

**OPTIMAL CAPACITOR PLACEMENT ON PRIMARY DISTRIBUTION SYSTEM FOR
LOSS MINIMIZATION USING ARTIFICIAL INTELLIGENT TECHNIQUES : CASE
STUDY ON ADAMA TOWN DISTRIBUTION SYSTEM**

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CERTIFICATION BY BOARD OF EXAMINERS

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Abstract

A power system contains generation, transmission and distribution systems. Distribution system is the final part which delivers the power to the load and it usually has the highest loss and is very critical in power system reliability. The loss in a distribution system can be minimized by an appropriate placement of capacitor banks. But the problem is on how to optimally select the location and size of capacitor banks. This thesis presents artificial intelligent approaches for capacitor placement in radial distribution feeder to reduce the real power loss and to improve the voltage profile. Before installing the capacitor a load flow program using backward forward method is executed to analyze the present system.

The location of the nodes where the capacitors should be placed is decided by a set of rules given by the fuzzy expert System. Then the sizing of the capacitors is modeled as an optimization problem and the objective function (loss minimization) is solved using particle swarm optimization technique. The performance of the proposed method is applied on **75** bus radial distribution feeder of Adama town. Backward forward sweep load flow analysis also carried after selecting optimal capacitor sizes. The simulation result shows that by applying these methods **10** optimal locations are selected and optimal size capacitors are installed that results improvement of voltage at all buses. In addition to this by placing shunt capacitors **0.4 MW** of power is saved and power loss is decreased from **18.85%** to **14%** and due to this annually 700716.8 birr is saved.

Keywords: *Particle swarm optimization, Power loss, Fuzzy logic control*

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Acronym

| | |
|--------|----------------------------------|
| EEP | Ethiopian Electric Power |
| AI | Artificial Intelligent |
| PSO | Particles Swarm Optimization |
| MATLAB | Mathematical Laboratory |
| AC | Alternating Current |
| KVL | Kirchhoff's Voltage Law |
| KCL | Kirchhoff's Current Law |
| GA | Genetic Algorithm |
| BIBC | Bus Injection to Branch Currents |
| BCBV | Branch Current to Bus Voltage |
| FES | Fuzzy Inference System |
| PLI | Power Loss Index |
| CSI | Capacitor Suitability Index |
| PC | Personal Computer |
| PL | Power Loss (active) |
| QL | Power Loss (reactive) |
| CEL | Cost of Energy Loss |

1. INTRODUCTION

1.1 Background

The transmission systems are basically a bulk power transfer links between the power generating stations and the distribution sub-stations from which the power is carried to customer delivery points. The transmission system includes step-up and step-down transformers at the generating and distribution stations respectively. The transmission system is usually part of the electric utility's network. Power transmission systems may include sub transmission stages to supply intermediate voltage levels. Sub-transmission stages are used to enable a more practical or economic transition between transmission and distribution systems. It operates at the highest voltage levels (typically, 230 kV and above). The distribution system is the final link in the transfer of electrical energy to the individual customers. Between 30 to 40% of total investment in the electrical sector goes to distribution systems, but nevertheless, they haven't received the technological improvement in the same manner as the generation and transmission systems [1]. The distribution network differs from its two of siblings in topological structure as well as its associated voltage levels. The distribution networks are generally of radial or tree structure. Its primary voltage level is typically between 4.0 to 35 kV, while the secondary distribution feeders supply residential and commercial customers at 120/240/440 volts.

In general, the distribution system is the electrical system between the substation fed by the transmission system and the consumers' Premises. It generally consists of feeders, laterals (circuit-breakers) and the service mains[2, 3].

Elements of the distribution system: The distribution system is derived from electrical system which is fed by the consumers' premises and the transmission system. Figure 1:1 shows the single line diagram of a typical low tension distribution system.

Distributed feeders: A feeder is a conductor, which connects the sub-station (or localized generating station) to the area where power is to be distributed. Generally no tapping are taken from the feeder so that the current in it remains the same throughout.

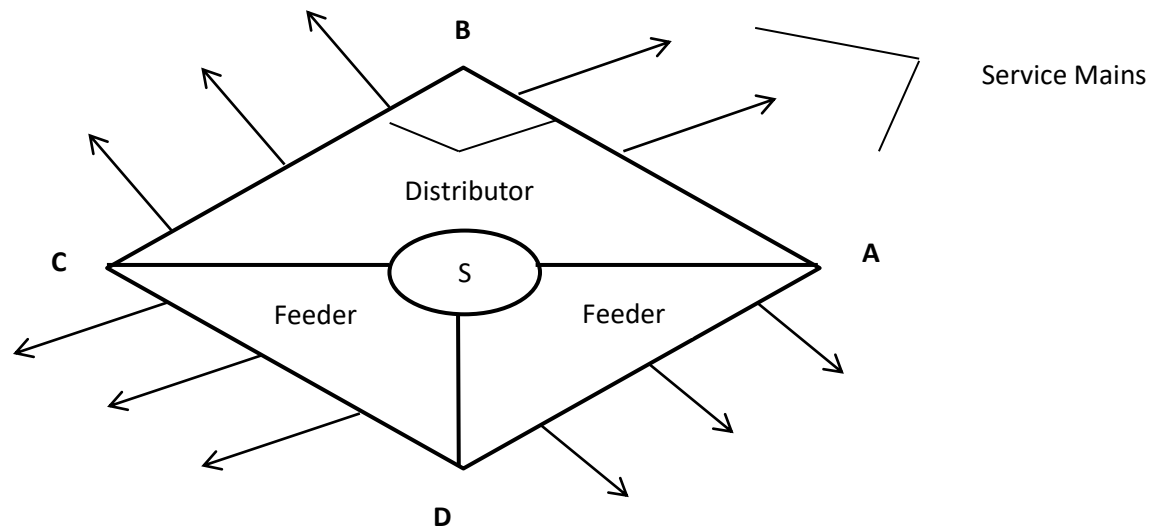


Figure 1:1 Elements of distribution System

Distributor: A distributor is a conductor from which tapping are taken for supply to the consumers. In Figure 1:1, AB, BC, CD, and DA are the distributors. The current through a distributor is not constant because tapping are taken at various places along its length.

Service mains: A service main is generally a small cable which connects the distributor to the consumer's terminals.

1.1.1 Classification of distribution System

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

- i) Type of construction: According to type of construction, distribution system is classified as
 - A. Overhead system
 - B. Underground system
- ii) Scheme of operation: According to scheme of operation, distribution system may be classified as:
 - a. Radial delivery network
 - b. Ring main system
 - c. Interconnected system

An electrical utility company engages in producing and providing electricity to its customers. The generation plants and loads are normally located geographically far from each other and they are connected by transmission lines. From generating plants to load, voltage quality, power loss and reliability are challenging issues in electrical utility industry [4].

Utilities in the electric sector are currently focusing in reducing power losses, in order to be more competitive. The electricity prices in deregulated markets are related to the system losses. In regulated markets like our country also reducing the losses have advantages for both utility company Ethiopian Electrical Power (EEP) and end users. This loss reduction can be done using effective and efficient optimization tools which reduce losses and cost of energy at the consumer end[5].

The application of shunt capacitor in distribution feeders has always been an important research area. Most of loads have inductive nature and due to this current and line losses will increase. To decrease the power loss and to improve the power factor we use capacitor. It is because a portion of power loss in distribution systems could be reduced by adding shunt capacitors to supply a part of the reactive power demands. For this reason, the source of the system does not necessarily have to supply all reactive power demands and losses. Consequently, there is a possibility to decrease the losses associated with the reactive power flow through the branches in the distribution systems. The benefits of capacitor placement in distribution systems are power factor correction, bus voltage regulation, power and energy loss reduction, feeder and system capacity increase as well as power quality improvement [6]. The extent of the aforementioned advantages of capacitor placement depends on how capacitors are allocated and controlled under possible loading conditions. This means that the optimization problem, namely, capacitor placement problem should be formulated with the desired objective function of loss minimization and various technical constraints. After that, the proper solution techniques should be applied to determine the optimal number, location and size of capacitors.

The intention of this thesis is to reduce reactive loss by placing shunt capacitors at selected feeder of Adama city electric power distribution networks using artificial intelligence techniques.

1.2 Statement of the problem

Distribution power losses can be divided into two categories technical and non-technical losses. The technical losses are related to the material properties and its resistance to the flow of the electrical current that is dissipated as heat. The most obvious examples are the power dissipated in distribution lines and transformers due to their internal electrical resistance. On the other hand, non-technical losses are caused by clandestine connections, frauds in energy meters and diversity of readings of energy measurement. High rate of technical losses might cause [7]:-

- Poor quality of service offered to customers.
- High cost, Therefore, the reduction of technical losses leads to a real gain in energy cost.

The losses in distribution lines are larger than at transmission level. Since power loss in the distribution lines can be considered to be entirely due to copper losses, it can be calculated using equation below.

$$P=I^2R \quad (1.1)$$

From this, it is apparent that anything that changes either current or line resistance will affect the amount of power lost in the line. The primary determining factor for the magnitude of line current is the amount of real and reactive power loading at the end of the line. As the power that is transmitted along the line increases, the current flow in the line becomes larger. Higher voltage line will have also lower copper losses. A long line will have a higher resistance and larger losses than a short line with the same current flow.[8]

In most of the distribution systems in developing countries, feeders carry large currents to load points which lead to higher power loss (around 20%) resulting in poor power quality and higher electricity prices [2, 9].

Ethiopia is currently a developing country with one of the fastest growth rate in Africa region. The national average power loss was 15.7 % in 2006 and it rose to 23% in 2014 and most of the power loss is at distribution level, this is due to increase of inductive load demand, overloading of

transformers and long distance of loads with distribution transformers[10]. In Adama city distribution system also electric power losses are high due to lower voltage magnitude. To reduce the above losses most commonly used techniques are:-

- A. Capacitor Placement
- B. Feeder reconfiguration and
- C. Distributed generation allocation.

Allocating standard size shunt capacitor banks on distribution primary feeders is better technique. However installing capacitors have the disadvantage of need protective equipment and may create certain disturbances; they are easy to implementation and cost effective. In addition to this installing of shunt capacitors banks is very important to improve the power factor, to improve feeder voltage profile, to reduce Power loss and to increase available capacity of feeders.

1.3 Objective of the thesis

1.3.1 General objectives

The general objective of this thesis is to study and analyze power loss of selected feeder in Adama city power distribution system and minimize the losses associated with reactive component of branch currents by applying artificial intelligent techniques.

1.3.2 Specific objectives

The specific objective of this thesis includes the following.

- ❖ To model a feeder of Adama distribution substation and analyze the system losses.
- ❖ To select the location and size of capacitors to be used for compensation using fuzzy and PSO as optimization techniques
- ❖ To reduce power loss in distribution lines and
- ❖ To improve voltage profile.

1.4 Research methodology

The procedures including in this Thesis are: -

- 1) **Literature review:** Ideas about loss minimization by optimize reactive power using fuzzy and PSO in books, papers, articles, journals and lectures have been reviewed.
- 2) **Data collection:** Line data and bus data used in this research are measured from the AutoCAD and distribution transformers.
- 3) **Modeling:** Model single line diagrams of selected feeder of Adama distribution have been done Using Microsoft viso 2010.
- 4) **Final result analysis:** The data is analyzed by using MATLAB R2010a.

1.5 Significance of the study

This research has a great significance in contributing to the loss minimization on distribution system. Moreover, the output of the research has contributions in the following ways:

- ❖ It helps to improve voltage profile of distribution networks which is one important quality measure for a power system and
- ❖ It also helps to improve system capacity and hence permits additional loads to be added without overloading the system.

1.6 Adama city power distribution background

Adama is a city in central Ethiopia and the previous capital of the Oromia region. Adama forms a Special zone of Oromia and is surrounded by east Shewa zone. It is located at 8.54°N 39.27°E at an elevation of 1712 meters, 99 km southeast of Addis Ababa. The city sits between the base of an escarpment to the west, and the great rift valley to the east. Adama is a busy transportation center. The city is situated along the road that connects Addis Ababa with Dire Dawa. A large number of trucks use this same route to travel to and from the seaports of Djibouti. Additionally, the new Addis Ababa-Djibouti railroad runs through Adama[11]. The city population is estimated to be around 599,621 and the life of population depends mainly up on trading.

There are some big industries in the city also. Due to these industries and population size the electric power consumption in the city is very high. The Nazareth substation takes 132 KV directly from the Koka and Adama wind farm power station and step down it to 15 KV by using two substation power transformers of ratings 25 MVA, 132/15 KV, 109.3/962.3 A, 50 HZ of a reactance 18% of each and feeds it to the city main distribution bus, as one can see from figure 1:2 Adama city contains seven feeders, which provides power to the consumers. Three of them supplies three different large factories namely the Adama Turk textile factory, Modjo cement factory and Koka metal factory respectively the remaining four feeders supply other residential and commercial loads plus some medium and small industries in the city. In this research, feeder four has been considered for loss minimization.

There are different transformers in the system, of which the two 25 MVA parallel connected power transformers step down the main incoming 132 KV voltage in to 15 KV to feed main distribution bus. The other types of transformers are distribution transformer. The distribution transformers at each feeder have different KVA ratings and they convert primary distribution voltage of 15 KV to the consumer usable form secondary distribution voltage of 0.38 KV. Most of the distribution transformers have no loss compensating devices, so that enhancement should be needed to increase the voltage profile and to minimize distribution power losses.

The selected feeder has 15 KV voltage rating, 71 transformers, annual average peak load of 8.4 Mw and 33.75km length.

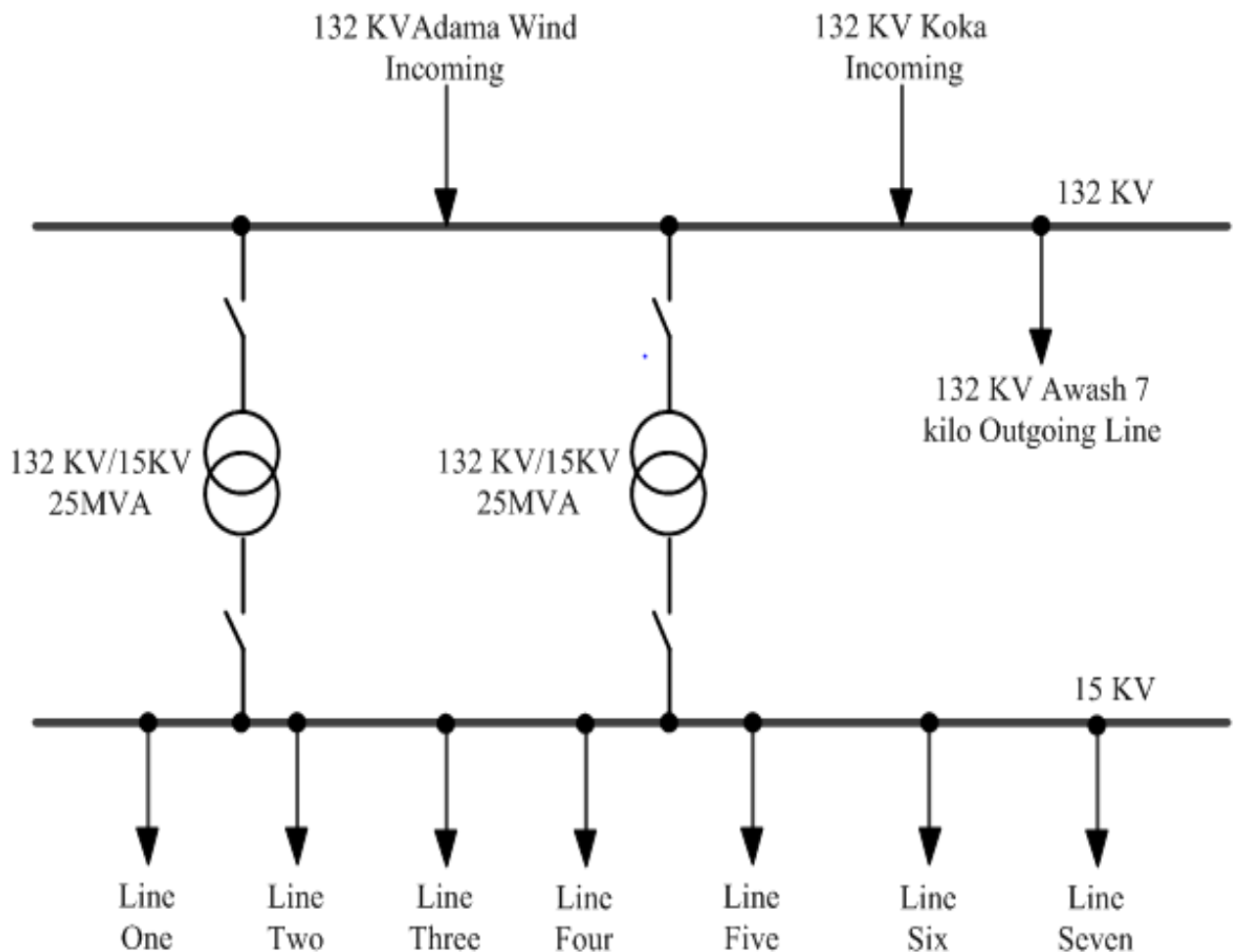


Figure 1:2 Single Line diagram of Adama substation

1.7 Overview of the thesis

Chapter 1: has presented the Introduction of distribution system, Statement of the problem, Objective of the research and organization of the research.

Chapter 2: presents review of related literatures.

Chapter 3: presents proposed methodologies and algorithms to solve the problem. Backward forward load flow technique is applied to determine the bus voltage and branch powers. Fuzzy logic and PSO optimization techniques are presented to get optimal locations and appropriate capacitor sizes respectively.

Chapter 4: outlines the necessary datas to solve problem of this research. The results of number of buses to be compensated and results of buses after sizing optimal location of capacitor are shown.

Chapter 5: presents the overall conclusions and future work of this research.

2. LITERATURE REVIEW

2.1 Introduction

Most loads on an electrical distribution system can be resistive, inductive, capacitive or combination of them. Currently most common loads are inductive loads, like transformers, fluorescent lighting and AC induction motors. All inductive loads require active and reactive power to function properly. Without capacitors the inductive loads draw active and reactive power and the transformer is fully loaded. With appropriately rated capacitors connected in parallel the reactive power drawn from the supply is neutralized and the transformer only feeds active power. Applying shunt capacitors to primary distribution feeders provides an alternative source of reactive power to reduce the level of reactive power provided by the supply.

Capacitors have been commonly used to provide reactive power compensation in distribution Systems. The amount of compensation provided is very much linked to the placement of capacitors in the distribution system which is essentially determination of the location, size, number and type of capacitors to be placed in the system. The proper application of capacitors serves to reduce the system current and raise the system voltage. This accomplishes following benefits [1, 12, 13]:

1. Reduces loading of thermally limited equipment
2. Reduces system voltage drop
3. Reduces system losses
4. Increase the capacity.

The optimal reactive power is a complicated combinatorial optimization problem. Many different optimization techniques and algorithms have been proposed in the past. Some load flow techniques and optimization algorithms are reviewed as below.

2.2 Load flow

In power engineering, the load flow study is a numerical analysis of the flow of electric power in an interconnected system. A power-flow study usually uses simplified notation such as a one-line diagram and per-unit system, and focuses on various aspects of AC power parameters, such as voltages, voltage angles, real power and reactive power. It analyzes the power systems in normal steady-state operation.

It is very important tool for analysis of power systems and used in operational as well as planning stages. Certain applications, particularly in distribution automation and optimization require repeated load flow solutions. As the power distribution networks become more and more complex, there is a higher demand for efficient and reliable system operation. It is observed that the radial distribution systems are unbalanced because of single-phase, two-phase and three phase loads.

There have been a lot of interests in the area of three phase distribution load flows. A fast decoupled power flow method has been proposed in [5]. This method orders the laterals instead of buses into layers, thus reducing the problem size to the number of laterals. Using of lateral variables instead of bus variables makes this method more efficient for a given system topology, but it may add some difficulties if the network topology is changed regularly, which is common in distribution systems because of switching operations.

Due to the high R/X ratios and unbalanced operation in distribution systems, the conventional load flow method may provide inaccurate results and may not be converged. Therefore, conventional load flow methods cannot be directly applied to distribution systems [14].

J. B. V. Subrahmanyam presented a forward method, in this method the sending end voltage becomes the main concern of the system convergence. Voltage drop and the information on system structure have been considered in the forward sweep [15].

Jianweiet et al stated that the ladder network method could be Performed in two directions: a backward sweep for current summation and then a forward sweep for voltage calculation [14].

This iteration sequence could speed up the convergence compared to the forward ladder network method.

J. A. Michline et al. proposed backward /forward sweep load flow algorithm for radial distribution systems which includes the backward sweep and the decomposed forward sweep. Backward sweep uses KVL and KCL to obtain the calculated voltage at each bus and current on each branch [16]. This algorithm demonstrated its better convergence compared to other method in terms of computational efficiency.

In this thesis load flow analysis of a network is performed by backward forward load flow technique by treating every lateral and sub laterals. The branch current evaluation starts from the far end of each of the sub lateral and main lines and moves towards the root node. Once the branch current is determined, the node voltage evaluation begins from the root node and moves towards the node located at the far end of main lateral.

2.3 Optimization techniques

Shunt capacitors are very commonly used on the primary feeders of a radial distribution system to reduce the power losses and to improve the voltage profile of the system. The objective of the capacitor placement problem is to determine the location and size of the capacitor so that the annual savings are maximized. A variety of solution techniques have been employed to solve the capacitor placement problem. These techniques are classified into four categories. They are analytical methods, numerical programming methods, heuristic search methods and artificial intelligence (AI) based methods. In recent years, AI- based methods have been applied to the capacitor placement problem with promising results[13].

Mahdi Mozaffari Legha and Others proposed a new meta heuristic artificial bee colony algorithm to find the optimal and simultaneous place and capacity of these resources to reduce losses, improve voltage profile. It is inspired by the intelligent foraging behavior of honey bee swarm. The proposed method is tested on actual power network of Kerman Province, Iran and the simulation results are presented and discussed [17].

Priyanka das and S.Banerejee presented cuckoo search algorithm for optimal allocation of capacitor in a radial distribution system. Loss sensitivity factor is used to calculate the location and the cuckoo search algorithm is used for minimization of cost that includes capacitor cost and cost due to power loss [17].

A.Kartikeya Sarma et al have applied a new approach for capacitor placement in radial distribution systems that determine the optimal locations and size of capacitor with an objective of improving the voltage profile and reduction of power loss [19]. In part one the loss sensitivity factors are used to select the candidate locations for the capacitor placement and in part two Plant growth simulation algorithm is used to estimate the optimal size of capacitors at the optimal buses determined in part one. The proposed method is applied to 33, 34 and 69-bus radial distribution systems.

Priya Kanta Bansal has applied genetic algorithm (GA) and particle swarm optimization for capacitor placement in the radial distribution system. He applied his method to identify the optimal location of the capacitor using GA and to determine the size of the capacitor using PSO. The proposed method is implemented on 34-bus [1].

M.Y.Balaji Prasanna et al presented a two-stage methodology of finding the optimal locations and sizes of shunt capacitors for reactive power compensation of radial distribution systems. Fuzzy approach is proposed to find the optimal capacitor locations and PSO method is proposed to find the optimal capacitor sizes [20].

S.M kannan has applied hybrid fuzzy particle swarm optimization for solution of the reactive power problem. The purposes of this paper is to minimize real power loss and to improve the voltage profile of a given power system [3].

M. Damodar Reddy et al proposed the capacitor placement problem by using fuzzy approximate reasoning and PSO. In the first stage fuzzy logic is applied to determine the optimal capacitor locations. In the second stage, a particle swarm optimization (PSO) method is proposed to find the sizes of the capacitors [21]. The capacitor placement problem is modeled with the objective function, which maximizes the annual savings. The proposed method is tested on 15-bus, 34-bus, and 69-bus test systems and the results are presented.

As we understand from the above reviews, AI techniques give faster and accurate solution to an optimization problem than the existing conventional techniques. Artificial intelligence techniques generally make use of multiple solutions to obtain an optimal solution.

Fuzzy logic has the advantage of including heuristics and representing engineering judgments into the capacitor allocation optimization process. Furthermore, the solutions obtained from a fuzzy algorithm can be quickly assessed to determine their feasibility in being implemented in the distribution system.

PSO is the most popular optimization technique because of its implementation is simple, it has small computational load, and its convergence is fast. PSO is efficient for the solution of difficult problems.

In this thesis the location of the nodes where the capacitors should be placed is decided by a set of rules given by the fuzzy expert system and the sizing of the capacitors is selected using PSO.

3. PROPOSED METHODOLOGY

3.1 Problem formulation

The main objective of the reactive power optimization is to minimize the system real power losses and improve voltage quality due to capacitor placement and loss with constraints that include limits. The control variable is shunt capacitor bank.

Objective function: Minimize feeder loss

$$\text{Min. } P_L \sum_{k=1}^n I_k^2 * R_k \quad (3.1)$$

Where:

P_L = System real power loss and

n = Number of bus

Reactive power optimization is subjected to the following equality and inequality constraints. Since power loss is a non-linear function of bus voltages, which are functions of control variables. The minimization problem is subject to operating constraints [22], which are the inequality constraints and the equality constraints.

i. Equality constraints:

1. Active power constraint

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{NB} (V_j (G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij})) = 0 \quad (3.2)$$

$i = 1, 2, \dots, N_B - 1$

2. Reactive power constraints

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{NB} (V_j (G_{ij} \sin \theta_{ij} - B_{ij} \cos \theta_{ij})) = 0 \quad (3.3)$$

$i = 1, 2, \dots, N_B - 1$

Where,

V_i = Voltage magnitude at bus i

V_j = Voltage magnitude at bus j

P_i, Q_i = Real and reactive powers injected into network at bus i

G_{ij}, B_{ij} = Mutual conductance and susceptance between bus i and bus j

Q_{ji} = Reactive power generation at bus i

$N_B - 1$ = Total number of buses excluding slack bus

N_{pq} = Number of PQ buses

θ_{ij} = Voltage angle difference between bus i and bus j

The equality constraints can be automatically satisfied by load flow calculation.

II. Inequality constraint:

Bus voltage magnitude constraint

$$V_i^{\min} \leq V_i \leq V_i^{\max} \quad (3.4)$$

Where:

V_i^{\min} = Minimum acceptable bus voltage

V_i = Voltage at i^{th} bus

V_i^{\max} = Maximum acceptable bus voltage

The lower/upper limit of control variables corresponds to the coding on the PSO, so the inequality constraints of the control variable are satisfied.

3.2 Resistance and reactance calculation

Resistance and reactance of each branch are calculated using equation 3.5 and 3.6 respectively.

$$R = t * l \quad (3.5)$$

$$X = k * l \quad (3.6)$$

Where: R = Resistance of a branch between two buses

x = Reactance of a branch between two buses

l = Length of conductor

t = Standard resistance value per km

k = Standard Inductance value per km

The electrical parameters for conductors for modeling the feeder of Adama taken from standard books and manufacturer catalogues are shown in the Appendix a.

The feeder is 15 KV three phase systems, the system base loads are assumed as constant and S_{base} is 1.5 MVA.

$$Z_{base} = (15Kv)^2 / 1.5Mva = 150\Omega$$

$I_{base} = S_{base} / \sqrt{3} V = 57.8A$, the Pu values of the line data's are calculated using Z_{base} and Pu values of bus data are obtained using S_{base} .

The selected feeder is modeled as shown in Figure 3:1 by using Microsoft office visio.

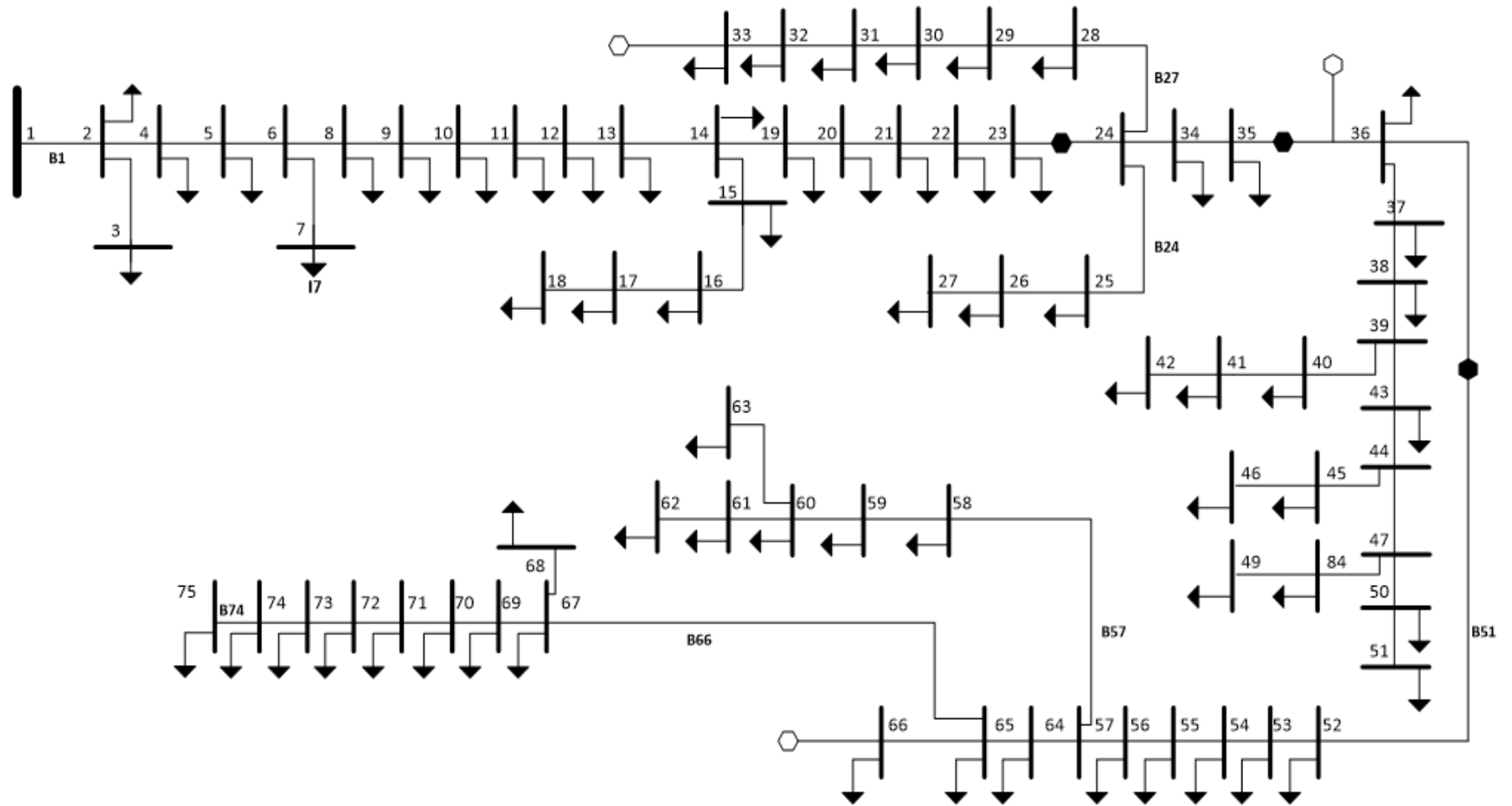


Figure 3:1 Single line diagram of a feeder

3.3 Backward forward power flow algorithm

The goal of a power-flow study is to obtain complete voltage angle and magnitude information for each bus in a power system for specified load and generator real power and voltage conditions. Once this information is known, real and reactive power flow on each branch as well as generator reactive power output can be analytically determined. The solution to the power-flow problem begins with identifying the known and unknown variables in the system. The known and unknown variables are dependent on the type of bus [23].

Forward/backward sweep-based power flow algorithms take advantage of the radial network topology and consist of forward and/or backward sweep processes. The forward sweep is mainly the node voltage calculation from the sending end to the far end of the feeder and laterals, and the backward sweep is primarily the branch current and/or power summation from the far end to the sending end of the feeder and laterals.

This method includes two steps: the backward sweep and the forward sweep. In backward sweep currents are computed using KVL and KCL from the farthest node from the source node. In forward sweep, the downstream voltage is calculated starting from source node. The input data of this algorithm is given by node-branch oriented data. Basic data required are, active and reactive powers, nomenclature for sending and receiving nodes, and impedance model for all branches. Listed below summarize major steps of the proposed solution algorithm with appropriate equations. Two matrices are used to obtain power flow solutions. These are the bus-injection to branch-current (BIBC) matrix and the branch-current to bus-voltage (BCBV) matrix. The BIBC presents the relationships between branch currents flowing through the radial network and node currents injected at each bus. For bus, the complex load S_i is expressed as:-

$$S_i = P_i + jQ_i \quad (3.7)$$

$$i = 1 \dots \dots N$$

3.3.1 Backward sweep [22]

For each iteration k , branch currents are aggregated from loads to origin. But before finding the branch current we need to find the current injected at each bus and the bus-injection to branch-

current (BIBC) which relates the bus injected current to the branch current. The current injection at the k-th iteration of the ith bus is expressed in Equation:-

$$I_{ki} = I_i^r(V_i^k) + jI_i^i(V_i^k) = \left(\frac{P_i + jQ_i}{V_{ki}}\right) \tag{3.8}$$

Where V_i^k and I_i^k are the bus voltage and equivalent current injection of the ith bus at the kth iteration, respectively. I_i^r and I_i^i are the real and imaginary parts of the equivalent current injection of bus i at the kth iteration, respectively.

Matrix development:

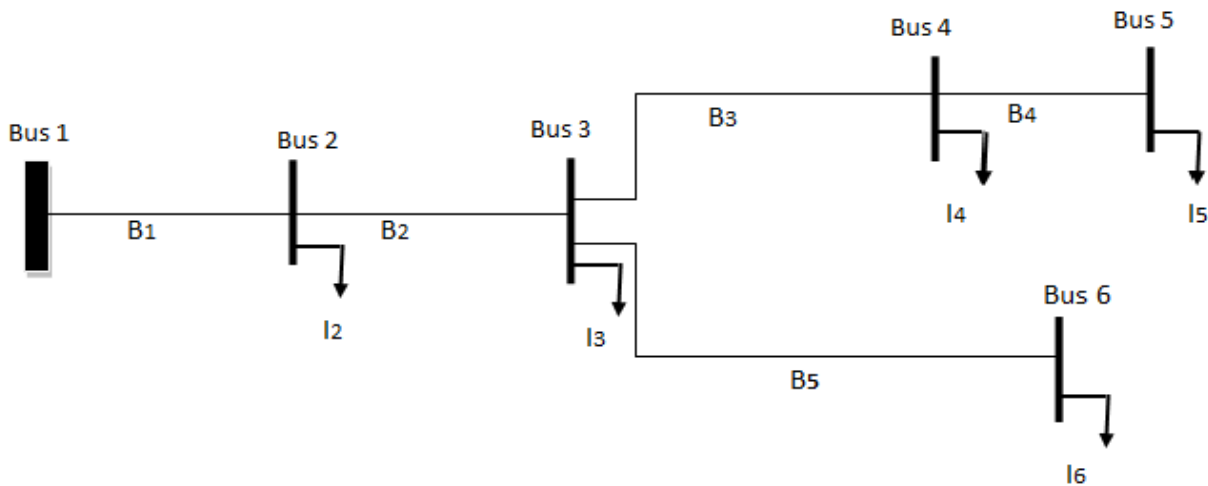


Figure 3:2 Simple radial networks

From equation (3.8), injected currents are obtained by applying Kirchhoff’s current law (KCL) to the distribution network. A simple distribution system shown in the Figure 3:2 is used as example. Branch currents can then be formulated as functions of equivalent current injections. For example, the branch currents B_1 , B_3 and B_5 can be expressed as:

$$\begin{aligned} B_1 &= I_2 + I_3 + I_4 + I_5 + I_6 \\ B_2 &= I_3 + I_4 + I_5 + I_6 \\ B_3 &= I_4 + I_5 \\ B_4 &= I_5 \end{aligned} \tag{3.9}$$

$$B_5 = I_6$$

Therefore, the relationship between the bus current injections and branch currents can be expressed as:-

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \quad (3.10)$$

Equation (3.10) can also be expressed as shown in Equation 3.11

$$[B] = [BIBC] [I] \quad (3.11)$$

Where: BIBC is a bus injection to brunch current matrix, which is the upper triangular matrix and contains values of zeros and ones only.

3.3.2 Forward sweep [22]

Nodal voltage vector V is updated from the origin to loads according the Kirchhoff voltage laws (KVL), using previously calculated branch currents vector B and branch-current to bus-voltage (BCBV). The relationship between branch currents and bus voltages as shown in Figure 3:2 can be expressed as;

$$V_2 = V_1 - B_1 Z_{12} \quad (3.12)$$

$$V_3 = V_2 - B_2 Z_{23} \quad (3.13)$$

$$V_4 = V_3 - B_3 Z_{34} \quad (3.14)$$

$$V_5 = V_4 - B_4 Z_{45} \quad (3.15)$$

$$V_6 = V_3 - B_5 Z_{36} \quad (3.16)$$

Where V_i is the voltage of bus i , and Z_{ij} is the line impedance between bus i and bus j .

Substituting equation (3.12) and (3.13) in to (3.14), then (3.14) can be rewritten as

$$V_4 = V_1 - B_1 Z_{12} - B_2 Z_{23} - B_3 Z_{34} \quad (3.17)$$

From equation 3.17, it can be seen that the bus voltage can be expressed as a function of branch currents, line parameters, and the substation voltage. Similar procedures can be performed on other buses; therefore, the relationship between branch currents and bus voltages can be expressed as,

$$\begin{bmatrix} V_2 \\ V_3 \\ V_4 \\ V_5 \\ V_6 \end{bmatrix} = \begin{bmatrix} V_1 \\ V_1 \\ V_1 \\ V_1 \\ V_1 \end{bmatrix} - \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & Z_{45} & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{36} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} \quad (3.18)$$

Equation (3.18) can be rewritten in general form as,

$$[V_{k+1}] = [V_1] - [BCBV] [B] \quad (3.19)$$

3.3.3 Procedure forming BIBC and BCBV matrix

As seen above the BIBC and BCBV matrices are developed based on the topological structure of distribution systems. The BIBC matrix represents the relationship between bus current injections and branch currents. The corresponding variations at branch currents, generated by the variations at bus current injections, can be calculated directly by the BIBC matrix. The BCBV matrix represents the relationship between branch currents and bus voltages. The corresponding variations at bus voltages, generated by the variations at branch currents, can be calculated directly by the BCBV matrix. So the procedures for forming the BIBC and BCBV are shown below:

Procedure 1: Forming BIBC: Step1: For a distribution system with m-branch section and n-bus, the dimension of the BIBC matrix is $m \times (n-1)$.

Step 2: If a line section (B_k) is located between bus i and bus j, copy the column of the ith bus of the BIBC matrix to the column of the j-th bus and fill a 1 to the position of the k-th row and the j-th bus column.

Step 3: Repeat step (2) until all line sections are included in the BIBC matrix.

Procedure 2: Forming BCBV: Step1: For a distribution system with m-branch section and n-bus, the dimension of the BCBV matrix is $(n-1) \times m$.

Step 2: If a line section is located between bus i and bus j, copy the row of the i-th bus of the BCBV matrix to the column of the j-th bus and fill the line impedance (Z_{ij}) to the position of the j-th column and the i-th bus row.

Step 3: Repeat step (2) until all line sections are included in the BCBV matrix.

3.4 Fuzzy logic model

Fuzzy models in a broad sense are of two types. The first category of the model proposed by Mamdani is based on the collection of if-then rules with both fuzzy-antecedent and consequent predicates. The advantage of this model is that the rule base is generally provided by an expert and to a certain degree, it is transparent to interpretation and analysis. Because of its simplicity the Mamdani model is the most widely used technique for solving many real world problems.

The second category of the fuzzy model is based on Takagi-Sugeno-Kang. These types of models are formed by *if-then* rules that have a fuzzy antecedent part and functional consequent. The fuzzy models are also called fuzzy rule based systems and fuzzy controllers. A fuzzy rule-based system is composed of four parts: fuzzifier, knowledge base, inference engine, and defuzzifier[24]. A typical fuzzy rule based system is depicted in Figure 3:3.

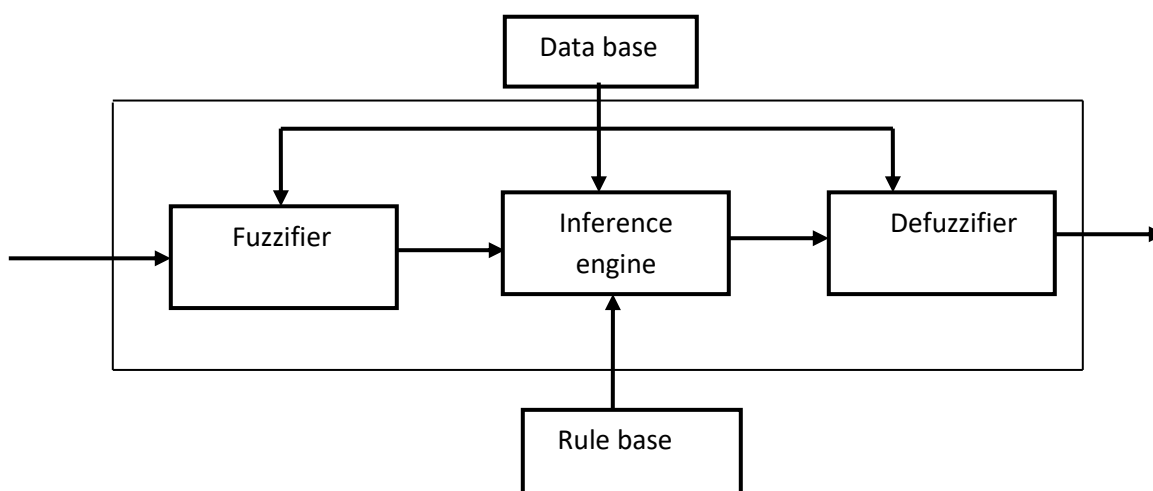


Figure 3:3 Structure of a fuzzy rule based System

The fuzzy logic is used to identify the optimal location to place the capacitor in a radial distribution system so as to minimize the losses. The fuzzy expert system (FES) contains a set of rules which are developed from qualitative descriptions. In a FES rules may be fired with some degree using fuzzy inference, where as in a conventional expert System a rule is either fired or not fired. For the capacitor placement problem rules are defined to determine the suitability of a bus for capacitor placement [24].

For determining the suitability of a particular bus for capacitor placement, sets of multiple-antecedent fuzzy rules have been established. The inputs to the rules are the bus voltages in p.u, power loss indices, and the output consequent is the suitability of a bus for capacitor placement.

3.4.1 Procedure to calculate power loss index

The power loss index at i_{th} bus is the variable which is given to fuzzy expert system to identify suitable location for the capacitor.

Step 1: Read radial distribution system data

Step 2: Perform the load flows and calculate active power loss of each bus

Step 3: Calculate power loss indices using the following equation:-

$$PLI(i) = \frac{P_L(i)}{P_L(max)} \quad (3.20)$$

Where,

PLI (i) = Power loss index at each bus

$P_L(i)$ = Power loss of each bus

$P_L(max)$ = Maximum power loss

3.4.2 Identification of sensitive bus by fuzzy expert system

The power loss indices and bus voltages are used as the inputs to the fuzzy expert system, which determines the buses which are more suitable for capacitor installation. The power loss indices range varies from 0 to 1. The voltage range varies from 0.9 to 1.1 and the output [capacitor

suitability index (CSI)] range varies from 0 to 1. These variables are described by five membership functions of high, high-medium, medium, low-medium and low [25].

The membership functions of power loss indices voltage and CSI are combination of triangular and trapezoidal membership functions. These are graphically shown in Figure 3:4 to 3:6. The membership functions for describing the voltage have been created based on standards of acceptable operating voltage ranges for distribution systems. The membership functions for the PLI and CSI indices are created to provide a ranking [26]. Therefore, as shown in table 3:1 partitions of the membership functions for the power and capacitor suitability indices are equally spaced apart.

Table 3:1 Fuzzy membership functions

| Membership function for power loss index | | | | | |
|--|--------|---------------|---------------|---------------|--------|
| Variable | Low | Low - medium | Medium | High – medium | High |
| PLI | < 0.25 | 0.00 --- 0.5 | 0.25 --- 0.75 | 0.5 --- 1.00 | > 0.75 |
| Membership function for bus voltage | | | | | |
| Variable | Low | Low - medium | Medium | High – medium | High |
| Voltage | < 0.94 | 0.92 --- 0.98 | 0.96 --- 1.04 | 1.02 --- 1.08 | > 1.06 |
| Membership function for suitability of capacitor placement | | | | | |
| Variable | Low | Low - medium | Medium | High – medium | High |
| CSI | < 0.25 | 0.00 --- 0.5 | 0.25 --- 0.75 | 0.5 --- 1.00 | > 0.75 |

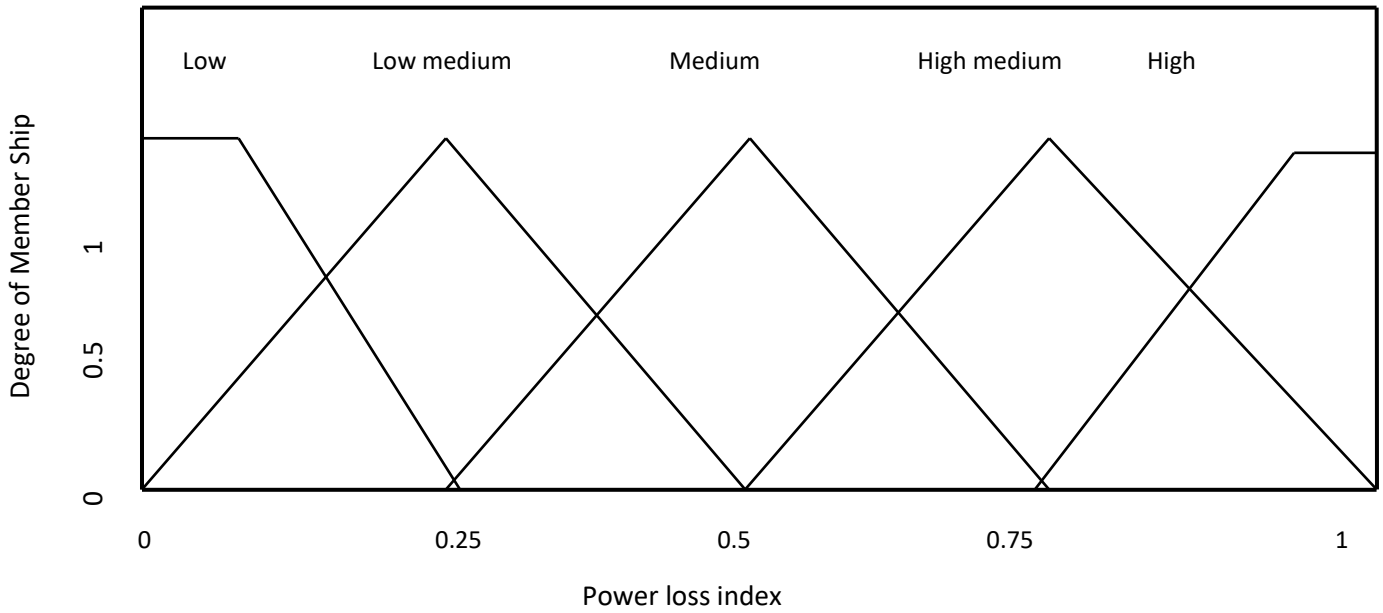


Figure 3:4 Power loss index membership function

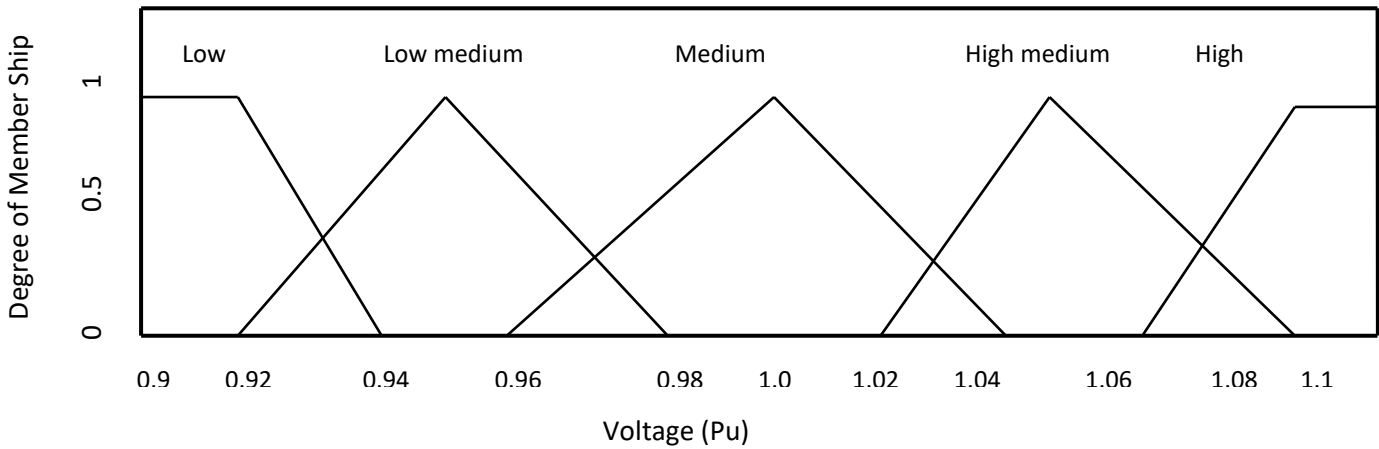


Figure 3:5 Voltage membership function

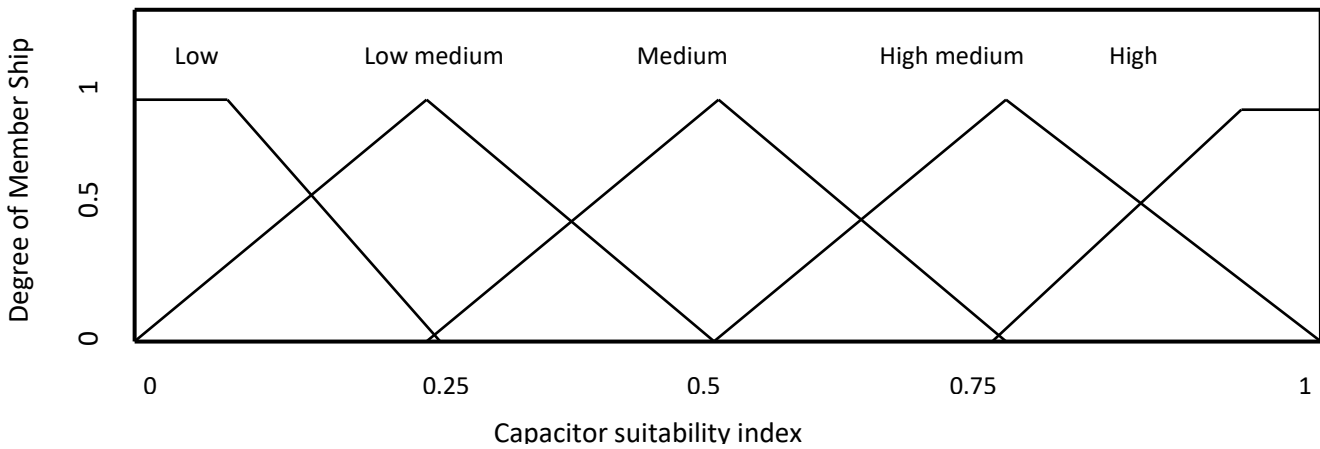


Figure 3:6 Capacitor suitability index membership function

For the capacitor placement problem rules are defined to determine the suitability of a bus for capacitor installation. For determining the suitability for capacitor placement at a particular bus, a set of multiple antecedent fuzzy rules have been established [26]. The rules are summarized in the fuzzy decision matrix in Table 3:2. The consequent of the rules are in the shaded part of the matrix.

Table 3:2 Decision matrix for determining suitable capacitor locations

| | | Voltage | | | | |
|----------------|------------|------------|-------------|-----------|--------------|----------|
| | | Low | Low- medium | Medium | High- medium | High |
| Power | Low | Low – med | Low – med | Low | Low | Low |
| | Loss | Low – med | Med | Low – med | Low – med | Low |
| Index (PLI) | Med | High – med | Med | Low – med | Low | Low |
| | High – med | High – med | High – med | Med | Low – med | Low |
| | High | High | High – med | Med | Low – med | Low- med |

Defuzzification process depends on the output fuzzy set which is generated from the fired rules. centroid method of defuzzification is selected for this research [27].

3.5 Particles swarm optimization algorithm

3.5.1 Background

Particle swarm optimization (PSO) is an effective computation technique developed by Kennedy and Eberhart in 1995 [28]. It is developed from swarm intelligence and is based on the research of bird and fish flock movement behavior. While searching for food the birds are either scattered or go together before they locate the place where they can find the food. While the birds are searching for food from one place to another, there is always a bird that can smell the food very well, that is the bird is perceptible of the place where the food can be found having the better food resource information. Because they are transmitting the information, especially the good information at any time while searching the food from one place to another, conducted by the good information, the birds will eventually flock to the place where food can be found. As far as

particle swarm optimization algorithm is concerned, solution swarm is compared to the bird swarm, the birds' moving from one place to another is equal to the development of the solution swarm, good information is equal to the most optimist solution, and the food resource is equal to the most optimist solution during the whole course.

The most optimist solution can be worked out in particles swarm optimization algorithm by the cooperation of each individual. The particle without quality and volume serves as each individual, and the simple behavioral pattern is regulated for each particle to show the complexity of the whole particle swarm. The original objective of the research particle swarm was to graphically simulate the social behavior of bird flocks and fish schools. The first version of PSO was intended to handle only nonlinear continuous optimization problems. However, many advances in PSO development elevated its capabilities to handle a wide class of complex optimization problems involved in engineering and science.

3.5.2 Basic particle swarm optimization algorithm

Different variants of the PSO algorithm were proposed but the most standard one is introduced by Shi and Eberhart in [29]. Key attractive feature of PSO is its simplicity as it involves only two model equations. In PSO, the coordinates of each particle represent a possible solution associated with two vectors, the position (X_i) and velocity (V_i) vectors. The size of vectors X_i and V_i is equal to the problem space dimension. A swarm consists of number of particles "or possible solutions" that proceed (fly) through the feasible solution space to explore optimal solutions. Each particle updates its position based on its own best exploration; best swarm overall experience, and its previous velocity vector according to the following model:

$$V_i^{k+1} = \omega V_i^k + c_1 * r_1 * (pbest_i - x_i^k) + c_2 * r_2 * (gbest_i - x_i^k) \quad (3.21)$$

$$X_i^{k+1} = x_i^k + v_i^{k+1} \quad (3.22)$$

Where

V_i^k : is the i^{th} velocity component at iteration k ,

r_1 and r_2 : is random number between 0 and 1,

x_i^k : is the current position in the i th dimension,

C_1, C_2 : are the acceleration coefficients,

$Pbest_i$: is the personal best position in the i th dimension,

$gbest_i$: is the global best position in the i th dimension and

ω : is the inertia weight.

In a PSO algorithm, population is initiated randomly with particles and evaluated to compute fitness's together with finding the particle best (best value of each individual so far) and global best (best particle in the whole swarm). Initially, each individual with its dimensions and fitness value is assigned to its particle best. The best individual among particle best population, with its dimension and fitness value is assigned to the global best. Then a loop starts to converge to an optimum solution. In the loop, particle and global bests are determined to update the velocity first. Then the current position of each particle is updated with the current velocity. Evaluation is again performed to compute the fitness of the particles in the swarm. This loop is terminated with a stopping criterion is satisfied.

3.5.3 PSO algorithm parameters

There are some parameters in PSO algorithm that may affect its performance. For any given optimization problem, some of these parameter's values and choices have large impact on the efficiency of the PSO method, and other parameters have small or no effect. The basic PSO parameters are swarm size or number of particles, number of iterations, velocity components, and acceleration coefficients illustrated bellow.

3.5.3.1 Swarm size

Swarm size or population size is the number of particles in the swarm. A big swarm generates larger parts of the search space to be covered per iteration. A large number of particles may reduce the number of iterations need to obtain a good optimization result. In contrast, huge amounts of particles increase the computational complexity per iteration, and more time consuming. From a

number of empirical studies, it has been shown that most of the PSO implementations use an interval of 20 - 60 for the swarm size [28].

3.5.3.2 Iteration numbers

The number of iterations to obtain a good result is also problem-dependent. A too low number of iterations may stop the search process prematurely, while too large iterations has the consequence of unnecessary added computational complexity and more time needed [30]. In this research the iteration number is 100.

3.5.3.3 Velocity components

The velocity components are very important for updating particle's velocity. There are three terms of the particle's velocity in Equations 3:20.

1. The term ωV_i^k is called inertia component that provides a memory of the previous flight direction that means movement in the immediate past. This component represents as a momentum which prevents to drastically change the direction of the particles and to bias towards the current direction.
2. The term $c_1 * r_1 * (pbest_i - x_i^k)$ is called cognitive component which measures the performance of the particles relative to past performances. This component looks like an individual memory of the position that was the best for the particle. The effect of the cognitive component represents the tendency of individuals to return to positions that satisfied them most in the past.
3. The term $c_2 * r_2 * (gbest_i - x_i^k)$ is called social component which measures the performance of the particles relative to a group of particles or neighbors. The social component's effect is that each particle flies towards the best position found by the swarm.

3.5.3.4 Acceleration coefficients particle's neighborhood

The acceleration coefficients c_1 and c_2 , together with the random values r_1 and r_2 , maintain the stochastic influence of the cognitive and social components of the particle's velocity respectively.

The constant c_1 expresses how much confidence a particle has in itself, while c_2 expresses how much confidence a particle has in its neighbors.

- ❖ When $c_1 = c_2$, all particles are attracted towards the average of $pbest_i$ and $gbest_i$.
- ❖ When $c_1 \gg c_2$, each particle is more strongly influenced by its personal best position, resulting in excessive wandering.
- ❖ When $c_1 \ll c_2$ then all particles are much more influenced by the global best position, which causes all particles to run prematurely to the optima.

Normally, c_1 and c_2 are static, with their optimized values being found empirically. Wrong initialization of c_1 and c_2 may result in divergent or cyclic behavior [30]. From the different empirical researches, it has been proposed that the two acceleration constants should be $c_1 = c_2 = 2$

3.5.3.5 Steps for particle swarm optimization technique

The PSO technique for this study can be described in the following steps.

Step 1: Initialization: define all parameters and generate random n particles with random positions, in this thesis the selected swarm size is 20.

Step 2: Fitness evaluation: Calculate the fitness value for the given objective function for each particle. The objective function will be calculated after running the back ward forward sweep load flow.

Step 3: Compare the particle fitness value with previous $pbest$.

Step 4: Update the particle P_{best} value to g_{best}

Step 5: Update the velocity using Equation 3.21

Step 6: Update the particles Position using Equation 3.22

Step 7: Updates data value based on velocity value of particles

Step 8 Stopping criteria: The iteration is repeated until the convergence is made. The flow chart which shows the above steps is shown in Figure 3:7.

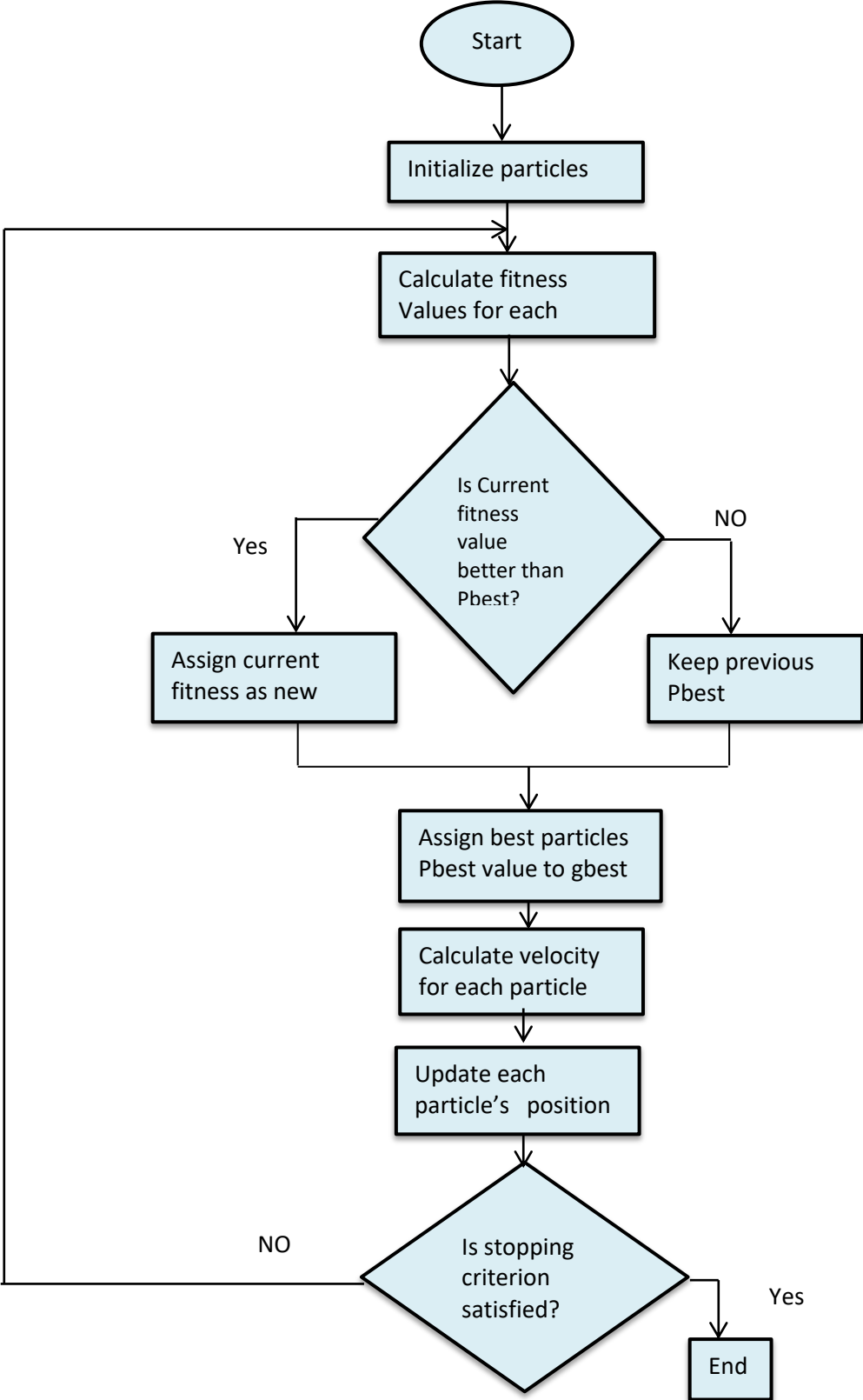


Figure 3:7 Flow chart of PSO algorithm

4. RESULTS AND DISCUSSION

4.1 Load flow before compensation

The data needed for this research work are collected from Adama substation, standard conductor datasheet, EEP Adama district distribution department employees and measurement of active reactive powers using Power meter. The lengths of the conductors, area of conductors and conductor types are obtained from the AutoCAD design of Adama town electrical distribution system.

Reactive power optimization process is applied on feeder four of Adama town 15kV distribution feeder. The selected feeder has 75 buses, 71 transformers, annual average peak load of 8.4 Mw and 33.75km length. 1st bus is source bus, 7 buses are connecting buses and other 67 buses are load buses.

To apply backward forward load flow algorithm line data and bus data are required, Resistance and reactance of each branch are calculated using equation 3.5 and 3.6 respectively. The sample of line data and bus data of feeder four are shown on Table 4:1 and 4.2. Full datas of this feeder are shown on Table b: 1 and b: 2 of Appendix b.

Table 4:1 Line data

| Branch | Sending end | Receiving end | Resistance (pu) | Reactance (pu) | Conductor type | Length (km) | Resistance (ohm) | reactance (ohm) |
|--------|-------------|---------------|-----------------|----------------|----------------|-------------|------------------|-----------------|
| 1 | 1 | 2 | 0.00121 | 0.00064 | AAC 50 | 0.267 | 0.1816 | 0.0967 |
| 2 | 2 | 3 | 0.00066 | 0.00035 | AAC 50 | 0.145 | 0.0986 | 0.0525 |
| 3 | 2 | 4 | 0.00076 | 0.00041 | AAC 50 | 0.168 | 0.1142 | 0.0608 |
| 4 | 4 | 5 | 0.00183 | 0.00097 | AAC 50 | 0.404 | 0.2747 | 0.1462 |
| 5 | 5 | 6 | 0.00070 | 0.00037 | AAC 50 | 0.154 | 0.1047 | 0.0557 |
| 6 | 6 | 7 | 0.00166 | 0.00047 | AAC 25 | 0.186 | 0.2489 | 0.0707 |
| 7 | 6 | 8 | 0.00060 | 0.00032 | AAC 50 | 0.132 | 0.0898 | 0.0478 |
| 8 | 8 | 9 | 0.00196 | 0.00104 | AAC 50 | 0.432 | 0.2938 | 0.1564 |
| 9 | 9 | 10 | 0.00197 | 0.00105 | AAC 50 | 0.434 | 0.2951 | 0.1571 |
| 10 | 10 | 11 | 0.00210 | 0.00112 | AAC 50 | 0.464 | 0.3155 | 0.1680 |
| 11 | 11 | 12 | 0.00127 | 0.00068 | AAC 50 | 0.28 | 0.1904 | 0.1014 |
| 12 | 12 | 13 | 0.00188 | 0.00100 | AAC 50 | 0.414 | 0.2815 | 0.1499 |
| 13 | 13 | 14 | 0.00078 | 0.00042 | AAC 50 | 0.172 | 0.1170 | 0.0623 |
| 14 | 14 | 15 | 0.00260 | 0.00139 | AAC 50 | 0.574 | 0.3903 | 0.2078 |
| 15 | 15 | 16 | 0.00061 | 0.00033 | AAC 50 | 0.135 | 0.0918 | 0.0489 |
| 16 | 16 | 17 | 0.00140 | 0.00075 | AAC 50 | 0.309 | 0.2101 | 0.1119 |
| 17 | 17 | 18 | 0.00219 | 0.00116 | AAC 50 | 0.482 | 0.3278 | 0.1745 |
| 18 | 14 | 19 | 0.00084 | 0.00045 | AAC 50 | 0.186 | 0.1265 | 0.0673 |
| 19 | 19 | 20 | 0.00283 | 0.00151 | AAC 50 | 0.624 | 0.4243 | 0.2259 |
| 20 | 20 | 21 | 0.00163 | 0.00087 | AAC 50 | 0.36 | 0.2448 | 0.1303 |

Table 4:2 Bus data

| Bus | P (pu) | Q (pu) | p (Kw) | q (Kvr) | Transformer KVA | Bus | P (pu) | Q (pu) | p (Kw) | q (Kvr) | Transformer KVA |
|-----|--------|--------|--------|---------|-----------------|-----|--------|--------|--------|---------|-----------------|
| 1 | 0.0000 | 0.0000 | 0.00 | 0.00 | 0 | 11 | 0.0856 | 0.0392 | 128.40 | 58.80 | 315 |
| 2 | 0.0876 | 0.0329 | 131.40 | 49.40 | 315 | 12 | 0.0615 | 0.0303 | 92.20 | 45.50 | 315 |
| 3 | 0.2625 | 0.1219 | 393.70 | 182.80 | 630 | 13 | 0.1083 | 0.0477 | 162.52 | 71.48 | 315 |
| 4 | 0.0944 | 0.0307 | 141.60 | 46.10 | 315 | 14 | 0.0610 | 0.0279 | 91.57 | 41.90 | 315 |
| 5 | 0.0497 | 0.0301 | 74.60 | 45.10 | 200 | 15 | 0.0649 | 0.0338 | 97.29 | 50.71 | 200 |
| 6 | 0.0000 | 0.0000 | 0.00 | 0.00 | 0 | 16 | 0.0356 | 0.0151 | 53.33 | 22.67 | 100 |
| 7 | 0.1439 | 0.0710 | 215.80 | 106.50 | 315 | 17 | 0.0129 | 0.0059 | 19.30 | 8.80 | 25 |
| 8 | 0.0307 | 0.0145 | 46.12 | 21.80 | 50 | 18 | 0.2852 | 0.1553 | 427.76 | 232.95 | 2*315 |
| 9 | 0.1100 | 0.0407 | 165.00 | 61.00 | 315 | 19 | 0.0523 | 0.0204 | 78.43 | 30.67 | 315 |
| 10 | 0.0593 | 0.0141 | 89.00 | 21.20 | 100 | 20 | 0.0833 | 0.0418 | 125.00 | 62.67 | 315 |

The active and reactive powers of each transformer listed in table 4.2 are directly measured at selected feeder. It is clear that from the above tables we can see that some transformers like transformers at bus 8, 33 and 58 are over loaded because they carry above their rating value.

By using line data and bus data that are given in Table 4:1 and Table 4:2 as inputs of backward forward load flow method, MATLAB code is generated and running, The MATLAB code is attached at appendix c. The result of MATLAB load flow program indicates that only node 1 – 12 are in permissible limit .The voltage at the rest of the nodes are out of acceptable voltage limit ($\pm 10\%$). Large distribution radial systems produce very low voltage at the load buses located far from the substation. These low voltages at the load will cause large power losses and reduce the power factor. Such kind of node voltage limit violation of radial distribution system can be improved by placing shunt capacitors on distribution feeders.

Power flow simulation results of MATLAB of the power loss of the feeder and bus voltage are indicated in Table 4:3 and Table 4:4.

Table 4:3 Active and reactive power losses before compensation

| Branch | I(a) | PL (kw) | QL (kvar) | | Branch | I(a) | PL (kw) | QL (kvar) |
|--------|-------|---------|-----------|--|--------|-------|---------|-----------|
| 1 | 729.1 | 96.5 | 51.15 | | 23 | 498.7 | 67.2 | 27.85 |
| 2 | 29.2 | 0.1 | 0.04 | | 24 | 68.8 | 0.4 | 0.19 |
| 3 | 690.4 | 54.3 | 29.39 | | 25 | 48.9 | 0.2 | 0.11 |
| 4 | 680.4 | 127.1 | 67.53 | | 26 | 21.8 | 0.2 | 0.09 |
| 5 | 674.4 | 47.8 | 25.31 | | 27 | 31.4 | 0.1 | 0.02 |
| 6 | 16.6 | 0.1 | 0.02 | | 28 | 23.7 | 0.1 | 0.04 |
| 7 | 657.8 | 38.9 | 20.83 | | 29 | 20.7 | 0.1 | 0.04 |
| 8 | 654.3 | 125.9 | 66.96 | | 30 | 17.8 | 0.1 | 0.04 |
| 9 | 641.9 | 121.8 | 65.08 | | 31 | 12.6 | 0.1 | 0.01 |
| 10 | 635.5 | 127.2 | 68.04 | | 32 | 4.5 | 0.1 | 0.01 |
| 11 | 625.3 | 74.5 | 29.99 | | 33 | 398.6 | 11.4 | 4.75 |
| 12 | 617.7 | 107.6 | 57.22 | | 34 | 386.3 | 50.6 | 29.70 |
| 13 | 604.5 | 42.7 | 23.02 | | 35 | 374.4 | 31.7 | 14.58 |
| 14 | 50.9 | 1.0 | 0.54 | | 36 | 101.3 | 1.7 | 0.62 |
| 15 | 42.6 | 0.3 | 0.09 | | 37 | 89.2 | 6.1 | 3.10 |
| 16 | 38.3 | 0.3 | 0.16 | | 38 | 84.2 | 0.7 | 0.37 |
| 17 | 36.7 | 0.4 | 0.23 | | 39 | 26.6 | 0.3 | 0.17 |
| 18 | 546.1 | 37.6 | 20.14 | | 40 | 12.8 | 0.2 | 0.08 |
| 19 | 539.8 | 123.7 | 66.02 | | 41 | 7.4 | 0.1 | 0.01 |
| 20 | 529.0 | 68.4 | 31.50 | | 42 | 57.6 | 1.2 | 0.33 |
| 21 | 518.5 | 83.9 | 39.74 | | 43 | 55.8 | 0.3 | 0.15 |
| 22 | 511.4 | 68.3 | 35.92 | | 44 | 10.9 | 0.1 | 0.01 |
| | | | | | | | | |

| Branch | I(a) | PL (kw) | QL (kvar) | | Branch | I(a) | PL (kw) | QI (kvar) |
|--------|-------|---------|-----------|--|--------|------|---------|-----------|
| 45 | 7.2 | 0.1 | 0.01 | | 69 | 74.9 | 2.0 | 1.06 |
| 46 | 45.0 | 0.2 | 0.07 | | 70 | 68.8 | 0.8 | 0.40 |
| 47 | 20.1 | 0.1 | 0.05 | | 71 | 46.6 | 0.5 | 0.10 |
| 48 | 14.6 | 0.1 | 0.04 | | 72 | 30.3 | 0.2 | 0.11 |
| 49 | 19.5 | 0.6 | 0.03 | | 73 | 23.5 | 0.2 | 0.10 |
| 50 | 5.2 | 0.1 | 0.01 | | 74 | 5.0 | 0.1 | 0.01 |
| 51 | 265.4 | 5.8 | 3.01 | | | | | |
| 52 | 232.5 | 19.9 | 10.44 | | | | | |
| 53 | 227.6 | 11.4 | 5.95 | | | | | |
| 54 | 218.9 | 3.2 | 1.69 | | | | | |
| 55 | 210.8 | 4.5 | 2.36 | | | | | |
| 56 | 201.8 | 27.5 | 14.15 | | | | | |
| 57 | 49.7 | 0.8 | 0.32 | | | | | |
| 58 | 47.3 | 0.9 | 0.47 | | | | | |
| 59 | 33.6 | 0.2 | 0.08 | | | | | |
| 60 | 25.1 | 0.2 | 0.12 | | | | | |
| 61 | 14.4 | 0.1 | 0.05 | | | | | |
| 62 | 8.5 | 0.1 | 0.04 | | | | | |
| 63 | 152.1 | 4.3 | 2.25 | | | | | |
| 64 | 140.8 | 2.6 | 1.40 | | | | | |
| 65 | 44.1 | 0.3 | 0.16 | | | | | |
| 66 | 89.0 | 3.3 | 1.71 | | | | | |
| 67 | 6.5 | 0.1 | 0.01 | | | | | |
| 68 | 79.7 | 2.4 | 1.25 | | | | | |

Table 4:4 Voltage profiles of buses

| | | | | | | | | | | | | | | | |
|--------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Bus No | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| V (pu) | 1.00 | 0.99 | 0.99 | 0.98 | 0.97 | 0.96 | 0.96 | 0.96 | 0.95 | 0.93 | 0.92 | 0.91 | 0.89 | 0.89 | 0.89 |
| Bus No | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| V (pu) | 0.89 | 0.89 | 0.8 | 0.88 | 0.87 | 0.86 | 0.84 | 0.83 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 |
| Bus No | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 |
| V (pu) | 0.82 | 0.82 | 0.82 | 0.82 | 0.81 | 0.81 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 |
| Bus No | 46 | 47 | 48 | 46 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 |
| V (pu) | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.79 | 0.79 | 0.79 | 0.78 | 0.78 | 0.78 |
| Bus No | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 |
| V (pu) | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 |

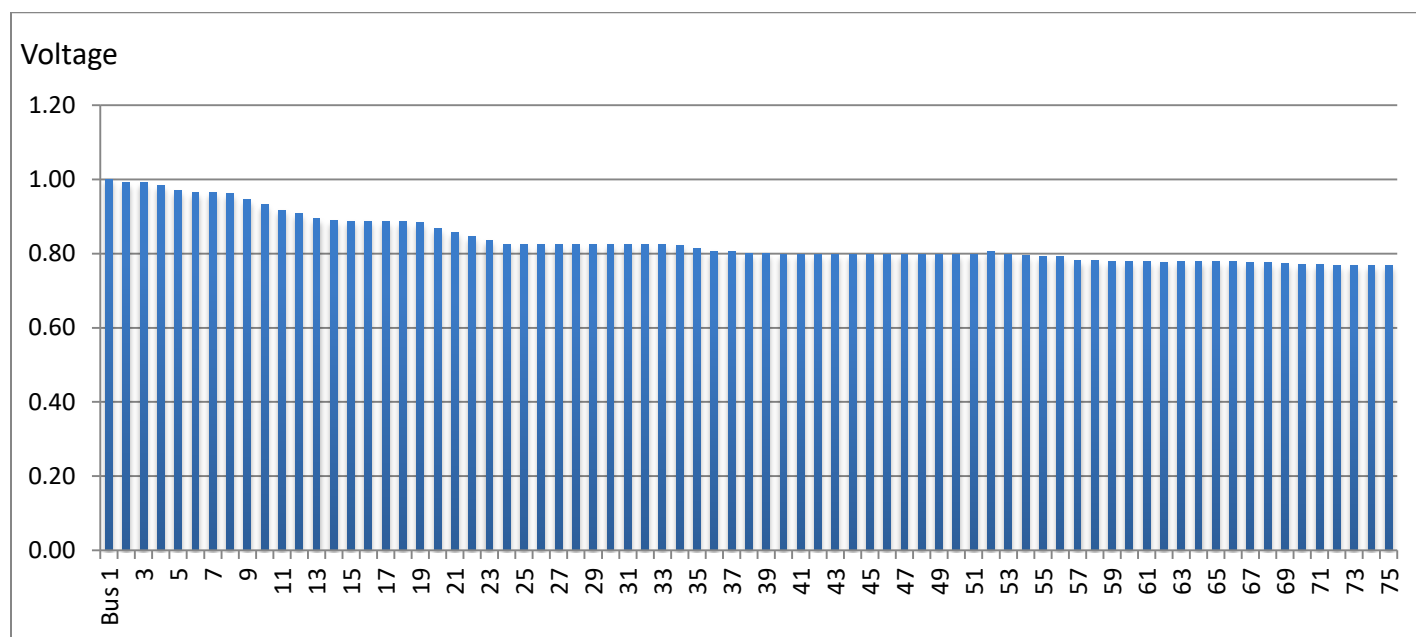


Figure 4:1 Bus voltages

Table 4.3 shows that some transformers carry above their rated KVA and have high power losses. The total loads of the feeder are **8.33 MW** and **3.85 Mvar**. In addition to this Table 4.4 and Figure 4:1 indicate that the voltage profiles of most of buses are very poor, which are less than 0.9. The initial active power loss of the feeder is **1.57 MW** which is **18.85 %** of the feeder's total power. So the existing selected distribution feeder of Adama city is over loaded. This indicates that the feeder needs reactive power compensation devices to minimize losses.

4.2 Optimal locations

To determine the optimal locations the voltage magnitude (obtain from load flow) and power loss index at each bus (calculated using Equation 3.20) are represented in fuzzy membership function. The membership functions created in MATLAB fuzzy tool box are shown in figure 4:2, 4:3 and 4:4. Established fuzzy rules and other fuzzy output of MATLAB are attached at Appendix d.

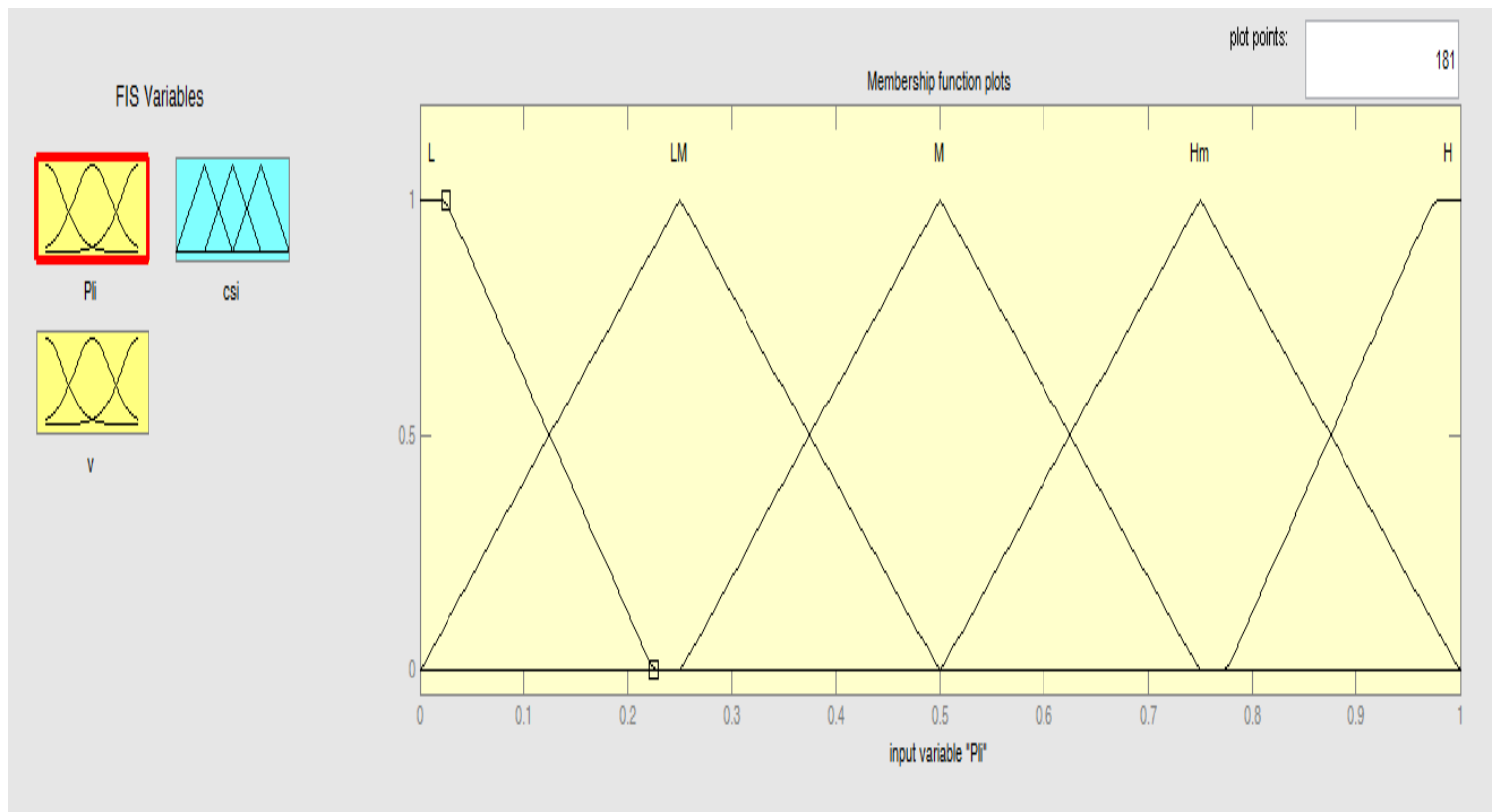


Figure 4:2 Member ship function of PLI

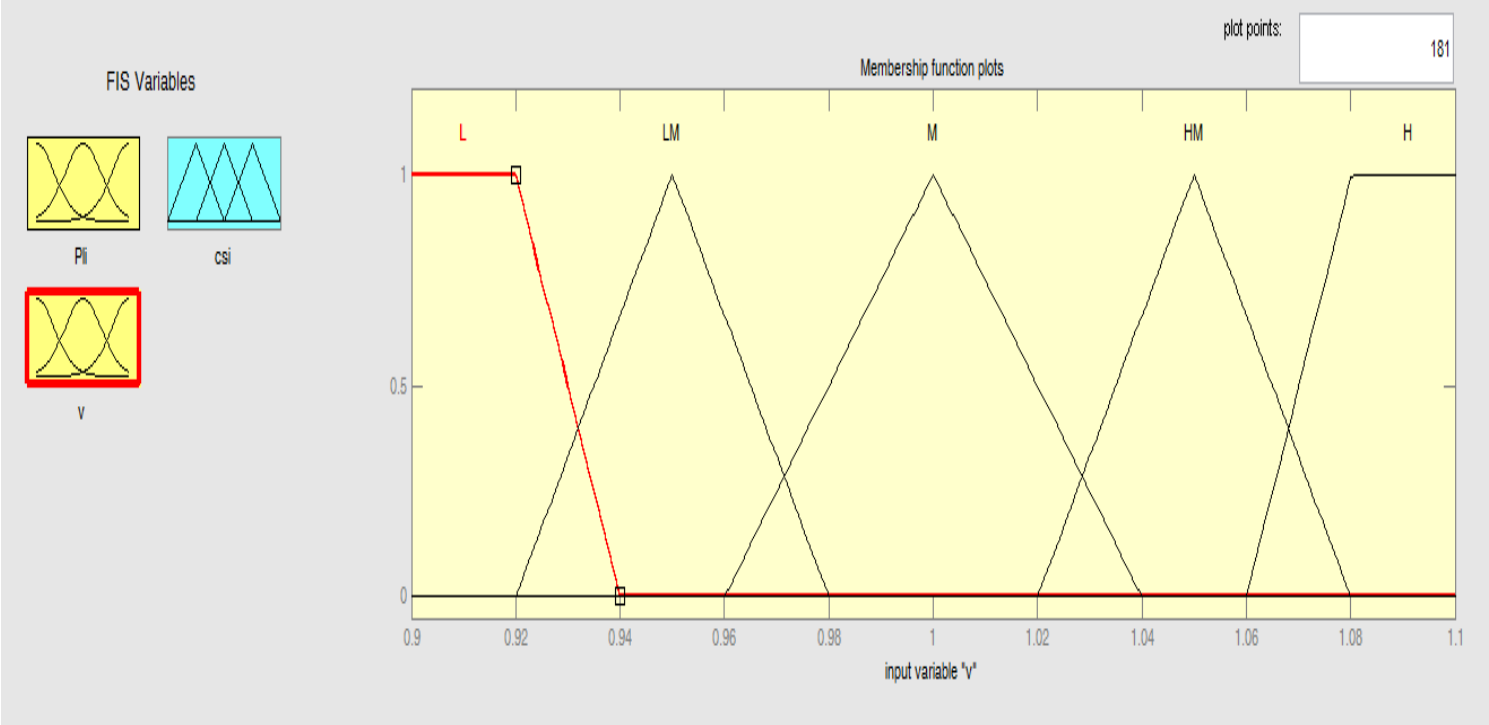


Figure 4:3 Member ship function of V

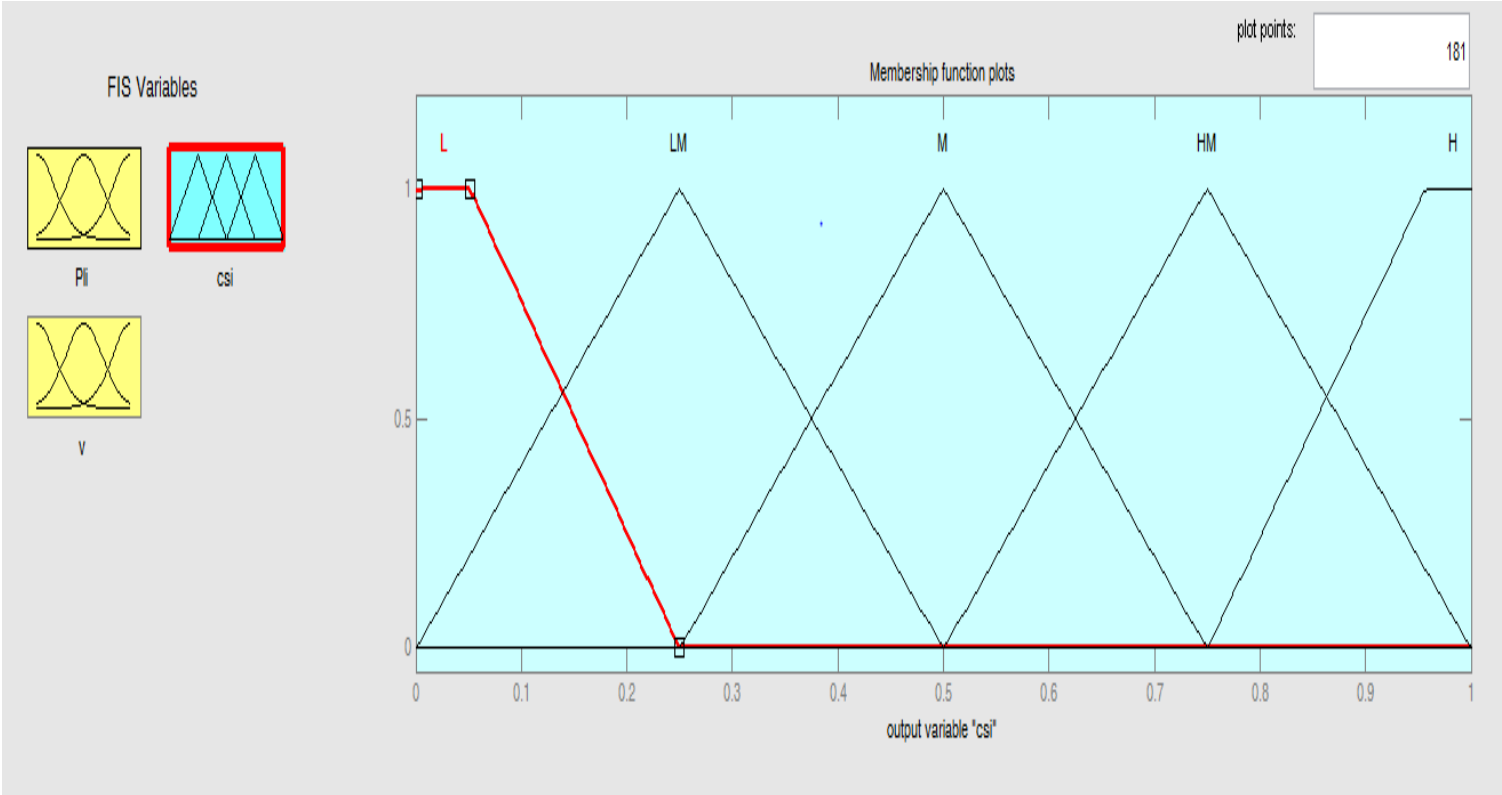


Figure 4:4 Member Ship function of CSI

Table 4:5 Fuzzy inputs

| Bus No | Input 1 Voltage (Pu) | Input 2 PLI | Bus No | Input 1 Voltage (Pu) | Input 2 PLI | Bus No | Input 1 Voltage (Pu) | Input 2 PLI | Bus No | Input 1 Voltage (Pu) | Input 2 PLI |
|--------|----------------------|-------------|--------|----------------------|-------------|--------|----------------------|-------------|--------|----------------------|-------------|
| 1 | 1.00 | 0.000 | 20 | 0.87 | 0.972 | 39 | 0.80 | 0.006 | 58 | 0.78 | 0.006 |
| 2 | 0.99 | 0.758 | 21 | 0.86 | 0.538 | 40 | 0.80 | 0.003 | 59 | 0.78 | 0.007 |
| 3 | 0.99 | 0.001 | 22 | 0.84 | 0.659 | 41 | 0.80 | 0.001 | 60 | 0.78 | 0.001 |
| 4 | 0.98 | 0.427 | 23 | 0.83 | 0.537 | 42 | 0.80 | 0.001 | 61 | 0.78 | 0.002 |
| 5 | 0.97 | 0.999 | 24 | 0.82 | 0.528 | 43 | 0.80 | 0.009 | 62 | 0.78 | 0.001 |
| 6 | 0.96 | 0.375 | 25 | 0.82 | 0.004 | 44 | 0.80 | 0.002 | 63 | 0.78 | 0.001 |
| 7 | 0.96 | 0.001 | 26 | 0.82 | 0.002 | 45 | 0.80 | 0.001 | 64 | 0.78 | 0.034 |
| 8 | 0.96 | 0.306 | 27 | 0.82 | 0.001 | 46 | 0.80 | 0.001 | 65 | 0.78 | 0.021 |
| 9 | 0.95 | 0.989 | 28 | 0.82 | 0.001 | 47 | 0.80 | 0.001 | 66 | 0.78 | 0.002 |
| 10 | 0.93 | 0.957 | 29 | 0.82 | 0.001 | 48 | 0.80 | 0.001 | 67 | 0.77 | 0.026 |
| 11 | 0.92 | 1.000 | 30 | 0.82 | 0.001 | 49 | 0.80 | 0.001 | 68 | 0.77 | 0.001 |
| 12 | 0.91 | 0.585 | 31 | 0.82 | 0.001 | 50 | 0.80 | 0.004 | 69 | 0.77 | 0.019 |
| 13 | 0.89 | 0.846 | 32 | 0.82 | 0.001 | 51 | 0.80 | 0.001 | 70 | 0.77 | 0.016 |
| 14 | 0.89 | 0.336 | 33 | 0.82 | 0.001 | 52 | 0.80 | 0.046 | 71 | 0.77 | 0.006 |
| 15 | 0.89 | 0.008 | 34 | 0.82 | 0.090 | 53 | 0.80 | 0.156 | 72 | 0.77 | 0.004 |
| 16 | 0.89 | 0.002 | 35 | 0.81 | 0.398 | 54 | 0.79 | 0.090 | 73 | 0.77 | 0.002 |
| 17 | 0.89 | 0.002 | 36 | 0.81 | 0.250 | 55 | 0.79 | 0.025 | 74 | 0.77 | 0.001 |
| 18 | 0.89 | 0.003 | 37 | 0.80 | 0.013 | 56 | 0.79 | 0.035 | 75 | 0.77 | 0.001 |
| 19 | 0.88 | 0.295 | 38 | 0.80 | 0.048 | 57 | 0.78 | 0.216 | | | |

For determining the suitability for capacitor placement at a particular bus established fuzzy rules have been tested on MATLAB toolbox and the fuzzy output is summarized in Table 4.6.

Table 4:6 CSI of buses

| | | | | | | | | | | | | | | | |
|----------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Bus No | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| CSI (pu) | 0.00 | 0.50 | 0.08 | 0.25 | 0.63 | 0.43 | 0.25 | 0.42 | 0.79 | 0.81 | 0.92 | 0.75 | 0.77 | 0.59 | 0.13 |
| Bus No | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| CSI (pu) | 0.09 | 0.09 | 0.10 | 0.56 | 0.87 | 0.75 | 0.75 | 0.75 | 0.75 | 0.10 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |
| Bus No | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 |
| CSI (pu) | 0.09 | 0.09 | 0.09 | 0.32 | 0.64 | 0.5 | 0.15 | 0.25 | 0.10 | 0.10 | 0.09 | 0.09 | 0.13 | 0.09 | 0.09 |
| Bus No | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 |
| CSI (pu) | 0.09 | 0.09 | 0.09 | 0.09 | 0.11 | 0.09 | 0.25 | 0.39 | 0.32 | 0.19 | 0.22 | 0.46 | 0.12 | 0.12 | 0.09 |
| Bus No | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 |
| CSI (pu) | 0.09 | 0.09 | 0.09 | 0.22 | 0.18 | 0.09 | 0.20 | 0.09 | 0.17 | 0.16 | 0.12 | 0.11 | 0.09 | 0.09 | 0.09 |

As shown in Table 4:6 the bus which needs compensating will give maximum CSI. Buses which are already balanced will give lesser values. In this research buses having high CSI value of 0.75 and above are selected for optimal locations. Therefore bus **9** , bus **10** , bus **11** , bus **12** , bus **13** , bus **20** , bus **21** , bus **22** , bus **23** and bus **24** have high CSI. So they are selected for capacitor placement. The remaining buses will not need compensation.

4.3 Optimal size of capacitors

The particle swarm optimization based reactive power optimization problem was implemented using MATLAB R2010a programming language. Based on the flowchart given in Section 3.5.3 MATLAB code was executed on a PC. The proposed algorithm was run for minimization of real power loss. The MATLAB code of PSO is attached at appendix E. The parameters used are the following.

- ❖ Population size = 20
- ❖ Number of decision variables = 10
- ❖ Lower bound of variables = 0.067
- ❖ Upper bound of variables = 1
- ❖ Personal learning coefficient = 2

- ❖ Global learning coefficient = 2
- ❖ Maximum number of iterations = 100

The PSO MATLAB code takes elapsed time of 165.2 seconds (figure 4.5).

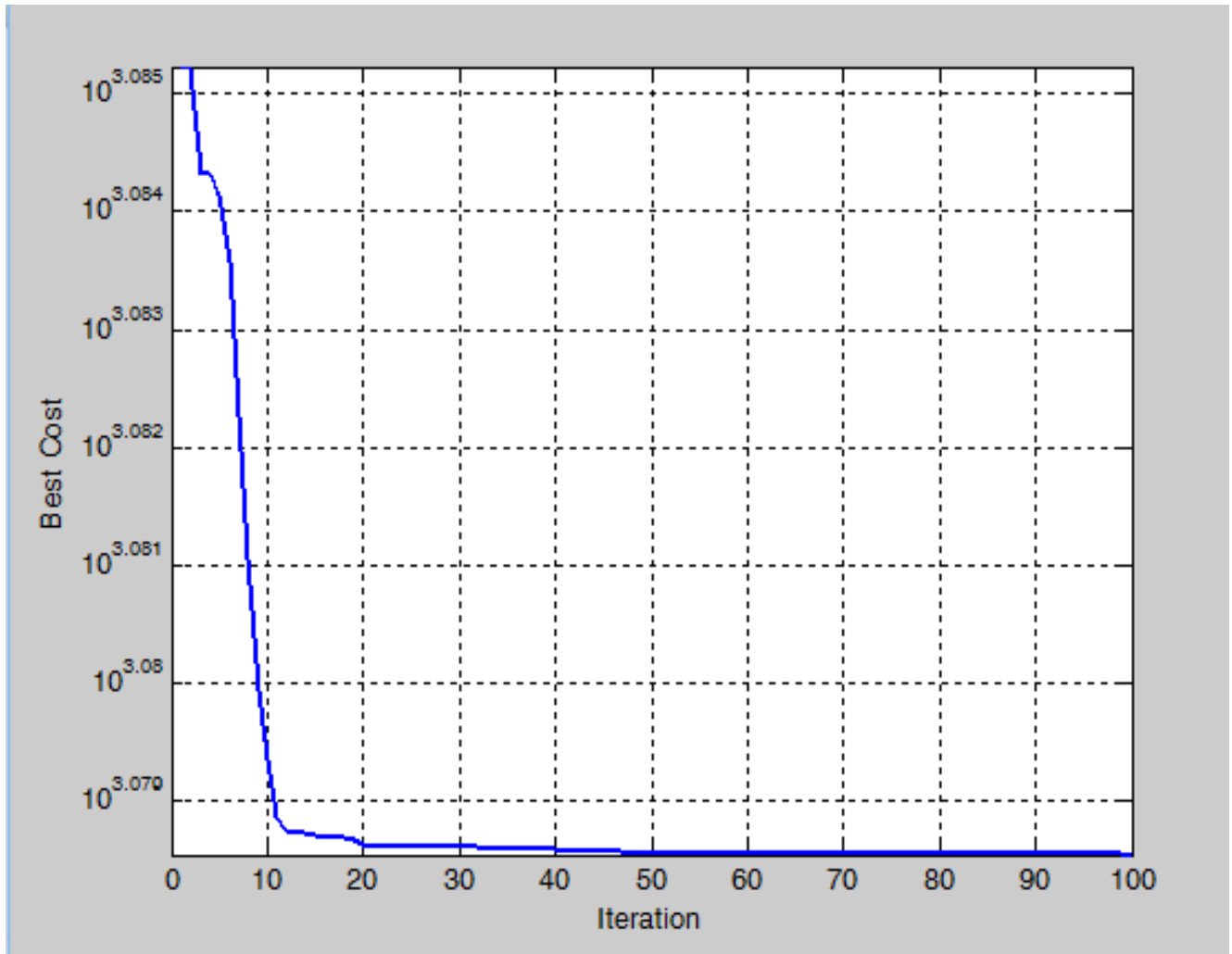


Figure 4:5 Elapsed time of PSO

The PSO result that shows optimum capacitor sizes for selected buses are summarized in table 4:7

Table 4:7 Selected capacitor sizes

| Bus No | size of capacitor (pu) | Size of capacitor (Kvar) |
|--------|------------------------|--------------------------|
| 9 | 0.313 | 470.49 |
| 10 | 0.122 | 183.76 |
| 11 | 0.096 | 144.5 |
| 12 | 0.098 | 147.57 |
| 13 | 0.336 | 505.2 |
| 20 | 0.266 | 399.8 |
| 21 | 0.069 | 103.89 |
| 22 | 0.191 | 286.77 |
| 23 | 0.899 | 1350 |
| 24 | 0.899 | 1350 |
| Total | | 4941.98 Kvar |

As shown in Table 4:7 the best value of the capacitor size for the selected bus are 470.5, 183.4, 144.5, 147.6, 505.2, 399.8, 103.9, 286.77 and 1350 Kvar respectively. But the values in standard form become **450, 150, 150, 150, 600, 450, 150, 300 and 1350 Kvar** respectively [31]. Optimal locations with shunt capacitors are shown in figure 4.6.

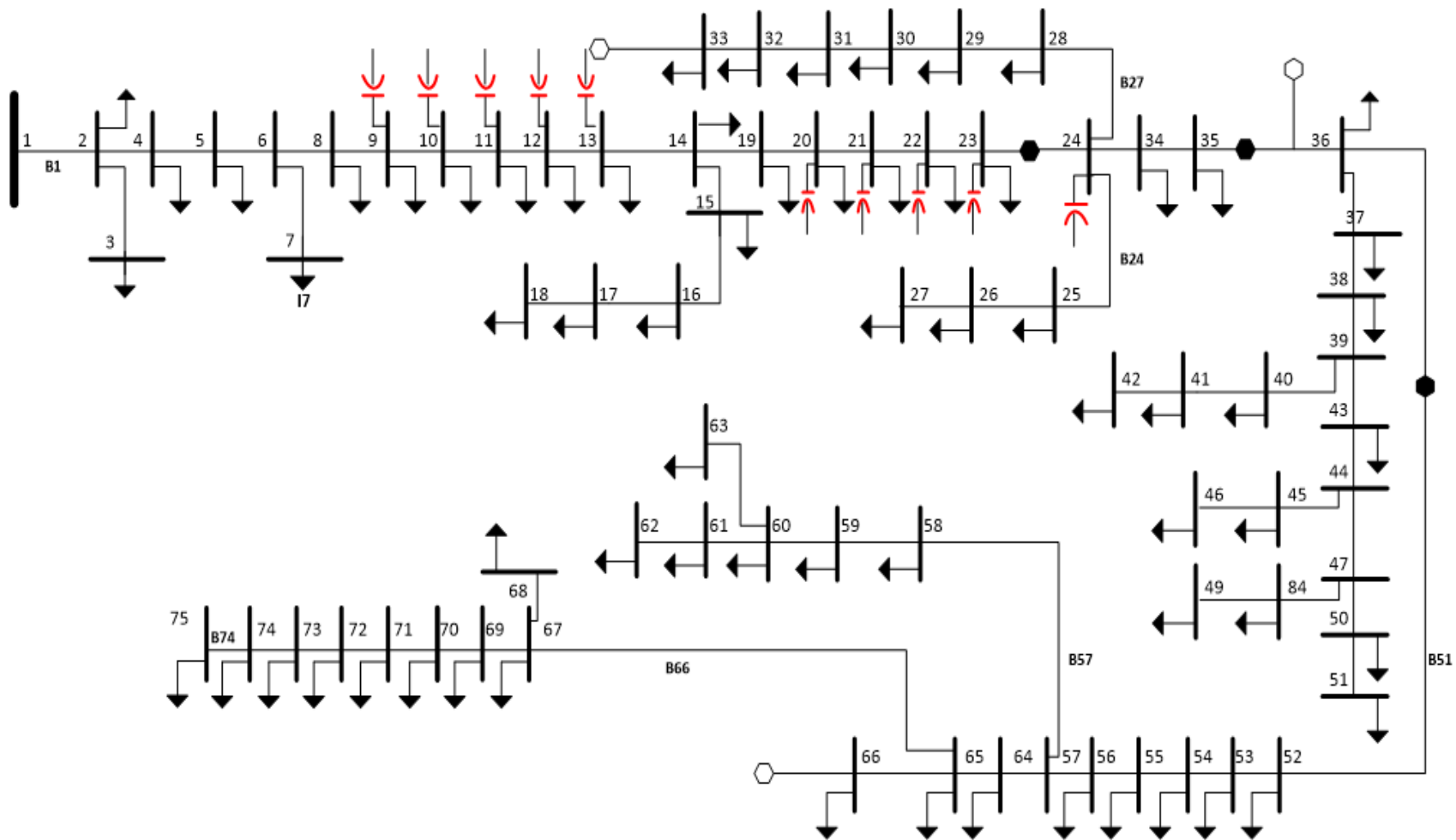


Figure 4:6 Designed capacitors at optimal locations

4.4 Load flow result after compensation

In this thesis after sizing of optimal capacitors Power flow solution method using MATLAB is applied again on feeder four of Adama distribution system network and the simulation results are shown on table 4.8 and 4.9.

Table 4:8 P_L and Q_L of branches

| BRANCH | I(A) | PL (KW) | QL(Kvar) | BRANCH | I(A) | PL (KW) | QL(Kvar) |
|--------|--------|---------|----------|--------|--------|---------|----------|
| 1 | 629.2 | 71.8545 | 38.0057 | 23 | 432.86 | 50.5897 | 21.0791 |
| 2 | 29.16 | 0.0842 | 0.0447 | 24 | 64.76 | 0.3145 | 0.1699 |
| 3 | 595.13 | 40.377 | 21.7824 | 25 | 46.04 | 0.1812 | 0.0954 |
| 4 | 585.91 | 94.234 | 49.9492 | 26 | 20.49 | 0.1435 | 0.0768 |
| 5 | 581.19 | 35.4667 | 18.7467 | 27 | 29.53 | 0.0419 | 0.0222 |
| 6 | 16.47 | 0.0676 | 0.0191 | 28 | 22.34 | 0.0658 | 0.0352 |
| 7 | 567.39 | 28.974 | 15.4528 | 29 | 19.44 | 0.0681 | 0.0363 |
| 8 | 564.45 | 93.6711 | 49.703 | 30 | 16.75 | 0.0707 | 0.0375 |
| 9 | 549.44 | 89.2064 | 47.5466 | 31 | 11.87 | 0.0173 | 0.0093 |
| 10 | 542.28 | 92.6319 | 49.4037 | 32 | 4.23 | 0.0065 | 0.0034 |
| 11 | 532.74 | 40.4439 | 21.712 | 33 | 372.63 | 9.9976 | 4.1657 |
| 12 | 525.69 | 77.9321 | 41.4532 | 34 | 361.05 | 44.19 | 26.0056 |
| 13 | 512.82 | 30.769 | 16.5679 | 35 | 349.84 | 22.0297 | 12.8507 |
| 14 | 49.04 | 0.9378 | 0.5014 | 36 | 94.83 | 1.0387 | 0.5531 |
| 15 | 41.09 | 0.1545 | 0.0836 | 37 | 83.51 | 5.1884 | 2.7616 |
| 16 | 36.9 | 0.2859 | 0.1532 | 38 | 78.83 | 0.6153 | 0.3263 |
| 17 | 35.36 | 0.4107 | 0.2175 | 39 | 24.9 | 0.2864 | 0.1525 |
| 18 | 463.85 | 27.11 | 14.5232 | 40 | 11.97 | 0.1394 | 0.0743 |
| 19 | 458.33 | 89.1738 | 47.5804 | 41 | 6.89 | 0.0197 | 0.0105 |
| 20 | 447.71 | 42.3939 | 22.55 | 42 | 53.95 | 1.0261 | 0.2925 |
| 21 | 438.8 | 53.4313 | 28.5929 | 43 | 52.26 | 0.2499 | 0.1352 |
| 22 | 432.34 | 48.7865 | 25.7952 | 44 | 10.18 | 0.0185 | 0.0098 |

| BRANCH | I(A) | PL (KW) | QL(Kvar) | | BRANCH | I(A) | PL (KW) | QL(Kvar) |
|--------|--------|---------|----------|--|--------|-------|---------|----------|
| 45 | 6.76 | 0.0212 | 0.0113 | | 71 | 43.44 | 0.167 | 0.0877 |
| 46 | 42.08 | 0.1275 | 0.0664 | | 72 | 28.23 | 0.1852 | 0.098 |
| 47 | 18.77 | 0.0783 | 0.0418 | | 73 | 21.86 | 0.1592 | 0.0846 |
| 48 | 13.64 | 0.0597 | 0.0318 | | 74 | 4.61 | 0.0043 | 0.0023 |
| 49 | 18.25 | 0.0225 | 0.012 | | | | | |
| 50 | 4.87 | 0.0125 | 0.0036 | | | | | |
| 51 | 247.76 | 5.0641 | 2.6702 | | | | | |
| 53 | 212.32 | 9.9404 | 5.2745 | | | | | |
| 54 | 204.2 | 2.752 | 1.5011 | | | | | |
| 55 | 196.64 | 3.8862 | 2.0881 | | | | | |
| 56 | 188.16 | 23.5789 | 12.5329 | | | | | |
| 57 | 46.38 | 0.5323 | 0.2839 | | | | | |
| 58 | 44.13 | 0.7857 | 0.4177 | | | | | |
| 59 | 31.3 | 0.1323 | 0.0705 | | | | | |
| 60 | 23.39 | 0.2011 | 0.1067 | | | | | |
| 61 | 13.43 | 0.0877 | 0.0465 | | | | | |
| 62 | 7.92 | 0.0611 | 0.0325 | | | | | |
| 63 | 141.81 | 3.7103 | 1.9909 | | | | | |
| 64 | 131.31 | 2.302 | 1.2415 | | | | | |
| 65 | 41.13 | 0.269 | 0.1421 | | | | | |
| 66 | 82.92 | 2.8566 | 1.5159 | | | | | |
| 67 | 6.09 | 0.0044 | 0.0023 | | | | | |
| 68 | 74.27 | 2.0767 | 1.1087 | | | | | |
| 69 | 69.78 | 1.7528 | 0.9348 | | | | | |
| 70 | 64.11 | 0.672 | 0.3576 | | | | | |

The shunt capacitors improve the voltage profile, and due this the active component of branch current for constant power load demand is reduced.

Table 4:9 Voltage profile of feeder

| | | | | | | | | | | | | | | | |
|--------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Bus No | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| V (pu) | 1 | 0.99 | 0.99 | 0.99 | 0.98 | 0.97 | 0.97 | 0.97 | 0.96 | 0.95 | 0.94 | 0.94 | 0.93 | 0.92 | 0.92 |
| Bus No | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| V (pu) | 0.92 | 0.92 | 0.92 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.88 | 0.88 | 0.88 | 0.87 | 0.88 | 0.88 | 0.87 |
| Bus No | 31 | 32 | 33 | 34 | 35 | 35 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 |
| V (pu) | 0.87 | 0.87 | 0.87 | 0.87 | 0.86 | 0.86 | 0.86 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Bus No | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 |
| V (pu) | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.86 | 0.85 | 0.85 | 0.85 | 0.85 | 0.84 | 0.84 | 0.83 | 0.83 |
| Bus No | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 |
| | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.82 | 0.82 | 0.82 |

Comparison of active power in table 4.3 with table 4.8 and Comparison of reactive power in table 4.4 with 4.9 shows that the power losses are decreased and bus voltage values are raised after optimum capacitor size is designed. The total active power loss after optimization is found to be 1.17 MW and before optimization it was 1.57MW. Therefore the total power saving due to the installation of the total shunt capacitor size of **5100 Kvar** is obtained as **400 KW**. It is because a portion of power loss in distribution systems could be reduced by adding shunt capacitors to supply a part of the reactive power demands. It has been realized that the benefits of capacitor placement in distribution systems are bus voltage regulation, power and energy loss reduction. Reduced power and voltage values are shown in the following graphs.

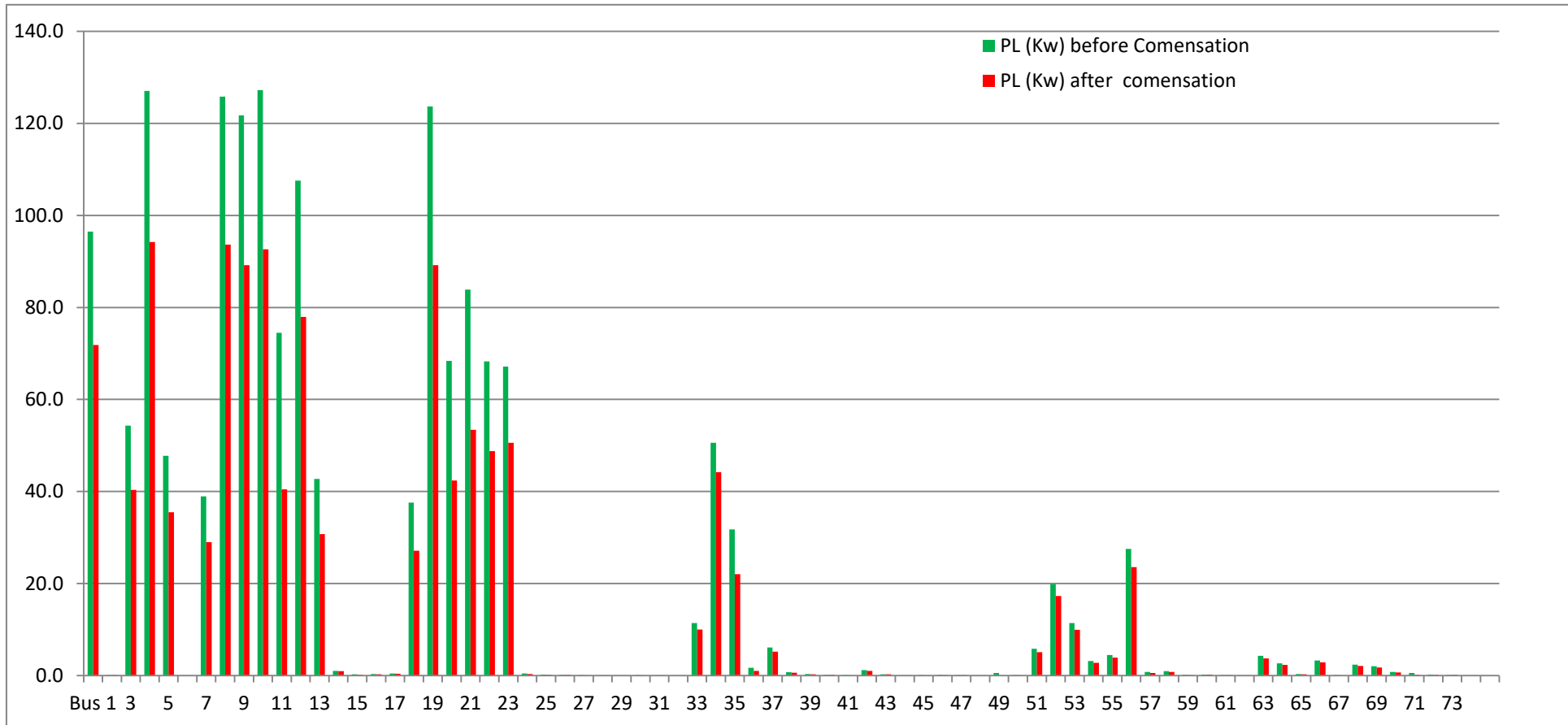


Figure 4:7 Active power simulation result

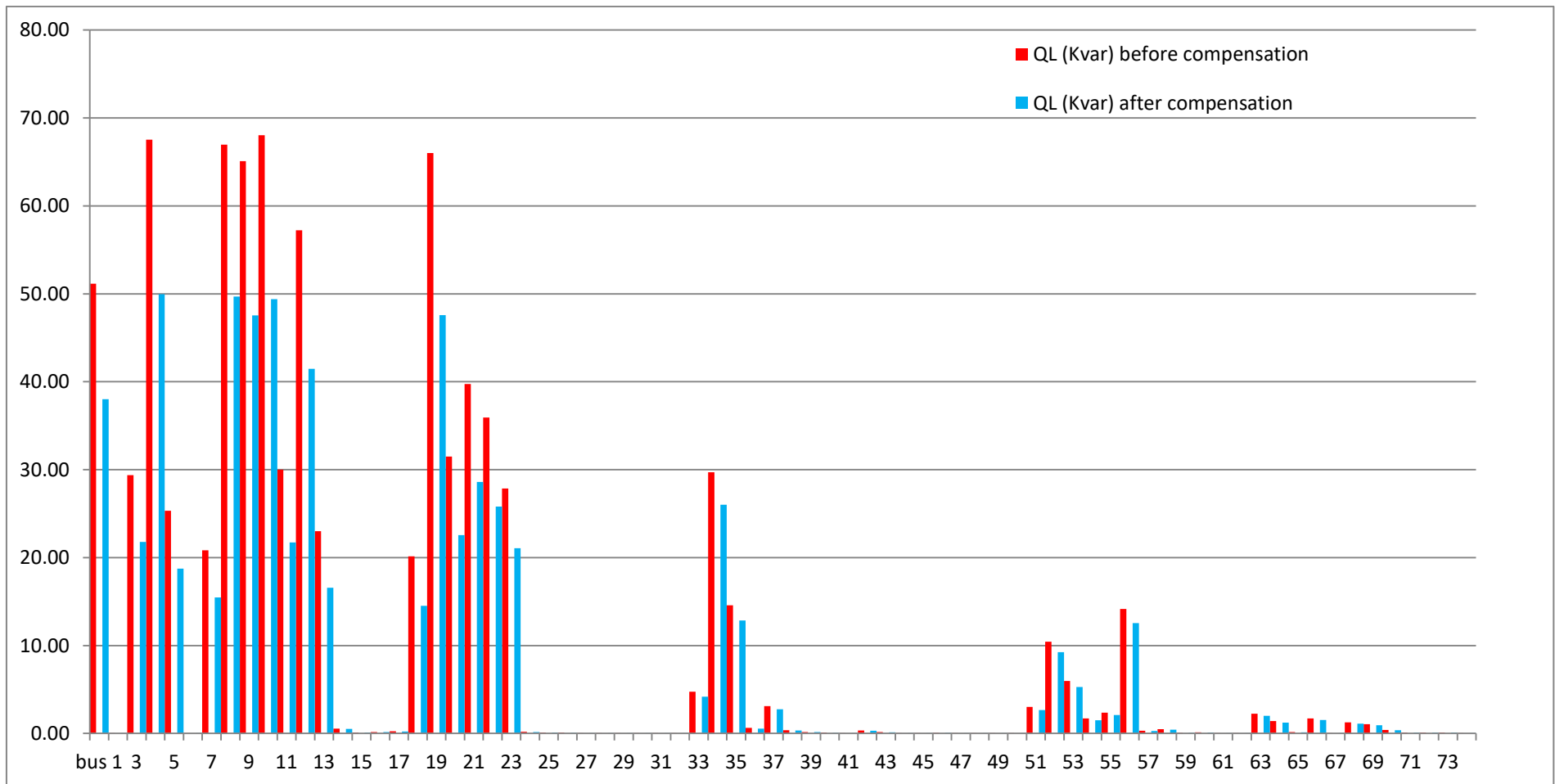


Figure 4:8 Reactive power Simulation result

From the graph of figure 4:7 and 4:8 it can be seen that adding optimal capacitor sizes on feeder buses P_L and Q_L of all branches are reduced. The total reactive power loss is reduced from 0.83 Mvar to 0.62 Mvar. It can be conclude that the total active power loss is also reduced from 1.57 MW to 1.17MW (Figure 4:7).

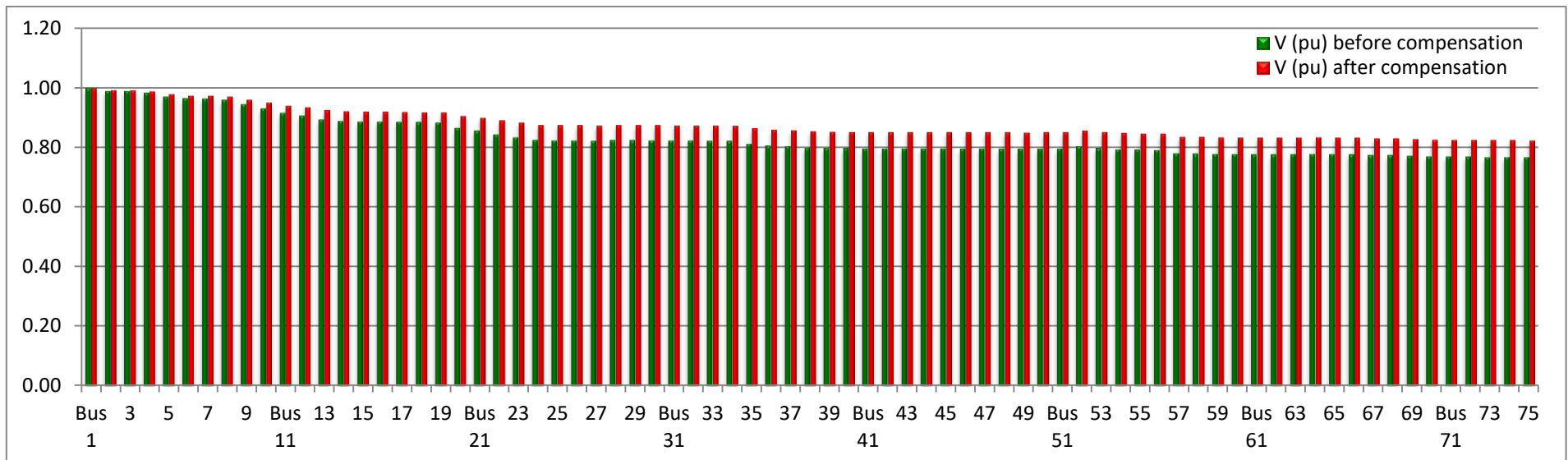


Figure 4:9 Bus voltage simulation result

Due to installing shunt capacitors voltage profile of each bus is improved and Figure 4:10 shows the power saved.



Figure 4:10 Power comparison

4.5 Energy cost analysis

This section shows how the cost of the feeder is calculated before and after compensation. For the analysis, the following billing information is used:

1. Only fixed capacitors are used in the analysis (the maintenance and running costs are neglected).
2. Energy rate = birr 0.2730/Kwh (for residential and commercial) and birr 0.5778/Kwh for industry.
3. Capacitor installation cost = birr 22600 [31]
4. Time used = 5 Years
5. Possible capacitor sizes and sizes in birr/Kvar are taken from reference [31].

Cost of energy loss (CEL): The cost of energy loss is energy loss of a feeder before capacitor placement, CEL becomes:-

$$CEL = \text{Total Power loss} * \text{time duration} * \text{energy rate}$$

$$CEL = 1570 \text{ KW} * 0.2730 \text{ birr/Kwh} * 8760 \text{ hr (Most of loads are residential and commercial loads)}$$

$$CEL = \underline{3754632.6} \text{ birr}$$

Cost of Capacitor (CC): Cost of capacitor has two parts: constant installation cost and variable cost. Capacitor cost is expressed as [31]:-

$$CC = \sum_{i=1}^n (Cki + (Cr * Qc))$$

Where;

Cki ; is the constant installation cost of capacitor

Cr ; is the price rate of capacitor per Kvar

Qc ; is the rating of capacitor on bus k in Kvar, the cost of designed capacitor is:-

1. At bus 9 $CC = 22600 + 5.71 * 450 = 25169.5$ Birr
2. At bus 10 $CC = 22600 + 11.3 * 150 = 24295$

3. At bus 11 CC = $22600 + 11.3 * 150 = 24295$
4. At bus 12 CC = $22600 + 11.3 * 150 = 24295$
5. At bus 13 CC = $22600 + 4.97 * 600 = 25583.2$
6. At bus 20 CC = $22600 + 5.71 * 450 = 25169.5$
7. At bus 21 CC = $22600 + 11.3 * 150 = 24295$
8. At bus 22 CC = $22600 + 7.91 * 300 = 24973$
9. At bus 23 CC = $22600 + 4.67 * 1350 = 28904.5$
10. At bus 24 CC = $22600 + 4.67 * 1350 = 28904.5$

$$CC = \underline{255884.2} \text{ Birr}$$

Therefore; the total cost of the designed capacitor is given as:-

$$TCC = \text{CEL with Capacitor} + CC$$

$$\text{CEL with capacitor} = 1170 \text{ Kw} * 0.2730 \text{ birr/Kwh} * 8760 \text{ hr}$$

$$\text{CEL with capacitor} = \underline{2798031.6} \text{ Birr}$$

$$TCC = 2798031 + 255884.2$$

$$TCC = \underline{3053915.8} \text{ birr}$$

The net cost saving of the system (S) is;

$$S = \text{CEL without capacitor} - \text{CEL with Capacitor}$$

$$S = 3754632.6 - 3053915.8 \text{ birr}$$

$$S = \underline{700716.8} \text{ birr per year is saved.}$$

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this thesis 75 bus of Adama town radial distribution feeder is considered for analysis of reactive power optimization problem to determine the optimal location and size of capacitor banks. Two-stage methodology of finding the optimal locations and sizes of shunt capacitors for reactive power compensation of radial distribution systems is presented. Fuzzy approach is proposed to find the optimal capacitor locations and PSO method is proposed to find the optimal capacitor sizes.

The simulation results indicate that by applying the proposed method **400KW** power is saved. The loss minimization using shunt capacitors reduces the current flowing in each section of the feeder and hence the voltage drop in the section is reduced. Therefore the voltage profile is improved after the feeder line is compensated and the quality of the power is improved. It is found that by placing a total of 5100 Kvar Optimal capacitors at ten different locations, the loss associated with reactive branch current can be reduced from **1.57 MW** to **1.17 MW** and due to this **700716.8** Ethiopian birr per year is saved.

It is concluded that applying the proposed artificial intelligent techniques to optimal capacitor placement on the radial distribution network can be reduced losses significantly.

5.2 Recommendation

The following recommendations are suggested for further study:

- ❖ It is very important that to reduce more power and to save costs more capacitor placement has to be made for all feeders by measuring loads at each transformer.
- ❖ Use fixed and switches capacitor banks. By using this type of capacitor banks more optimal values can be obtained.
- ❖ There must need to consider nonlinear load for this research. When the nonlinear load is considered, the harmonic effect can be including.

REFERENCE

- [1]. Priya Kanta Bansal, "Maximum loss reduction by optimal placement of capacitors on radial distribution system", Patalia, 2009.
- [2]. Ritu Parasher, "load flow analysis of Radial distribution network using Linear data structure", Hata, 2013.
- [3]. S.M.Kannan, P.Renuga and A.Rathina Grace Monica, "Application of fuzzy logic and Particle swarm optimization for reactive power compensation of Radial distribution system", JES, 2010.
- [4]. Haung Tung, "Expansion planning of the distribution system in daking prvuine", thailan, 2008.
- [5]. Altaf Badar, Dr. B.S. Umre and Dr. A. S. Junghare, "Study of Artificial Intelligence Optimization Techniques applied to Active Power Loss Minimization", Journal of Electrical and Electronics Engineering (JOSR-JEEE), 2014, PP, 39-45.
- [6]. Sundharajan and Pahwa A., "Optimal selection of capacitors for radial distribution systems using a genetic algorithm", IEEE Transactions on Power Systems, 19(3), 1994, pp. 1499- 1507.
- [7]. Ray Piecy, "Distribution losses", 2007.
- [8]. A. Alshehri, "Optimal reconfiguration of distribution networks using Ant colony method", king Saud University, 2007.
- [9]. T.Asakura, T.Genji, T.Yura, N.Hayashi, and Y. Fukuyama. "Long-term Distribution Network Expansion Planning by Network Reconfiguration and Generation of Construction Plans", IEEE, 2000.
- [10]. Joe Gurowsky, "[http://foreignpolicyblogs.com/2014/01/21/filling-ethiopias-power void/](http://foreignpolicyblogs.com/2014/01/21/filling-ethiopias-power-void/)", 2014.
- [11]. "<https://en.wikipedia.org/wiki/Adama>", 2014.
- [12]. R. Srinivasa Rao and S. V. L. Narasimham, "Optimal Capacitor Placement in a Radial Distribution System using Plant Growth Simulation Algorithm", 2008.

- [13]. *RM.Damodar Reddy, and N.V. Vijaya Kumar, "Optimal capacitor placement for loss reduction in distribution systems using fuzzy and harmony search algorithm" ARPN Journal of Engineering and Applied Sciences, Vol. 7, No. 1, pp.15-19, January 2012.*
- [14]. *Jianwei Liu, M. M. A. Salama and R. R. Mansour, "An efficient power flow algorithm for distribution systems with polynomial load", Canada, 2010.*
- [15]. *J.B.V.Subrahmanyam, "load flow solution of unbalanced radial distribution systems", india, 2009.*
- [16]. *J. A. Michline Rupa, S. Ganesh, "power-flow-analysis-for-radial-distribution-system-using-backwardforward-sweep-method", world academy of science, engineering and technology international journal of electrical, computer, energetic, electronic and communication engineering vol:8, no:10, 2014.*
- [17]. *Mahdi Mozaffari Legha, "capacitor placement in radial distribution system for improve network efficiency using artificial bee colony", journal of engineering research and applications, 2248-9622, vol. 3, issue 6, nov-dec 2013, pp.228-233.*
- [18]. *Priyanka Das and S.Banerjee, "placement of capacitor in a radial distribution system using loss sensitivity factor and cuckoo search algorithm", international journal of scientific research and management volume 2, issue 4, pages 751-757, 2013.*
- [19]. *A.Kartikeya Sarma and K.Mahammad Rafi, "optimal selection of capacitors for radial distribution systems using plant growth simulation algorithm", international journal of advanced science and technology vol. 30, india, may, 2011.*
- [20]. *M.Y.Balaji Prasanna and S.M.Kannan, "combination of fuzzy and second order PSO based capacitor placement in radial distribution feeder", international conference on recent trends in computational methods, communication and controls (icon3c 2012).*
- [21]. *M. Damodar Reddy and V. C. Veera Reddy, "capacitor placement using fuzzy and particle swarm optimization method for maximum annual savings", india, 2008.*
- [22]. *Meseret Yenesew, "loss minimization in distribution networks through optimal reactive power allocation using particle swarm optimization", 2014.*

- [23]. Masoud Aliakbar Golkar, "a novel method for load flow analysis of unbalanced three-phase radial distribution networks", *turk j elec engin*, vol.15, no.3 2007.
- [24]. Anwar S. Siddiqui, "determination of size and location of capacitors for placement on a radial distribution system using fuzzy technique", *international journal on power system optimization and control*, 3 (1) january-june 2011, pp. 1– 8.
- [25]. Anwar S. Siddiqui and Farrukh Rahman, "Optimal Capacitor Placement to reduce losses in Distribution System", *E-ISSN: 2224-350X 12 Issue 1, Volume 7, January 2012, India*.
- [26]. S.M.Kannan, P. Renuga and A. Rathina Grace Monica, "application of fuzzy logic and particle swarm optimization for reactive power compensation of radial distribution system", *jes*, 2010.
- [27]. Vinay J. Shetty and S.G Ankaliki, "fuzzy logic based optimal capacitor placement and loss reduction in radial power system", *international journal of current engineering and technology*, 2016.
- [28]. Muhammad Haffiz Bin Zamidi "optimal number of capacitor banks in distribution system using artificial intelligence", 2013.
- [29]. Y. Shi and R. Eberhart, "a modified particle swarm optimizer," *proceedings of the 1998 ieee evolutionary computation conference*, pp. 69-73.
- [30]. Andries P. Engelbrecht, "computational intelligence an introduction", 2007, ch. 16, pp. 289-358.
- [31]. R. Srinivasa Rao and S. V. L. Narasimham, "Optimal-Capacitor-Placement-in-a-Radial-Distribution-System-using-Plant-Growth-Simulation-Algorithm", *World Academy of Science, Engineering and Technology International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering Vol:2, No:9, 2008*.

APPENDIX**Appendix A**

Table A: 1 Conductor type and standard resistance and reactance per KM

| Conductor Name (Size) | Resistance Per Km | Reactance Per Km |
|------------------------------|------------------------------|-----------------------------|
| CU-20 | 1.426 | 0.396 |
| AAC-25 | 1.338 | 0.380 |
| ACSR-30 | 1.139 | 0.372 |
| CU-25 | 0.936 | 0.387 |
| ACSR-46 | 0.681 | 0.365 |
| AAC-50 | 0.680 | 0.362 |
| CU-35 | 0.659 | 0.374 |
| ACSR-65 | 0.571 | 0.349 |
| AAC-95 | 0.58 | 0.341 |
| AAAC150 | 0.339 | 0.337 |
| UGAL120 | 0.325 | 0.097 |
| ACSR-129 | 0.291 | 0.317 |
| AAAC-157 | 0.230 | 0.309 |
| UGCU-120 | 0.196 | 0.097 |
| AAAC-200 | 0.164 | 0.332 |

Appendix B

Table B: 1 Feeder four line data

| Branch | Sending end | Receiving end | Resistance (pu) | Reactance (pu) | Conductor type | Length (km) | Resistance (ohm) | reactance (ohm) |
|--------|-------------|---------------|-----------------|----------------|----------------|-------------|------------------|-----------------|
| 1 | 1 | 2 | 0.00121 | 0.00064 | AAC 50 | 0.267 | 0.1816 | 0.0967 |
| 2 | 2 | 3 | 0.00066 | 0.00035 | AAC 50 | 0.145 | 0.0986 | 0.0525 |
| 3 | 2 | 4 | 0.00076 | 0.00041 | AAC 50 | 0.168 | 0.1142 | 0.0608 |
| 4 | 4 | 5 | 0.00183 | 0.00097 | AAC 50 | 0.404 | 0.2747 | 0.1462 |
| 5 | 5 | 6 | 0.00070 | 0.00037 | AAC 50 | 0.154 | 0.1047 | 0.0557 |
| 6 | 6 | 7 | 0.00166 | 0.00047 | AAC 25 | 0.186 | 0.2489 | 0.0707 |
| 7 | 6 | 8 | 0.00060 | 0.00032 | AAC 50 | 0.132 | 0.0898 | 0.0478 |
| 8 | 8 | 9 | 0.00196 | 0.00104 | AAC 50 | 0.432 | 0.2938 | 0.1564 |
| 9 | 9 | 10 | 0.00197 | 0.00105 | AAC 50 | 0.434 | 0.2951 | 0.1571 |
| 10 | 10 | 11 | 0.00210 | 0.00112 | AAC 50 | 0.464 | 0.3155 | 0.1680 |
| 11 | 11 | 12 | 0.00127 | 0.00068 | AAC 50 | 0.28 | 0.1904 | 0.1014 |
| 12 | 12 | 13 | 0.00188 | 0.00100 | AAC 50 | 0.414 | 0.2815 | 0.1499 |
| 13 | 13 | 14 | 0.00078 | 0.00042 | AAC 50 | 0.172 | 0.1170 | 0.0623 |
| 14 | 14 | 15 | 0.00260 | 0.00139 | AAC 50 | 0.574 | 0.3903 | 0.2078 |
| 15 | 15 | 16 | 0.00061 | 0.00033 | AAC 50 | 0.135 | 0.0918 | 0.0489 |
| 16 | 16 | 17 | 0.00140 | 0.00075 | AAC 50 | 0.309 | 0.2101 | 0.1119 |
| 17 | 17 | 18 | 0.00219 | 0.00116 | AAC 50 | 0.482 | 0.3278 | 0.1745 |
| 18 | 14 | 19 | 0.00084 | 0.00045 | AAC 50 | 0.186 | 0.1265 | 0.0673 |
| 19 | 19 | 20 | 0.00283 | 0.00151 | AAC 50 | 0.624 | 0.4243 | 0.2259 |
| 20 | 20 | 21 | 0.00163 | 0.00087 | AAC 50 | 0.36 | 0.2448 | 0.1303 |
| 21 | 21 | 22 | 0.00208 | 0.00111 | AAC 50 | 0.459 | 0.3121 | 0.1662 |
| 22 | 22 | 23 | 0.00174 | 0.00092 | AAC 50 | 0.383 | 0.2604 | 0.1386 |
| 23 | 23 | 24 | 0.00180 | 0.00075 | CU 25 | 0.29 | 0.2697 | 0.1122 |

| | | | | | | | | |
|----|----|----|---------|---------|--------|--------|--------|--------|
| 24 | 24 | 25 | 0.00050 | 0.00027 | AAC 50 | 0.11 | 0.0748 | 0.0398 |
| 25 | 25 | 26 | 0.00057 | 0.00030 | AAC 50 | 0.126 | 0.0857 | 0.0456 |
| 26 | 26 | 27 | 0.00228 | 0.00122 | AAC 50 | 0.504 | 0.3427 | 0.1824 |
| 27 | 24 | 28 | 0.00032 | 0.00017 | AAC 50 | 0.071 | 0.0483 | 0.0257 |
| 28 | 28 | 29 | 0.00088 | 0.00047 | AAC 50 | 0.195 | 0.1326 | 0.0706 |
| 29 | 29 | 30 | 0.00120 | 0.00064 | AAC 50 | 0.265 | 0.1802 | 0.0959 |
| 30 | 30 | 31 | 0.00168 | 0.00089 | AAC 50 | 0.37 | 0.2516 | 0.1339 |
| 31 | 31 | 32 | 0.00082 | 0.00044 | AAC 50 | 0.181 | 0.1231 | 0.0655 |
| 32 | 32 | 33 | 0.00241 | 0.00128 | AAC 50 | 0.532 | 0.3618 | 0.1926 |
| 33 | 24 | 34 | 0.00048 | 0.00020 | CU 25 | 0.078 | 0.0725 | 0.0302 |
| 34 | 34 | 35 | 0.00226 | 0.00133 | AAC 95 | 0.585 | 0.3393 | 0.1995 |
| 35 | 35 | 36 | 0.00151 | 0.00089 | AAC 95 | 0.39 | 0.2262 | 0.1330 |
| 36 | 36 | 37 | 0.00108 | 0.00058 | AAC 50 | 0.239 | 0.1625 | 0.0865 |
| 37 | 37 | 38 | 0.00510 | 0.00271 | AAC 50 | 1.124 | 0.7643 | 0.4069 |
| 38 | 38 | 39 | 0.00066 | 0.00035 | AAC 50 | 0.145 | 0.0986 | 0.0525 |
| 39 | 39 | 40 | 0.00308 | 0.00164 | AAC 50 | 0.68 | 0.4624 | 0.2462 |
| 40 | 40 | 41 | 0.00649 | 0.00346 | AAC 50 | 1.432 | 0.9738 | 0.5184 |
| 41 | 41 | 42 | 0.00277 | 0.00148 | AAC 50 | 0.612 | 0.4162 | 0.2215 |
| 42 | 39 | 43 | 0.00235 | 0.00067 | AAC 25 | 0.2632 | 0.3522 | 0.1000 |
| 43 | 43 | 44 | 0.00061 | 0.00033 | AAC 50 | 0.135 | 0.0918 | 0.0489 |
| 44 | 44 | 45 | 0.00119 | 0.00063 | AAC 50 | 0.262 | 0.1782 | 0.0948 |
| 45 | 45 | 46 | 0.00309 | 0.00165 | AAC 50 | 0.682 | 0.4638 | 0.2469 |
| 46 | 44 | 47 | 0.00048 | 0.00025 | AAC 50 | 0.105 | 0.0714 | 0.0380 |
| 47 | 47 | 48 | 0.00148 | 0.00079 | AAC 50 | 0.326 | 0.2217 | 0.1180 |
| 48 | 48 | 49 | 0.00214 | 0.00114 | AAC 50 | 0.471 | 0.3203 | 0.1705 |
| 49 | 47 | 50 | 0.00045 | 0.00024 | AAC 50 | 0.099 | 0.0673 | 0.0358 |
| 50 | 50 | 51 | 0.00353 | 0.00100 | AAC 25 | 0.396 | 0.5298 | 0.1505 |
| 51 | 36 | 52 | 0.00055 | 0.00029 | AAC 50 | 0.121 | 0.0823 | 0.0438 |

| Branch | Sending end | Receiving end | Resistance (pu) | Reactance (pu) | Conductor type | Length (km) | Resistance (ohm) | reactance (ohm) |
|--------|-------------|---------------|-----------------|----------------|----------------|-------------|------------------|-----------------|
| 52 | 52 | 53 | 0.00245 | 0.00131 | AAC 50 | 0.541 | 0.3679 | 0.1958 |
| 53 | 53 | 54 | 0.00147 | 0.00078 | AAC 50 | 0.324 | 0.2203 | 0.1173 |
| 54 | 54 | 55 | 0.00044 | 0.00024 | AAC 50 | 0.098 | 0.0666 | 0.0355 |
| 55 | 55 | 56 | 0.00067 | 0.00036 | AAC 50 | 0.148 | 0.1006 | 0.0536 |
| 56 | 56 | 57 | 0.00451 | 0.00240 | AAC 50 | 0.994 | 0.6759 | 0.3598 |
| 57 | 57 | 58 | 0.00210 | 0.00112 | AAC 50 | 0.463 | 0.3148 | 0.1676 |
| 58 | 58 | 59 | 0.00279 | 0.00148 | AAC 50 | 0.615 | 0.4182 | 0.2226 |
| 59 | 59 | 60 | 0.00090 | 0.00048 | AAC 50 | 0.198 | 0.1346 | 0.0717 |
| 60 | 60 | 61 | 0.00245 | 0.00130 | AAC 50 | 0.54 | 0.3672 | 0.1955 |
| 61 | 61 | 62 | 0.00324 | 0.00172 | AAC 50 | 0.714 | 0.4855 | 0.2585 |
| 62 | 60 | 63 | 0.00649 | 0.00345 | AAC 50 | 1.431 | 0.9731 | 0.5180 |
| 63 | 57 | 64 | 0.00123 | 0.00066 | AAC 50 | 0.272 | 0.1850 | 0.0985 |
| 64 | 64 | 65 | 0.00089 | 0.00048 | AAC 50 | 0.197 | 0.1340 | 0.0713 |
| 65 | 65 | 66 | 0.00106 | 0.00056 | AAC 50 | 0.233 | 0.1584 | 0.0843 |
| 66 | 65 | 67 | 0.00277 | 0.00147 | AAC 50 | 0.61 | 0.4148 | 0.2208 |
| 67 | 67 | 68 | 0.00125 | 0.00066 | AAC 50 | 0.275 | 0.1870 | 0.0996 |
| 68 | 67 | 69 | 0.00251 | 0.00134 | AAC 50 | 0.554 | 0.3767 | 0.2005 |
| 69 | 69 | 70 | 0.00240 | 0.00128 | AAC 50 | 0.529 | 0.3597 | 0.1915 |
| 70 | 70 | 71 | 0.00109 | 0.00058 | AAC 50 | 0.241 | 0.1639 | 0.0872 |
| 71 | 71 | 72 | 0.00165 | 0.00088 | AAC 50 | 0.365 | 0.2482 | 0.1321 |
| 72 | 72 | 73 | 0.00155 | 0.00082 | AAC 50 | 0.341 | 0.2319 | 0.1234 |
| 73 | 73 | 74 | 0.00131 | 0.00070 | AAC 50 | 0.289 | 0.1965 | 0.1046 |
| 74 | 74 | 75 | 0.00114 | 0.00061 | AAC 50 | 0.251 | 0.1707 | 0.0909 |

Table B: 2 Bus data of feeder four

| Bus | P (pu) | Q (pu) | p (Kw) | q (Kvr) | Transformer KVA | Bus | P (pu) | Q (pu) | p (Kw) | q (Kvr) | Transformer KVA |
|-----|--------|--------|--------|---------|-----------------|-----|--------|--------|--------|---------|-----------------|
| 1 | 0.0000 | 0.0000 | 0.00 | 0.00 | 0 | 39 | 0.0000 | 0.0000 | 0.00 | 0.00 | 0 |
| 2 | 0.0876 | 0.0329 | 131.40 | 49.40 | 315 | 40 | 0.0978 | 0.0509 | 146.76 | 76.29 | 200 |
| 3 | 0.2625 | 0.1219 | 393.70 | 182.80 | 630 | 41 | 0.0397 | 0.0171 | 59.48 | 25.67 | 100 |
| 4 | 0.0944 | 0.0307 | 141.60 | 46.10 | 315 | 42 | 0.0525 | 0.0262 | 78.81 | 39.24 | 100 |
| 5 | 0.0497 | 0.0301 | 74.60 | 45.10 | 200 | 43 | 0.0130 | 0.0063 | 19.52 | 9.48 | 25 |
| 6 | 0.0000 | 0.0000 | 0.00 | 0.00 | 0 | 44 | 0.0000 | 0.0000 | 0.00 | 0.00 | 0 |
| 7 | 0.1439 | 0.0710 | 215.80 | 106.50 | 315 | 45 | 0.0260 | 0.0132 | 39.00 | 19.81 | 100 |
| 8 | 0.0307 | 0.0145 | 46.12 | 21.80 | 50 | 46 | 0.0492 | 0.0298 | 73.81 | 44.71 | 100 |
| 9 | 0.1100 | 0.0407 | 165.00 | 61.00 | 315 | 47 | 0.0373 | 0.0215 | 55.95 | 32.24 | 100 |
| 10 | 0.0593 | 0.0141 | 89.00 | 21.20 | 100 | 48 | 0.0382 | 0.0212 | 57.33 | 31.76 | 100 |
| 11 | 0.0856 | 0.0392 | 128.40 | 58.80 | 315 | 49 | 0.1026 | 0.0542 | 153.90 | 81.33 | 200 |
| 12 | 0.0615 | 0.0303 | 92.20 | 45.50 | 315 | 50 | 0.0989 | 0.0567 | 148.40 | 85.10 | 200 |
| 13 | 0.1083 | 0.0477 | 162.52 | 71.48 | 315 | 51 | 0.0371 | 0.0184 | 55.71 | 27.62 | 100 |
| 14 | 0.0610 | 0.0279 | 91.57 | 41.90 | 315 | 52 | 0.2490 | 0.0904 | 373.57 | 135.57 | 800 |
| 15 | 0.0649 | 0.0338 | 97.29 | 50.71 | 200 | 53 | 0.0351 | 0.0184 | 52.62 | 27.62 | 100 |
| 16 | 0.0356 | 0.0151 | 53.33 | 22.67 | 100 | 54 | 0.0647 | 0.0243 | 97.05 | 36.43 | 315 |
| 17 | 0.0129 | 0.0059 | 19.30 | 8.80 | 25 | 55 | 0.0576 | 0.0279 | 86.40 | 41.80 | 200 |
| 18 | 0.2852 | 0.1553 | 427.76 | 232.95 | 2*315 | 56 | 0.0642 | 0.0321 | 96.30 | 48.14 | 200 |
| 19 | 0.0523 | 0.0204 | 78.43 | 30.67 | 315 | 57 | 0.0000 | 0.0000 | 0.00 | 0.00 | 0 |
| 20 | 0.0833 | 0.0418 | 125.00 | 62.67 | 315 | 58 | 0.0168 | 0.0085 | 25.20 | 12.80 | 25 |
| 21 | 0.0793 | 0.0419 | 119.00 | 62.80 | 315 | 59 | 0.0977 | 0.0437 | 146.60 | 65.50 | 200 |
| 22 | 0.0554 | 0.0239 | 83.14 | 35.90 | 315 | 60 | 0.0000 | 0.0000 | 0.00 | 0.00 | 0 |
| 23 | 0.0955 | 0.0458 | 143.20 | 68.65 | 315 | 61 | 0.0757 | 0.0346 | 113.60 | 51.90 | 200 |
| 24 | 0.0000 | 0.0000 | 0.00 | 0.00 | 0 | 62 | 0.1059 | 0.0359 | 158.80 | 53.80 | 315 |
| 25 | 0.1540 | 0.0572 | 231.00 | 85.80 | 200+315 | 63 | 0.0595 | 0.0286 | 89.20 | 42.88 | 100 |

| Bus | P (pu) | Q (pu) | p (Kw) | q (Kvr) | Transformer KVA | Bus | P (pu) | Q (pu) | p (Kw) | q (Kvr) | Transformer KVA |
|-----|--------|--------|--------|---------|-----------------|-----|--------|--------|--------|---------|-----------------|
| 26 | 0.2053 | 0.0891 | 308.00 | 133.60 | 200+315 | 64 | 0.0803 | 0.0350 | 120.50 | 52.50 | 200 |
| 27 | 0.1585 | 0.0834 | 237.81 | 125.05 | 315 | 65 | 0.0562 | 0.0228 | 84.26 | 34.25 | 200 |
| 28 | 0.0585 | 0.0242 | 87.71 | 36.29 | 200 | 66 | 0.3082 | 0.1491 | 462.29 | 223.71 | 2*800 |
| 29 | 0.0234 | 0.0100 | 35.05 | 14.95 | 100 | 67 | 0.0183 | 0.0110 | 27.38 | 16.57 | 100 |
| 30 | 0.0203 | 0.0120 | 30.52 | 17.95 | 100 | 68 | 0.0448 | 0.0235 | 67.14 | 35.29 | 100 |
| 31 | 0.0384 | 0.0189 | 57.67 | 28.38 | 100 | 69 | 0.0319 | 0.0196 | 47.86 | 29.43 | 100 |
| 32 | 0.0573 | 0.0343 | 85.90 | 51.38 | 200 | 70 | 0.0433 | 0.0179 | 64.90 | 26.86 | 100 |
| 33 | 0.0315 | 0.0194 | 47.19 | 29.14 | 50 | 71 | 0.1560 | 0.0693 | 234.05 | 104.00 | 630 |
| 34 | 0.0901 | 0.0462 | 135.10 | 69.24 | 315 | 72 | 0.1122 | 0.0564 | 168.30 | 84.60 | 315 |
| 35 | 0.0846 | 0.0476 | 126.86 | 71.43 | 315 | 73 | 0.0479 | 0.0214 | 71.90 | 32.14 | 100 |
| 36 | 0.0548 | 0.0321 | 82.19 | 48.14 | 200 | 74 | 0.1317 | 0.0551 | 197.50 | 82.60 | 315 |
| 37 | 0.0883 | 0.0409 | 132.52 | 61.38 | 315 | 75 | 0.0315 | 0.0213 | 47.19 | 31.95 | 100 |
| 38 | 0.0362 | 0.0169 | 54.29 | 25.29 | 100 | | | | | | |

Appendix C

Math Lab code of backward forward load flow before compensation.

```
%branch sending reciving R x
```

```
LD=[1 1 2 0.00121 0.00064
2 2 3 0.00066 0.00035
3 2 4 0.00076 0.00041
4 4 5 0.00183 0.00097
5 5 6 0.00070 0.00037
6 6 7 0.00166 0.00047
7 6 8 0.00060 0.00032
8 8 9 0.00196 0.00104
9 9 10 0.00197 0.00105
10 10 11 0.00210 0.00112
```

| | | | | |
|----|----|----|---------|---------|
| 11 | 11 | 12 | 0.00095 | 0.00051 |
| 12 | 12 | 13 | 0.00188 | 0.00100 |
| 13 | 13 | 14 | 0.00078 | 0.00042 |
| 14 | 14 | 15 | 0.00260 | 0.00139 |
| 15 | 15 | 16 | 0.00061 | 0.00033 |
| 16 | 16 | 17 | 0.00140 | 0.00075 |
| 17 | 17 | 18 | 0.00219 | 0.00116 |
| 18 | 14 | 19 | 0.00084 | 0.00045 |
| 19 | 19 | 20 | 0.00283 | 0.00151 |
| 20 | 20 | 21 | 0.00141 | 0.00075 |
| 21 | 21 | 22 | 0.00185 | 0.00099 |
| 22 | 22 | 23 | 0.00174 | 0.00092 |
| 23 | 23 | 24 | 0.00180 | 0.00075 |
| 24 | 24 | 25 | 0.00050 | 0.00027 |
| 25 | 25 | 26 | 0.00057 | 0.00030 |
| 26 | 26 | 27 | 0.00228 | 0.00122 |
| 27 | 24 | 28 | 0.00032 | 0.00017 |
| 28 | 28 | 29 | 0.00088 | 0.00047 |
| 29 | 29 | 30 | 0.00120 | 0.00064 |
| 30 | 30 | 31 | 0.00168 | 0.00089 |
| 31 | 31 | 32 | 0.00082 | 0.00044 |
| 32 | 32 | 33 | 0.00241 | 0.00128 |
| 33 | 24 | 34 | 0.00048 | 0.00020 |
| 34 | 34 | 35 | 0.00226 | 0.00133 |
| 35 | 35 | 36 | 0.00120 | 0.00070 |
| 36 | 36 | 37 | 0.00077 | 0.00041 |
| 37 | 37 | 38 | 0.00496 | 0.00264 |
| 38 | 38 | 39 | 0.00066 | 0.00035 |
| 39 | 39 | 40 | 0.00308 | 0.00164 |
| 40 | 40 | 41 | 0.00649 | 0.00346 |
| 41 | 41 | 42 | 0.00277 | 0.00148 |

| | | | | |
|----|----|----|---------|---------|
| 42 | 39 | 43 | 0.00235 | 0.00067 |
| 43 | 43 | 44 | 0.00061 | 0.00033 |
| 44 | 44 | 45 | 0.00119 | 0.00063 |
| 45 | 45 | 46 | 0.00309 | 0.00165 |
| 46 | 44 | 47 | 0.00048 | 0.00025 |
| 47 | 47 | 48 | 0.00148 | 0.00079 |
| 48 | 48 | 49 | 0.00214 | 0.00114 |
| 49 | 47 | 50 | 0.00045 | 0.00024 |
| 50 | 50 | 51 | 0.00353 | 0.00100 |
| 51 | 36 | 52 | 0.00055 | 0.00029 |
| 52 | 52 | 53 | 0.00245 | 0.00131 |
| 53 | 53 | 54 | 0.00147 | 0.00078 |
| 54 | 54 | 55 | 0.00044 | 0.00024 |
| 55 | 55 | 56 | 0.00067 | 0.00036 |
| 56 | 56 | 57 | 0.00444 | 0.00236 |
| 57 | 57 | 58 | 0.00165 | 0.00088 |
| 58 | 58 | 59 | 0.00269 | 0.00143 |
| 59 | 59 | 60 | 0.00090 | 0.00048 |
| 60 | 60 | 61 | 0.00245 | 0.00130 |
| 61 | 61 | 62 | 0.00324 | 0.00172 |
| 62 | 60 | 63 | 0.00649 | 0.00345 |
| 63 | 57 | 64 | 0.00123 | 0.00066 |
| 64 | 64 | 65 | 0.00089 | 0.00048 |
| 65 | 65 | 66 | 0.00106 | 0.00056 |
| 66 | 65 | 67 | 0.00277 | 0.00147 |
| 67 | 67 | 68 | 0.00079 | 0.00042 |
| 68 | 67 | 69 | 0.00251 | 0.00134 |
| 69 | 69 | 70 | 0.00240 | 0.00128 |
| 70 | 70 | 71 | 0.00109 | 0.00058 |
| 71 | 71 | 72 | 0.00059 | 0.00031 |
| 72 | 72 | 73 | 0.00155 | 0.00082 |

73 73 74 0.00222 0.00118
74 74 75 0.00136 0.00073];

% bus active (P) reactive (Q)

BD=[1 0.0000 0.0000
2 0.0876 0.0329
3 0.2625 0.1219
4 0.0944 0.0307
5 0.0497 0.0301
6 0.0000 0.0000
7 0.1439 0.0710
8 0.0307 0.0145
9 0.1100 0.0407
10 0.0593 0.0141
11 0.0856 0.0392
12 0.0728 0.0270
13 0.1083 0.0477
14 0.0610 0.0279
15 0.0649 0.0338
16 0.0356 0.0151
17 0.0129 0.0059
18 0.2852 0.1553
19 0.0523 0.0204
20 0.0833 0.0418
21 0.0993 0.0285
22 0.0554 0.0239
23 0.0955 0.0458
24 0.0000 0.0000
25 0.1540 0.0572
26 0.2053 0.0891

| | | |
|----|--------|--------|
| 27 | 0.1585 | 0.0834 |
| 28 | 0.0585 | 0.0242 |
| 29 | 0.0234 | 0.0100 |
| 30 | 0.0203 | 0.0120 |
| 31 | 0.0384 | 0.0189 |
| 32 | 0.0573 | 0.0343 |
| 33 | 0.0315 | 0.0194 |
| 34 | 0.0901 | 0.0462 |
| 35 | 0.0952 | 0.0523 |
| 36 | 0.0668 | 0.0334 |
| 37 | 0.0883 | 0.0409 |
| 38 | 0.0362 | 0.0169 |
| 39 | 0.0000 | 0.0000 |
| 40 | 0.0978 | 0.0509 |
| 41 | 0.0397 | 0.0171 |
| 42 | 0.0525 | 0.0262 |
| 43 | 0.0130 | 0.0063 |
| 44 | 0.0000 | 0.0000 |
| 45 | 0.0260 | 0.0132 |
| 46 | 0.0492 | 0.0298 |
| 47 | 0.0373 | 0.0215 |
| 48 | 0.0382 | 0.0212 |
| 49 | 0.1026 | 0.0542 |
| 50 | 0.0989 | 0.0567 |
| 51 | 0.0371 | 0.0184 |
| 52 | 0.2490 | 0.0904 |
| 53 | 0.0351 | 0.0184 |
| 54 | 0.0647 | 0.0243 |
| 55 | 0.0576 | 0.0279 |
| 56 | 0.0642 | 0.0321 |
| 57 | 0.0000 | 0.0000 |

```
58 0.0168 0.0085
59 0.0977 0.0437
60 0.0000 0.0000
61 0.0757 0.0346
62 0.1059 0.0359
63 0.0595 0.0286
64 0.0803 0.0350
65 0.0562 0.0228
66 0.3082 0.1491
67 0.0183 0.0110
68 0.0448 0.0235
69 0.0319 0.0196
70 0.0433 0.0179
71 0.1560 0.0693
72 0.1122 0.0564
73 0.0479 0.0214
74 0.1317 0.0551
75 0.0315 0.0213];
```

```
%Load flow using backward forward load flow method%%%%%%%%%
```

```
%code for bus-injection to branch-current matrix
```

```
bibc=zeros(size(LD,1),size(LD,1));
```

```
BCBV=zeros(size(LD,1),size(LD,1));
```

```
for i=1:length(LD)
```

```
if LD(i,2)==1
```

```
bibc(LD(i,3)-1,LD(i,3)-1)=1;
```

```
BCBV(LD(i,3)-1,LD(i,3)-1)=complex(LD(i,4),LD(i,5));
```

```
else
```

```
bibc(:,LD(i,3)-1)=bibc(:,LD(i,2)-1);
```

```
bibc(LD(i,3)-1,LD(i,3)-1)=1;
```

```
BCBV(LD(i,3)-1,:) = BCBV(LD(i,2)-1,:);
BCBV(LD(i,3)-1,LD(i,3)-1) = complex(LD(i,4),LD(i,5));
end
end
S = complex(BD(:,2),BD(:,3)); % complex power
Vo = ones(length(LD),1); % initial bus voltage % 10 change to specific
data value
S(1) = [];
size(Vo)
VB = Vo;
iteration = 500;
for i = 1:iteration
    %backward sweep
    I = conj(S./(1*VB)); % injected current
    Z = complex(LD(:,4),LD(:,5)); %branch impedance
    %ZD = diag(Z); %makeing it diagonal
    IB = bibr*I; %branch current
    %forward sweep
    TRX = BCBV*bibr;
    VB = Vo - TRX*I;
end
BCBV;
Vbus = [1;VB];
%display(abs(Vbus));
%display(abs(IB));
vb = abs(Vbus);
ibr = abs(IB);
```

```

min(vb)

x=[ibr;vb];

diag(real(BCBV));

p1=1500*(x(1:length(ibr),1).^2).*diag(real(BCBV));

q1=1500*(x(1:length(ibr),1).^2).*diag(imag(BCBV));

PL=sum(p1);

QL=sum(q1);
    
```

Appendix D

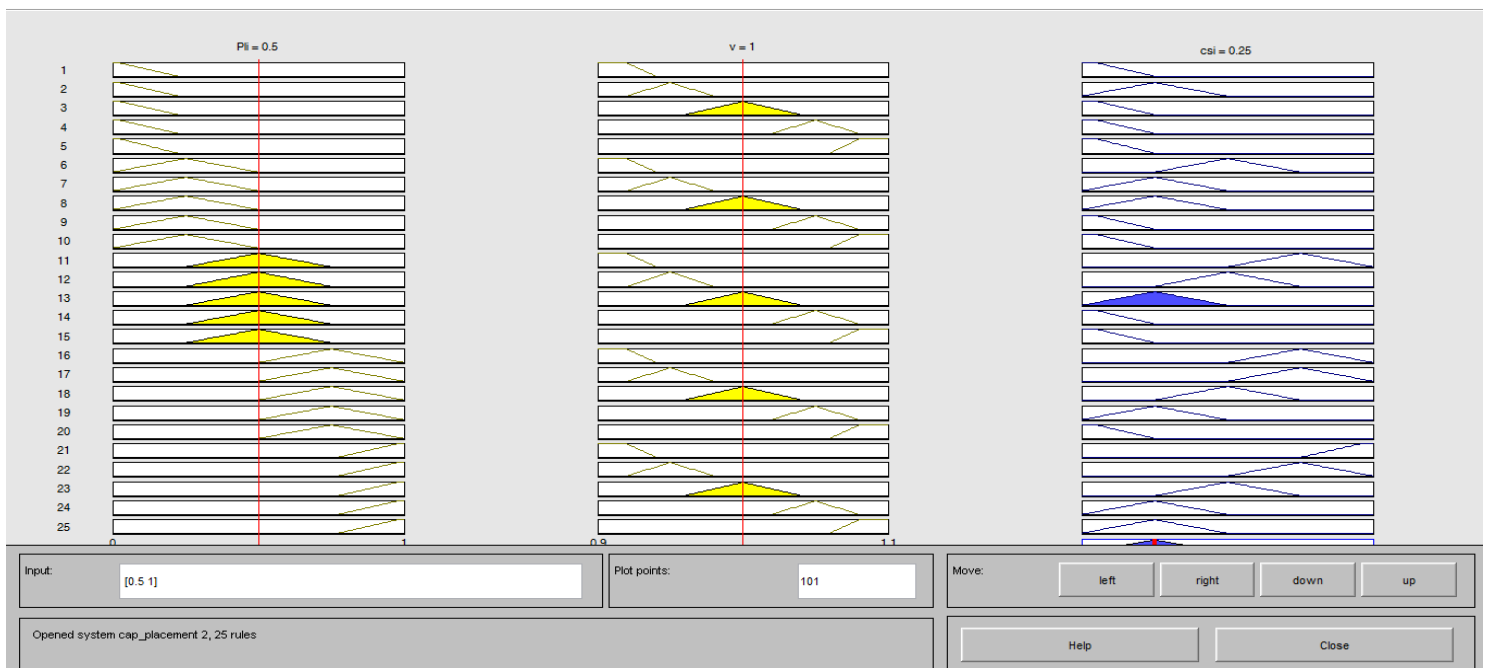


Figure D: 1 Rules of fuzzy inference system

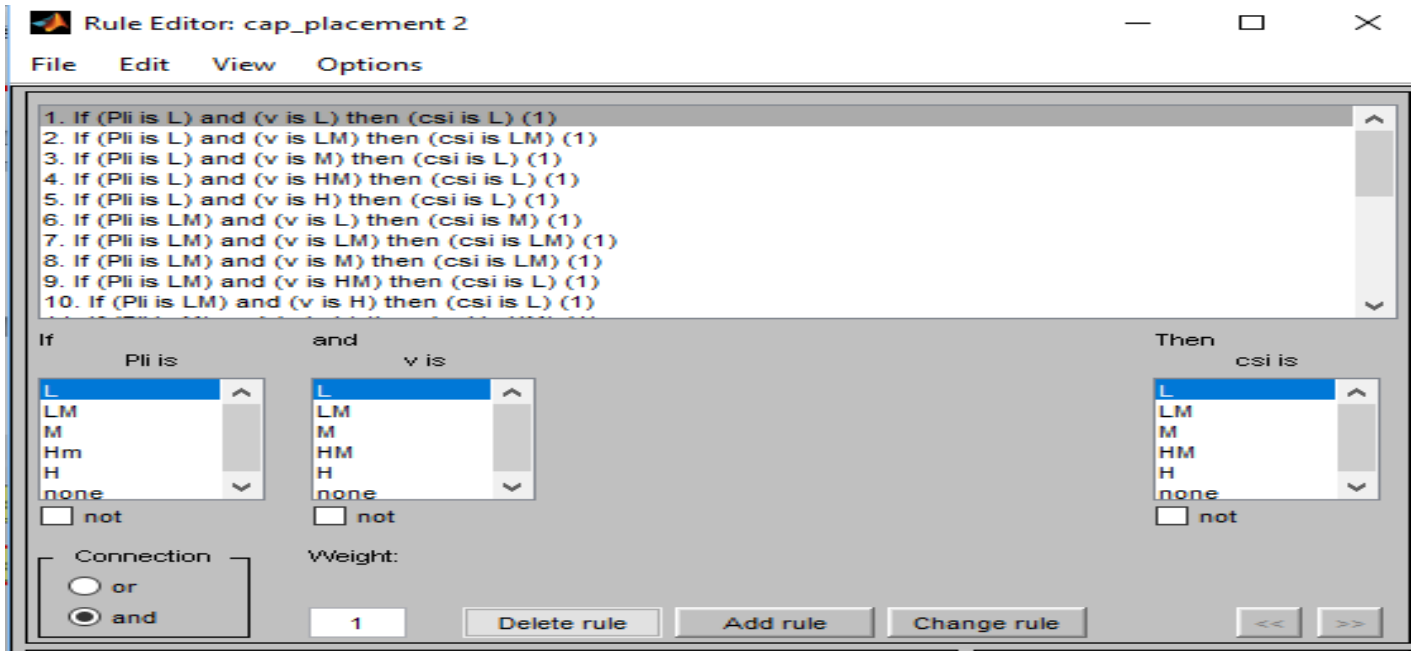


Figure D: 2 Fuzzy rules

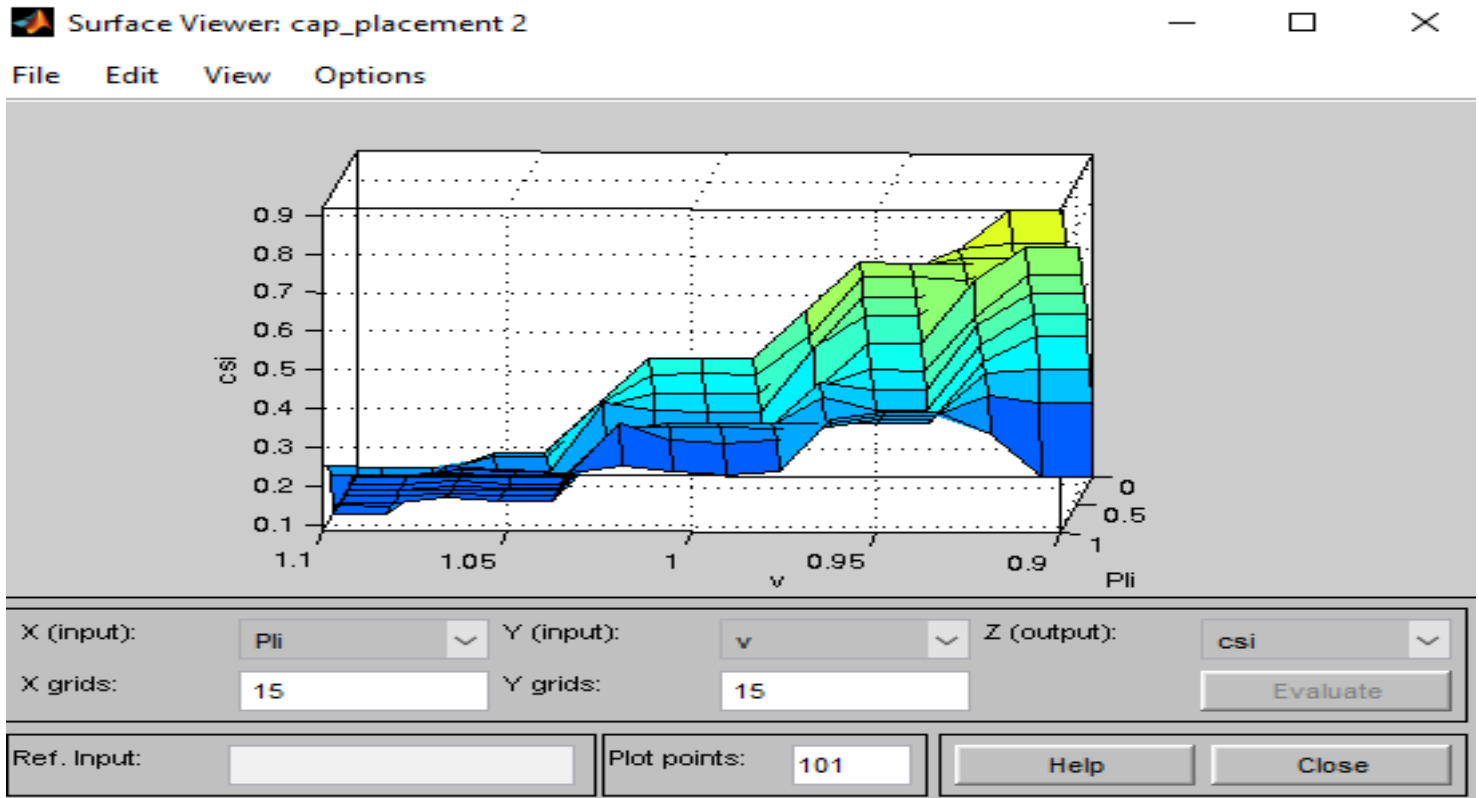


Figure D: 3 Surface of fuzzy

Appendix E**Math lab code of PSO****% Line Data**

```
%branch sending reciving R X
function y =linedata()
y=[1 1 2 0.00121 0.00064
2 2 3 0.00066 0.00035
3 2 4 0.00076 0.00041
4 4 5 0.00183 0.00097
5 5 6 0.00070 0.00037
6 6 7 0.00166 0.00047
7 6 8 0.00060 0.00032
8 8 9 0.00196 0.00104
9 9 10 0.00197 0.00105
10 10 11 0.00210 0.00112
11 11 12 0.00095 0.00051
12 12 13 0.00188 0.00100
13 13 14 0.00078 0.00042
14 14 15 0.00260 0.00139
15 15 16 0.00061 0.00033
16 16 17 0.00140 0.00075
17 17 18 0.00219 0.00116
18 14 19 0.00084 0.00045
19 19 20 0.00283 0.00151
20 20 21 0.00141 0.00075
21 21 22 0.00185 0.00099
22 22 23 0.00174 0.00092
23 23 24 0.00180 0.00075
24 24 25 0.00050 0.00027
25 25 26 0.00057 0.00030
```

| | | | | |
|----|----|----|---------|---------|
| 26 | 26 | 27 | 0.00228 | 0.00122 |
| 27 | 24 | 28 | 0.00032 | 0.00017 |
| 28 | 28 | 29 | 0.00088 | 0.00047 |
| 29 | 29 | 30 | 0.00120 | 0.00064 |
| 30 | 30 | 31 | 0.00168 | 0.00089 |
| 31 | 31 | 32 | 0.00082 | 0.00044 |
| 32 | 32 | 33 | 0.00241 | 0.00128 |
| 33 | 24 | 34 | 0.00048 | 0.00020 |
| 34 | 34 | 35 | 0.00226 | 0.00133 |
| 35 | 35 | 36 | 0.00120 | 0.00070 |
| 36 | 36 | 37 | 0.00077 | 0.00041 |
| 37 | 37 | 38 | 0.00496 | 0.00264 |
| 38 | 38 | 39 | 0.00066 | 0.00035 |
| 39 | 39 | 40 | 0.00308 | 0.00164 |
| 40 | 40 | 41 | 0.00649 | 0.00346 |
| 41 | 41 | 42 | 0.00277 | 0.00148 |
| 42 | 39 | 43 | 0.00235 | 0.00067 |
| 43 | 43 | 44 | 0.00061 | 0.00033 |
| 44 | 44 | 45 | 0.00119 | 0.00063 |
| 45 | 45 | 46 | 0.00309 | 0.00165 |
| 46 | 44 | 47 | 0.00048 | 0.00025 |
| 47 | 47 | 48 | 0.00148 | 0.00079 |
| 48 | 48 | 49 | 0.00214 | 0.00114 |
| 49 | 47 | 50 | 0.00045 | 0.00024 |
| 50 | 50 | 51 | 0.00353 | 0.00100 |
| 51 | 36 | 52 | 0.00055 | 0.00029 |
| 52 | 52 | 53 | 0.00245 | 0.00131 |
| 53 | 53 | 54 | 0.00147 | 0.00078 |
| 54 | 54 | 55 | 0.00044 | 0.00024 |
| 55 | 55 | 56 | 0.00067 | 0.00036 |
| 56 | 56 | 57 | 0.00444 | 0.00236 |

```
57 57 58 0.00165 0.00088
58 58 59 0.00269 0.00143
59 59 60 0.00090 0.00048
60 60 61 0.00245 0.00130
61 61 62 0.00324 0.00172
62 60 63 0.00649 0.00345
63 57 64 0.00123 0.00066
64 64 65 0.00089 0.00048
65 65 66 0.00106 0.00056
66 65 67 0.00277 0.00147
67 67 68 0.00079 0.00042
68 67 69 0.00251 0.00134
69 69 70 0.00240 0.00128
70 70 71 0.00109 0.00058
71 71 72 0.00059 0.00031
72 72 73 0.00155 0.00082
73 73 74 0.00222 0.00118
74 74 75 0.00136 0.00073
];
end
% busno p (pu) q (pu)

function z=busdata(x)
z=[1 0.0000 0.0000
2 0.0876 0.0329
3 0.2625 0.1219
4 0.0944 0.0307
5 0.0497 0.0301
6 0.0000 0.0000
7 0.1439 0.0710
8 0.0307 0.0145
```

| | | |
|----|--------|--------|
| 9 | 0.1100 | 0.0407 |
| 10 | 0.0593 | 0.0141 |
| 11 | 0.0856 | 0.0392 |
| 12 | 0.0728 | 0.0270 |
| 13 | 0.1083 | 0.0477 |
| 14 | 0.0610 | 0.0279 |
| 15 | 0.0649 | 0.0338 |
| 16 | 0.0356 | 0.0151 |
| 17 | 0.0129 | 0.0059 |
| 18 | 0.2852 | 0.1553 |
| 19 | 0.0523 | 0.0204 |
| 20 | 0.0833 | 0.0418 |
| 21 | 0.0993 | 0.0285 |
| 22 | 0.0554 | 0.0239 |
| 23 | 0.0955 | 0.0458 |
| 24 | 0.0000 | 0.0000 |
| 25 | 0.1540 | 0.0572 |
| 26 | 0.2053 | 0.0891 |
| 27 | 0.1585 | 0.0834 |
| 28 | 0.0585 | 0.0242 |
| 29 | 0.0234 | 0.0100 |
| 30 | 0.0203 | 0.0120 |
| 31 | 0.0384 | 0.0189 |
| 32 | 0.0573 | 0.0343 |
| 33 | 0.0315 | 0.0194 |
| 34 | 0.0901 | 0.0462 |
| 35 | 0.0952 | 0.0523 |
| 36 | 0.0668 | 0.0334 |
| 37 | 0.0883 | 0.0409 |
| 38 | 0.0362 | 0.0169 |
| 39 | 0.0000 | 0.0000 |

| | | |
|----|--------|--------|
| 40 | 0.0978 | 0.0509 |
| 41 | 0.0397 | 0.0171 |
| 42 | 0.0525 | 0.0262 |
| 43 | 0.0130 | 0.0063 |
| 44 | 0.0000 | 0.0000 |
| 45 | 0.0260 | 0.0132 |
| 46 | 0.0492 | 0.0298 |
| 47 | 0.0373 | 0.0215 |
| 48 | 0.0382 | 0.0212 |
| 49 | 0.1026 | 0.0542 |
| 50 | 0.0989 | 0.0567 |
| 51 | 0.0371 | 0.0184 |
| 52 | 0.2490 | 0.0904 |
| 53 | 0.0351 | 0.0184 |
| 54 | 0.0647 | 0.0243 |
| 55 | 0.0576 | 0.0279 |
| 56 | 0.0642 | 0.0321 |
| 57 | 0.0000 | 0.0000 |
| 58 | 0.0168 | 0.0085 |
| 59 | 0.0977 | 0.0437 |
| 60 | 0.0000 | 0.0000 |
| 61 | 0.0757 | 0.0346 |
| 62 | 0.1059 | 0.0359 |
| 63 | 0.0595 | 0.0286 |
| 64 | 0.0803 | 0.0350 |
| 65 | 0.0562 | 0.0228 |
| 66 | 0.3082 | 0.1491 |
| 67 | 0.0183 | 0.0110 |
| 68 | 0.0448 | 0.0235 |
| 69 | 0.0319 | 0.0196 |
| 70 | 0.0433 | 0.0179 |

```

71  0.1560  0.0693
72  0.1122  0.0564
73  0.0479  0.0214
74  0.1317  0.0551
75  0.0315  0.0213

];

a=[8  9  10 11 12 20 21 22 23 24];% selected buses
for h=1:10
    z(a(h),3)=z(a(h),3)-x(h);% a(h),3 is rective power at selected
buses
end
    %x(h) selected capacitor sizes by pso in each
iteration
end

%Load flow using backward forward load flow method%%%%%%%%%
function PL=loadflow(positionn)
LD=linedata;
BD=busdata(positionn);

%code for bus-injection to branch-current matrix
bibc=zeros(size(LD,1),size(LD,1));
BCBV=zeros(size(LD,1),size(LD,1));
for i=1:length(LD)
    if LD(i,2)==1
        bibc(LD(i,3)-1,LD(i,3)-1)=1;
        BCBV(LD(i,3)-1,LD(i,3)-1)=complex(LD(i,4),LD(i,5));
    else
        bibc(:,LD(i,3)-1)=bibc(:,LD(i,2)-1);
        bibc(LD(i,3)-1,LD(i,3)-1)=1;
        BCBV(LD(i,3)-1,:)=BCBV(LD(i,2)-1,:);
        BCBV(LD(i,3)-1,LD(i,3)-1)=complex(LD(i,4),LD(i,5));
    end
end

```

```
end

end

S=complex(BD(:,2),BD(:,3));% complex power

Vo=ones(length(LD),1);% initial bus votage% 10 change to specific
data value

S(1)=[];

size(Vo)

VB=Vo;

iteration=500;

for i=1:iteration

    %backward sweep

    I=conj(S./(1*VB));% injected current

    Z=complex(LD(:,4),LD(:,5));%branch impedance

    %ZD=diag(Z);%makeing it diagonal

    IB=bibc*I; %branch current

    %forward sweep

    TRX=BCBV*bibc;

    VB=Vo-TRX*I;

end

BCBV;

Vbus=[1;VB];

%display(abs(Vbus));

%display(abs(IB));

vb=abs(Vbus);

ibr=abs(IB);

min(vb)

x=[ibr;vb];
```

```
diag(real(BCBV));
p1=1500*(x(1:length(ibr),1).^2).*diag(real(BCBV));
PL=sum(p1);
q1=1500*(x(1:length(ibr),1).^2).*diag(imag(BCBV));
QL=sum(q1);
end
%% Problem Definition
clear all
clc
tic
CostFunction=@(positionn) loadflow(positionn); % fitness function

nVar=10; % Number of Decision Variables

VarSize=[1 nVar]; % Size of Decision Variables Matrix

VarMin=0.067; % Lower Bound of Variables
VarMax=1.0; % Upper Bound of Variables

%% PSO Parameters

MaxIt=100; % Maximum Number of Iterations

nPop=20; % Population Size (Swarm Size)
% PSO Parameters
w=1; % Inertia Weight
wdamp=0.99; % Inertia Weight Damping Ratio
c1=2.0; % Personal Learning Coefficient
c2=2.0; % Global Learning Coefficient

% If you would like to use Constriction Coefficients for PSO,
```

```
% uncomment the following block and comment the above set of
parameters.

% % Constriction Coefficients

%phi1=2.05;
%phi2=2.05;
%phi=phi1+phi2;
%chi=2/(phi-2+sqrt(phi^2-4*phi));
%w=chi;           % Inertia Weight
%wdamp=1;         % Inertia Weight Damping Ratio
%c1=chi*phi1;     % Personal Learning Coefficient
%c2=chi*phi2;     % Global Learning Coefficient

% Velocity Limits
VelMax=0.1*(VarMax-VarMin);
VelMin=-VelMax;

%% Initialization

empty_particle.Position=[];
empty_particle.Cost=[];
empty_particle.Velocity=[];
empty_particle.Best.Position=[];
empty_particle.Best.Cost=[];

particle= repmat(empty_particle, nPop, 1);

GlobalBest.Cost=inf;

for i=1:nPop
```

```
% Initialize Position
particle(i).Position=unifrnd(VarMin,VarMax,VarSize);

% Initialize Velocity
particle(i).Velocity=zeros(VarSize);

% Evaluation
particle(i).Cost=CostFunction(particle(i).Position);

% Update Personal Best
particle(i).Best.Position=particle(i).Position;
particle(i).Best.Cost=particle(i).Cost;

% Update Global Best
if particle(i).Best.Cost<GlobalBest.Cost

    GlobalBest=particle(i).Best;

end

end

end

BestCost=zeros(MaxIt,1);

%% PSO Main Loop
for it=1:MaxIt

    for i=1:nPop

        % Update Velocity

        particle(i).Velocity = w*particle(i).Velocity ...
```

```
+c1*rand(VarSize).* (particle(i).Best.Position-
particle(i).Position) ...

+c2*rand(VarSize).* (GlobalBest.Position-
particle(i).Position);

% Apply Velocity Limits
particle(i).Velocity = max(particle(i).Velocity, VelMin);
particle(i).Velocity = min(particle(i).Velocity, VelMax);

% Update Position
particle(i).Position = particle(i).Position +
particle(i).Velocity;

% Velocity Mirror Effect
IsOutside=(particle(i).Position<VarMin |
particle(i).Position>VarMax);
particle(i).Velocity(IsOutside)=-
particle(i).Velocity(IsOutside);

% Apply Position Limits
particle(i).Position = max(particle(i).Position, VarMin);
particle(i).Position = min(particle(i).Position, VarMax);

% Evaluation
particle(i).Cost = CostFunction(particle(i).Position);

% Update Personal Best
if particle(i).Cost<particle(i).Best.Cost

    particle(i).Best.Position=particle(i).Position;
    particle(i).Best.Cost=particle(i).Cost;

% Update Global Best
```

```
        if particle(i).Best.Cost<GlobalBest.Cost

            GlobalBest=particle(i).Best;

        end

    end

end

end

BestCost(it)=GlobalBest.Cost;

disp(['Iteration ' num2str(it) ': Best Cost = '
num2str(BestCost(it))]);

w=w*wdamp;

end

BestSol = GlobalBest;

%% Results

figure;
%plot(BestCost,'LineWidth',2);
semilogy(BestCost,'LineWidth',2);
xlabel('Iteration');
ylabel('Best Cost');
grid on;
toc
```