ij} = Z_{ij}$  the  $ij$  th element of  $[Z_{bus}]$  impedance matrix

$P_i$  and  $P_j$  are the active power injections at the  $i$  th and  $j$  th buses respectively

$Q_i$  and  $Q_j$  are the reactive power injections at the  $i$  th and  $j$  th buses respectively

$N$  are the number of buses.

### 4.3 CONSTRAINTS

i) Voltage limits:

Reactive power is directly proportional to the voltage. Thus a minor change in voltage largely affect the reactive power. Therefore voltage must be maintained within the permissible value.

$$V_{kmin} \leq V_k \leq V_{kmax} \quad \text{for } k \in \{1,2, \dots, N\}$$

(4.2)

where  $V_{kmin}, V_{kmax}$  are the minimum and maximum voltages at the  $k$ th bus.  
 $N$  is the number of buses.

ii) Feeder Capacity limits:

Current flowing through each feeder must be restricted its maximum capacity.

$$I_k \leq I_{kmax} \quad \text{for } k \in \{1,2, \dots, N_{br}\}$$

(4.3)

where  $I_k$  is the current flow in the  $k$ -th branch

$I_{kmax}$  is the maximum permissible value of current in  $k$ -th branch.

$N_{br}$  is the number of branches.

iii) Power flow equations:

Power generation must be equal to the sum of load and loss for both real as well as reactive power.

$$\sum P_G = \sum P_{LOAD} + \sum P_L$$

(4.4)

$$\sum Q_G = \sum Q_{LOAD} + \sum Q_L$$

(4.5)

where

$P_G, Q_G$  are the real and reactive power generation respectively

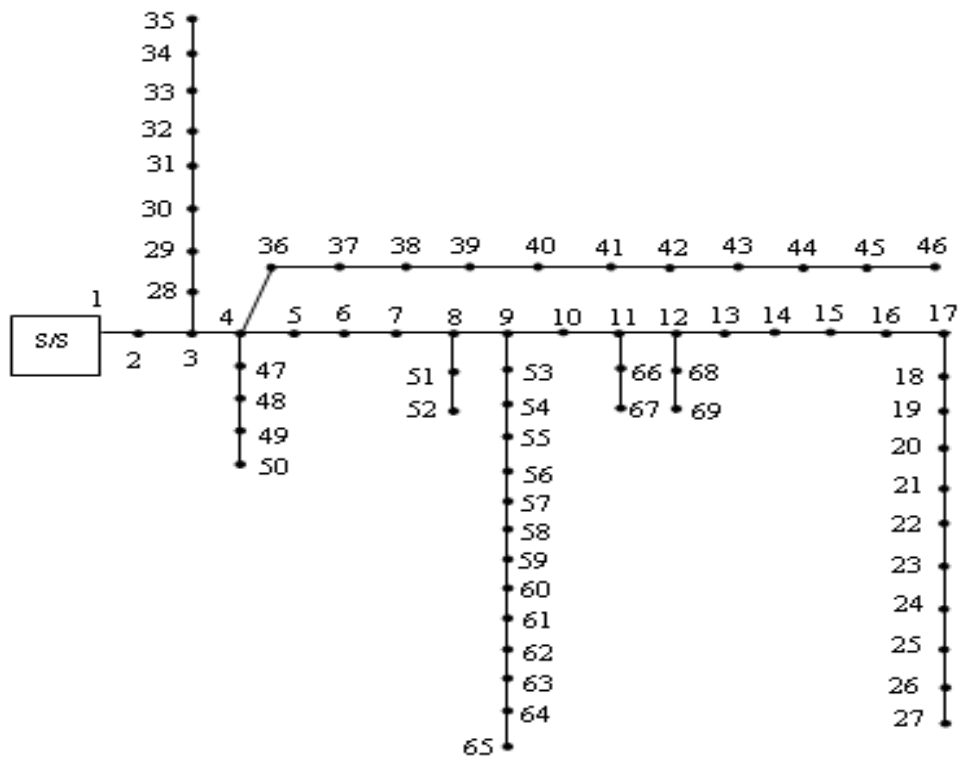
$P_{LOAD}, Q_{LOAD}$  are the real and reactive load respectively

$P_L, Q_L$  real and reactive power losses respectively.

## CHAPTER-5

### RESULTS

The proposed methodology is tested on 69-node Bus system shown in Fig. 5.1.



**Fig.5.1** 69-Node Bus Sytem[28].

The results for load-flow analysis are shown in table obtained by coding the given algorithm in MATLAB. The 69 bus system has following characteristics

Total number of nodes or buses = 69

Total number of branches or lines = 68

Base voltage = 12.66kV

Base MVA = 100

Bus 1 is the slack bus

Table 5.1 shows the voltage magnitude (p.u.) for each node of 69-node RDS without using the DG. The total real power loss of the system is 223.0067kW. and total reactive power loss is 102.022kVAr. Table5.2 shows the real and reactive power losses of each branch without using DG. Table 5.3 shows the voltage magnitude of each node in p.u. after placement of DG. Table 5.4 shows the real and reactive power loss of each branch after placement of DG.

The minimum voltage occurs at node 65 which is 0.9693. The total active power loss is 82.620kW and total reactive power loss is 40.93kVAr.

Figure 5.1 shows the plot of node voltage of each node Vs node before and after DG placement. Figure 5.2 shows the plot of real voltage of each node Vs node before and after DG placement. Figure 5.3 shows the plot of reactive voltage of each node Vs node before and after DG placement.

**Table5.1: Voltage Magnitude at each node for 69-node RDN.**

Node	Voltage (p.u)
1	1
2	0.9999
3	0.9999
4	0.9998
5	0.9990
6	0.9901
7	0.9809
8	0.9787
9	0.9776
10	0.9728
11	0.9718
12	0.9688
13	0.9660
14	0.9632

15	0.9605
16	0.9600
17	0.9592
18	0.9592
19	0.9587
20	0.9585
21	0.9580
22	0.9580
23	0.9579
24	0.9578
25	0.9576
26	0.9575
27	0.9575
28	0.9999
29	0.9998
30	0.9997
31	0.9997
32	0.9996
33	0.9993
34	0.9990
35	0.9989
36	0.9997
37	0.9993
38	0.9990
39	0.9989
40	0.9989
41	0.9969
42	0.9961
43	0.9960
44	0.9960
45	0.9957
46	0.9957
47	0.9997
48	0.9985
49	0.9946
50	0.9941
51	0.9787
52	0.9787
53	0.9748
54	0.9716
55	0.9671
56	0.9628
57	0.9403
58	0.9292
59	0.9250

60	0.9199
61	0.9125
62	0.9123
63	0.9119
64	0.9100
65	0.9094
66	0.9717
67	0.9717
68	0.9685
69	0.9685

**Table5.2: Real and Reactive power loss at every branch without DG allocation for 69- node RDN**

BRANCH NUMBER	P(kW)	Q(kVAr)
1	0.078	0.187
2	0.078	0.187
3	0.224	0.537
4	1.895	2.22
5	27.634	14.074
6	28.718	14.626
7	6.745	3.438
8	3.299	1.720
9	4.411	1.458
10	0.934	0.309
11	2.009	0.661
12	1.157	0.382
13	1.120	0.370
14	1.081	0.357
15	0.221	0.067
16	0.284	0.094
17	0.002	0.001
18	0.097	0.032
19	0.063	0.021
20	0.101	0.033
21	0.001	0
22	0.005	0.002
23	0.011	0.004
24	0.006	0.002
25	0.002	0.001
26	0	0
27	0	0.001
28	0.003	0.006
29	0.006	0.002
30	0.001	0

31	0.005	0.002
32	0.012	0.004
33	0.010	0.003
34	0	0
35	0.005	0.011
36	0.058	0.143
37	0.083	0.097
38	0.024	0.028
39	0.001	0.001
40	0.429	0.501
41	0.181	0.211
42	0.024	0.028
43	0.005	0.007
44	0.061	0.077
45	0	0
46	0.023	0.057
47	0.582	1.423
48	1.630	3.987
49	0.115	0.283
50	0.002	0.001
51	0	0
52	5.784	2.945
53	6.715	3.420
54	9.129	4.648
55	8.782	4.474
56	49.638	16.661
57	24.467	8.211
58	9.497	3.141
59	10.662	3.236
60	14.015	7.138
61	0.112	0.057
62	0.135	0.069
63	0.661	0.337
64	0.041	0.021
65	0.002	0.001
66	0	0
67	0.018	0.006
68	0	0

**Table5.3: Voltage Magnitude at each node for 69-node RDN**

Node	Node voltages (p.u)
1	1
2	0.9999
3	0.9999
4	0.9998

5	0.993
6	0.9952
7	0.9910
8	0.990
9	0.9895
10	0.9847
11	0.9836
12	0.9806
13	0.9778
14	0.9751
15	0.9723
16	0.9718
17	0.9710
18	0.9710
19	0.9705
20	0.9703
21	0.9698
22	0.9698
23	0.9697
24	0.9696
25	0.9694
26	0.9693
<b>27</b>	<b>0.9693</b>
28	0.9999
29	0.9998
30	0.9997
31	0.9997
32	0.9996
33	0.9993
34	0.9990
35	0.9989
36	0.9998
37	0.9994
38	0.9990
39	0.9989
40	0.9989
41	0.9970
42	0.9962
43	0.9961
44	0.9960
45	0.9957
46	0.9957
47	0.9998
48	0.9985
49	0.9947

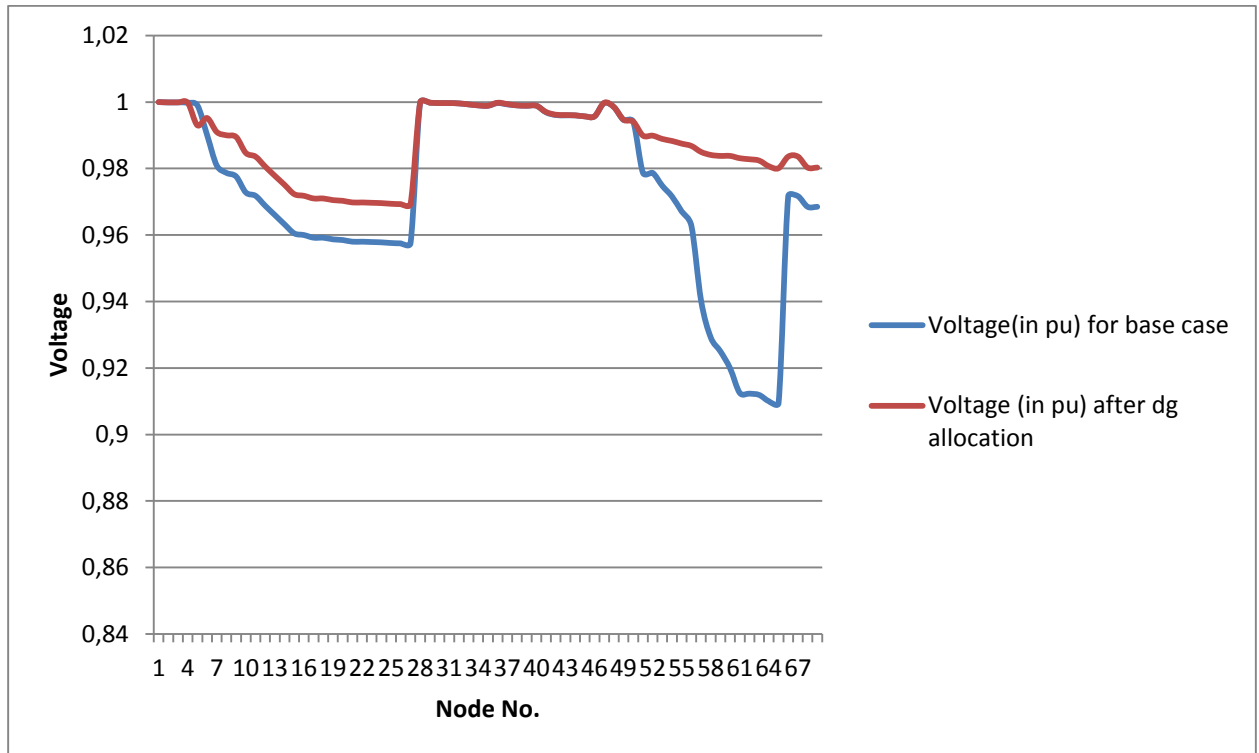
50	0.9941
51	0.9899
52	0.9899
53	0.9889
54	0.9883
55	0.9875
56	0.9868
57	0.9850
58	0.9841
59	0.9838
60	0.9838
61	0.9831
62	0.9828
63	0.9824
64	0.9807
65	0.9801
66	0.9836
67	0.9836
68	0.9803
69	0.9803

**Table5.4:Real and Reactive power loss at every branch after DG allocation for 69-node RDN**

Node	Real losses (kW)	Reactive losses (kVAr)
1	0.039	0.094
2	0.039	0.094
3	0.11	0.266
4	0.680	0.797
5	9.918	5.051
6	10.297	5.245
7	2.388	1.217
8	1.127	0.588
9	4.390	1.451
10	0.931	0.308
11	2.005	0.660
12	1.160	0.383
13	1.123	0.371
14	1.084	0.358
15	0.202	0.067
16	0.286	0.094
17	0.002	0.001
18	0.097	0.032
19	0.062	0.021
20	0.1	0.033
21	0.001	0

22	0.005	0.002
23	0.011	0.004
24	0.006	0.002
25	0.002	0.001
26	0	0
27	0	0.001
28	0.003	0.006
29	0.006	0.002
30	0.002	0
31	0.005	0.002
32	0.012	0.004
33	0.010	0.003
34	0	0
35	0.005	0.011
36	0.058	0.143
37	0.083	0.097
38	0.024	.028
39	0.001	.001
40	0.429	.501
41	0.181	.211
42	0.024	.028
43	0.005	.007
44	0.061	.077
45	0	0
46	0.023	0.057
47	0.581	1.423
48	1.629	3.987
49	0.115	0.282
50	0.002	0.001
51	0	0
52	1.737	0.884
53	2.017	1.027
54	2.755	1.403
55	2.670	1.360
56	15.094	5.066
57	7.44	2.497
58	2.888	0.955
59	3.39	1.030
60	4.461	2.272
61	0.096	0.049
62	0.116	0.059
63	0.569	0.290
64	0.035	0.018
65	0.002	0.001
66	0	0

67	0.019	0.006
68	0	0



**Fig 5.1: Plot showing improvement in voltage profile**

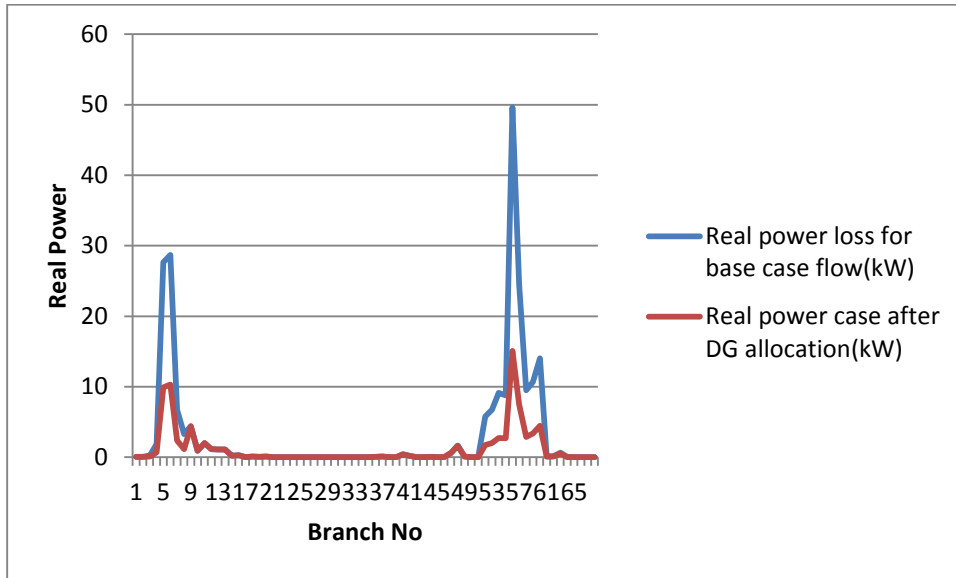


Fig 5.2: Plot showing decrease in real power loss

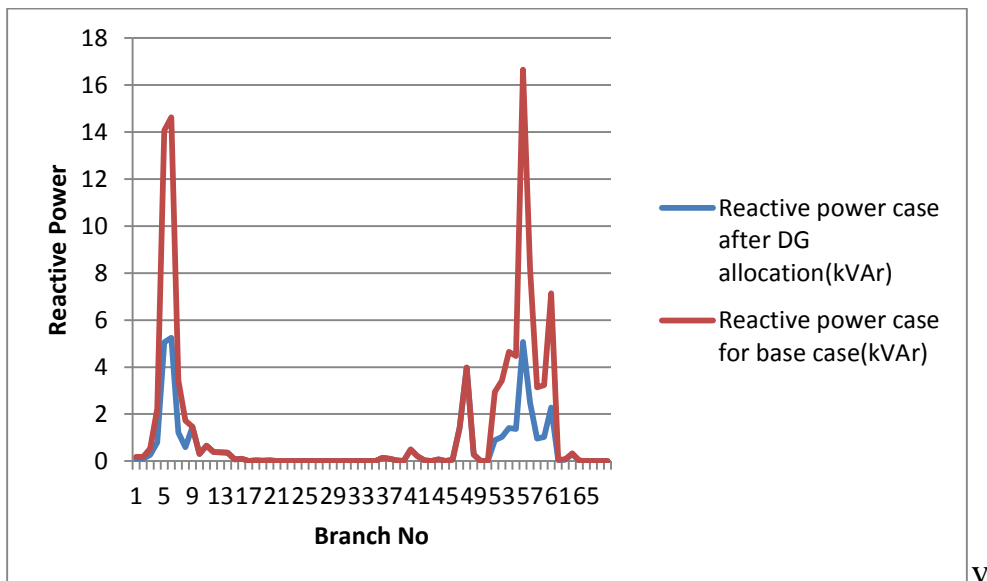


Fig5.3: Plot showing decrease in reactive power loss

### 5.3 Comparison

Results obtained using the proposed method on 69- node radial distribution system are compared with novel method are shown in Table5.4

**Table5.5:Comparison between various methods for 69-node RDS**

	Using novel method	Using proposed method
Total real power losses for base case(kW)	224.8799	223.0074
DG Size(kW)	1832.536	1905.83
DG Location(Bus No)	61	61
Total real power losses with DG(kW)	83.1951	82.6

## **CHAPTER-6**

### **CONCLUSION AND FUTURE SCOPE**

#### **6.1 CONCLUSION**

The thesis was carried out on a 69-node RDS. The objective of thesis was to minimize the losses of the system. It was carried out by placing the DG of optimal size. To select a node loss sensitivity factor method is used. DG of optimal size is allocated by bacterial foraging. The results thus obtained were better as it minimize the losses when compared with previous results.

#### **6.2 FUTURE SCOPE**

Further work could be done on this thesis to incorporate other algorithms and obtain better results. Various other test systems could be considered along with the modification in power factors.

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## APPENDIX: A

**Table (A.1): Line Data for 69-Bus Radial Distribution System [25]**

Branch Number	Sending-end Bus	Receiving end Bus	Branch Resistance ( $\Omega$ )	Branch Reactance ( $\Omega$ )
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	0.3660	0.1864
6	6	7	0.3810	0.1941
7	7	8	0.0922	0.0470
8	8	9	0.0493	0.0251
9	9	10	0.8190	0.2707
10	10	11	0.1872	0.0619
11	11	12	0.7114	0.2351
12	12	13	1.0300	0.3400
13	13	14	1.0440	0.3400
14	14	15	1.0580	0.3496
15	15	16	0.1966	0.0650
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	0.0690
20	20	21	0.3416	0.1129
21	21	22	0.0140	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	0.0640	0.1565
29	29	30	0.3978	0.1315
30	30	31	0.0702	0.0232
31	31	32	0.3510	0.1160
32	32	33	0.8390	0.2816
33	33	34	1.7080	0.5646
34	34	35	1.4740	0.4873
35	3	36	0.0044	0.0108
36	36	37	0.0640	0.1565
37	37	38	0.1053	0.1230
38	38	39	0.0304	0.0355
39	39	40	0.0018	0.0021

40	40	41	0.7283	0.8509
41	41	42	0.3100	0.3623
42	42	43	0.0410	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	0.114
52	9	53	0.1740	0.0886
53	53	54	0.2030	0.1034
54	54	55	0.2842	0.1447
55	55	56	0.2813	0.1433
56	56	57	1.5900	0.5337
57	57	58	0.7837	0.2630
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	0.1450	0.0738
63	63	64	0.7105	0.3619
64	64	65	1.0410	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 (A.2): Load Data for 69-Bus Radial Distribution Network [25]**

Bus Number	P(kW)	Q(kVAr)	Bus Number	P(kW)	Q(kVAr)
1	0.0	0.0	36	26.0	18.55
2	0.0	0.0	37	26.0	18.55
3	0.0	0.0	38	0.0	0.0
4	0.0	0.0	39	24.0	17.0
5	0.0	0.0	40	24.0	17.0
6	2.6	2.2	41	1.20	1.0
7	40.40	30.0	42	0.0	0.0
8	75.0	54.0	43	6.0	4.30
9	30.0	22.0	44	0.0	0.0
10	28.0	19.0	45	39.22	26.30
11	145.0	104.0	46	39.22	26.30
12	145.0	104.0	47	0.0	0.0
13	8.0	5.0	48	79.0	56.40
14	8.0	5.0	49	384.70	274.50
15	0.0	0.0	50	384.70	274.50
16	45.0	30.0	51	40.50	28.30
17	60.0	35.0	52	3.60	2.70
18	60.0	35.0	53	4.35	3.50
19	0.0	0.0	54	26.40	19.0
20	1.0	0.60	55	24.0	17.20
21	114.0	81.0	56	0.0	0.0
22	5.0	3.50	57	0.0	0.0
23	0.0	0.0	58	0.0	0.0
24	28.0	20.0	59	100.0	72.0
25	0.0	0.0	60	0.0	0.0
26	14.0	10.0	61	1244.0	888.0
27	14.0	10.0	62	32.0	23.0
28	26.0	18.6	63	0.0	0.0
29	26.0	18.6	64	227.0	162.0
30	0.0	0.0	65	59.0	42.0
31	0.0	0.0	66	18.0	13.0
32	0.0	0.0	67	18.0	13.0
33	14.0	10.0	68	28.0	20.0
34	19.50	14.0	69	28.0	20.0
35	6.0	4.0			

(Base voltage = 12.66 kV, Base VA = 100MVA)