Optimal Capacitor Placement in Radial Distribution Networks

A Thesis

Submitted in the fulfilment of the requirement
for the award of the degree of

DOCTOR OF PHILOSOPHY
in
Electrical Engineering

Submitted by

Sarika Sharma
(Registration No.: 950804008)

Under the supervision of

Dr. Smarajit Ghosh

Professor, EIED, TIET

Electrical and Instrumentation Engineering Department
Thapar Institute of Engineering & Technology
(Deemed to be University)
Patiala - 147 004
Punjab, India
DECEMBER 2020

CERTIFICATE

I hereby certify that the work, which is being presented in thesis entitled "***Optimal Capacitor Placement in Radial Distribution Networks***" to the Department of Electrical and Instrumentation Engineering, Thapar Institute of Engineering & Technology (Deemed to be university), Patiala in the fulfilment of the requirements for the award of degree of "Doctor of Philosophy" is an authentic record of my own research work carried out under the guidance of Dr. Smarajit Ghosh and refers other research work, which are duly listed in the reference section.

The matter presented in this thesis has not been submitted in part or full for the award of any degree in any other University or Institute.

09/12/2020

(Sarika Sharma)
Registration Number: 950804008

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

S. Ghosh
09-12-2020

(Dr. Smarajit Ghosh)
Professor
Department of Electrical and Instrumentation Engineering
Thapar Institute of Engineering & Technology (Deemed to be University)
Patiala, Punjab, India

ACKNOWLEDGEMENTS

First of all, I thank the almighty God, who gave me the opportunity and strength to carry out this research work in this esteemed University.

With great pleasure and privilege, I wish to express my heartfelt sense of gratitude to my supervisor, **Dr. Smarajit Ghosh**, for his guidance, motivational support and directions for completing this research work.

I am thankful to **Dr. Rafat Siddique** (Dean of Research and Sponsored Projects, TIET) for his support during this thesis work. Also, I am thankful to the former Deans (Research and Sponsored Projects) **Dr. P. K. Bajpai** and **Dr. O. P. Pandey** for their support during this research work. I express my deepest gratitude to **Dr. Prakash Gopalan** (Director TIET, Patiala), and **Dr. R. S. Kaler** (HEIED, TIET), for their encouragement and support. I am also thankful to **Dr. Gurbinder Singh** (Registrar, TIET) and staff for helping with smooth proceeding of the administrative needs associated with the research work.

I am thankful to my doctoral committee members, **Dr. Ravinder Agarwal** (Professor, EIED), **Dr. Mandeep Singh**, (Professor, EIED) and **Dr. S. S. Bhatia** (Dean of Academic Affairs, TIET), for their constructive comments and regularly ensuring the progress of research work.

I am totally indebted to my family for showering their blessings all the time and always stood beside me in my difficult times. Special thanks to my husband and kids for being my strength all the time. I offer the deepest gratitude to my friends for their love and moral support throughout the various stages of this work.

Sharma

(Sarika Sharma)

Dedicated to My Father

ABSTRACT

Electricity generated from the power stations can be distributed to the customers utilizing various systems and amongst these networks the radial distribution network is an alluring one. Power loss happened in this system can be endured and the voltage profile can be enhanced by putting optimal sized capacitors at the appropriate locations. Different calculations and methods are utilized beforehand for investigating the situation where the capacitors to be placed and its sizes. A methodology is proposed that decides the exact sensitive nodes of the radial distribution networks for integrating optimal capacitor placement to reduce power loss, energy loss and to upgrade the voltage profile by means of Loss Sensitivity Factor (LSF) technique and Hybrid ABC-PSO algorithm. The LSF method is applied to find the sensitive nodes and the optimal size of the capacitor has been solved by Hybrid ABC-PSO algorithm. Capacitor placement issue is remarkably a nonlinear problem and from the Fuzzy Inference System (FIS) the most appropriate nodes for the capacitor placement has been picked up. The capacitor size identifying with minimum real power loss has been settled. The proposed procedure is tested on 69-node and 34-node radial distribution networks and the outcomes in both cases are contrasted with other existing methods.

A fuzzy expert system (FES) comprising a game-plan of heuristic principles is then utilized for getting the capacitor position suitability of every node in the flow structure. The sizing of capacitor is determined by utilizing Hybrid Artificial Bee Colony-Cuckoo Search Optimization (ABC-CSO) algorithm. The proposed capacitor allocation is executed on 69-node and 34-node radial distribution networks and the outcome is assessed. Recreation outcomes have demonstrated that the proposed technique has decreased the overall losses of the system compared with the existing approaches and also by the ABC-PSO algorithm. The expansion of a 33-node radial distribution network through particle swarm optimization (PSO) is carried out by considering the objectives like power loss, short circuit capacity as well as energy not supplied function.

Then from the obtained modified or expanded distribution network, optimal positions of the capacitors have been carried out by using hybrid ABC-CSO algorithm by considering different loading conditions. Initially expansion of planning of distribution system is done before carrying out planning of capacitor. Under these different loading conditions, the required capacitive reactive power is computed for decreasing power losses and enlightening the voltage profile. Then finally, the impact of load progress in the distribution system is analysed before and after capacitor placement. Investigational outcomes specified the efficiency of the projected technique for expansion of distribution and capacitor placement shows high performance and the best method for planning of efficient distribution system.

TABLE OF CONTENTS

Chapter Number **Title** **Page Number**

CHAPTER-1 INTRODUCTION

CHAPTER-2 LITERATURE STUDY

CHAPTER-3 OPTIMAL CAPACITOR PLACEMENT USING FIS AND HYBRID ABC-PSO

CHAPTER-4 HYBRID ABC-CSO BASED CAPACITOR PLACEMENT

CHAPTER-5 OPTIMAL PLANNING AND PLACEMENT OF CAPACITOR IN DISTRIBUTION NETWORK

CHAPTER-6 OVERALL CONCLUSIONS AND FURURE SCOPES OF RESEARCH WORK

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

Symbol	**Description**
I_j	Current flowing through the branch j
$V_1\angle\delta_1$	Magnitude of voltage and its angle at node 1
$V_2\angle\delta_2$	Magnitude of voltage and its angle at node 2
Z_j	Impedance of branch j
R_j	Resistance of branch j
X_j	Reactance of branch j
P_2	Addition of real power of all nodes
Q_2	Addition of reactive power of all nodes
V (old)	Voltage obtained in previous iteration
V (new)	Voltage obtained in present iteration
ε	Maximum variation of voltage allowed

ΔF_{max}	Maximum value of the input signals ΔP and ΔQ
LN	Large negative
MN	Medium negative
SN	Small negative
SP	Small positive
MP	Medium positive
LP	Large positive
ZN	Zero
μ_p	Membership functions of power loss index
μ_v	Membership functions of voltage
μ_s	Capacitor suitability membership function
S	Capacitor placement suitability index
$\mu_s(x)$	Distribution function of capacitor placement suitability
x	Point at which the membership function is maximum

$P_{j(Loss)}$	Power loss at jth load level
Q_{ci}	Reactive power injection from capacitor to node i
S	Investments
T_j	Load period
N_L	Number of capacitor location
L	Number of load level
C_e	Capacitor Energy price of losses
C_{cf}	Capacitor fixing price
C_c	Capacitor marginal cost
γ, β, ran	Random values
F_j	Fitness function
C	Output of neural network
F_i	i^{th} input value
w_j^O	Weights assigned between hidden and output layer

w_{ij}^{I}	Weight assigned between input and hidden layer
M	Number of hidden neurons
∂_k	k^{th} learning error
Y	Desired output
BP_{error}	Back Propagation error
Δw	Weight deviation
δ	Average of hidden neurons output
N	Total number of input neurons
T	Total number of training
H_n	n^{th} output at hidden neuron
w^{new}	New weight or updated weight
w	Current weight

CHAPTER-1

INTRODUCTION

1.1 ELECTRICITY

Electricity defines the group of the physical method formulated by the existence and flow of electric charges. Numerous general concepts have a connection with electricity like lightning, electric discharges, electric heating, static electricity and so on. An electric field is produced either by the presence of positive or negative charges. The flow of charges is known as electric current, which forms magnetic field [1].

While a charge is in a non-zero electric field, a force is acting upon the field. Coulomb's law provides the amount of this force. For moving a charge, a certain amount of work is done by the electric field. This is known as electric potential that is equivalent to the amount of effort performed by the exterior representative to carry a sole positive charge from the randomly selected orientation point to that point with no speeding up and is regularly estimated in volts.

Power remains utilized in numerous applications such as for energizing certain machineries, to trigger electrical constituents present within the industrial equipment. Though electricity is introduced in ancient period, it remains slow till 18th century as a theory basis. After that electricity is made practicably possible by few scientists in the late 19th century, which is now being utilized for residential, commercial and industrial purposes. The sudden enhancement in the electrical power generation becomes a seed for the vast development of industries, which in turn led to a second industrial revolution. Since electricity has extreme portable facilities, it can be utilized in diverse purposes like lighting, transportation, computation, heating and communications. Now electricity is considered as the essential commodity of all industries, factories and even for houses also [2].

The invention of electric bulb made electricity a fabulous innovation above all other inventions. The integration of electricity and magnetism produces the electromagnetism, which is the basic principle of electric motor. The invention of electronic devices arises as a result of the impact of electricity development. Hence it is unblemished that electricity produced a great motivation for inventing numerous electronic devices in the 20th century.

Thus, electricity becomes a major part in our day-to-day life and becomes an essential thing for each and every operation of life. It is utilized in both houses and commercial buildings. It is an obvious statement that almost each and every component utilizes electricity for its normal functioning. Electricity opened innovation world to a new level as its impact is a vital one for almost all inventions. Without electricity the number of innovations becomes less. Electricity lightens the entire world and reduces a huge number of issues in the modern world. It enhances distributing facility to nodes, electric trains and ships etc. [3].

The demand for electricity is rising to a great extent. It rises to 4% only in the year of 2018 universally, which is almost twice the demand needed and it increases at a faster rate of 2010. This leads the way to the increasing generation of electricity using renewable resources, which meets most of the demands. Since the power plants increased in number for satisfying the demands, large amount of CO_2 emissions is generated and it is enhanced by 2.5%. Energy demand is directly proportional to increase in industries i.e., if the number of industries increases, the amount of energy demand also increases. The demand is five times greater than the last year because of the climatic circumstances. Similarly, when the climate is hot, the demand for a large number of air conditioners increases the total amount of global energy demand.

America and China remain as the country that has the largest power markets, which have almost 71% of the global energy demand development. The electricity demand rises up to 9% within one year in China. It is due to the increase in factories, population, industries and the lavish utilization of energy. The electricity demand is increased to a level of 5.5% in India. Moreover, India distributes electricity to almost all of the rural areas, which is also a reason for its growth in energy demand.

1.1.1 ELECTRICITY GENERATION

The overall process of generating electricity from various sources is termed as electricity generation. It is the foremost step necessary for satisfying the requirements of each and every utilization. After the generation of electricity, the electricity is transmitted, distributed, stored and utilized in several ways.

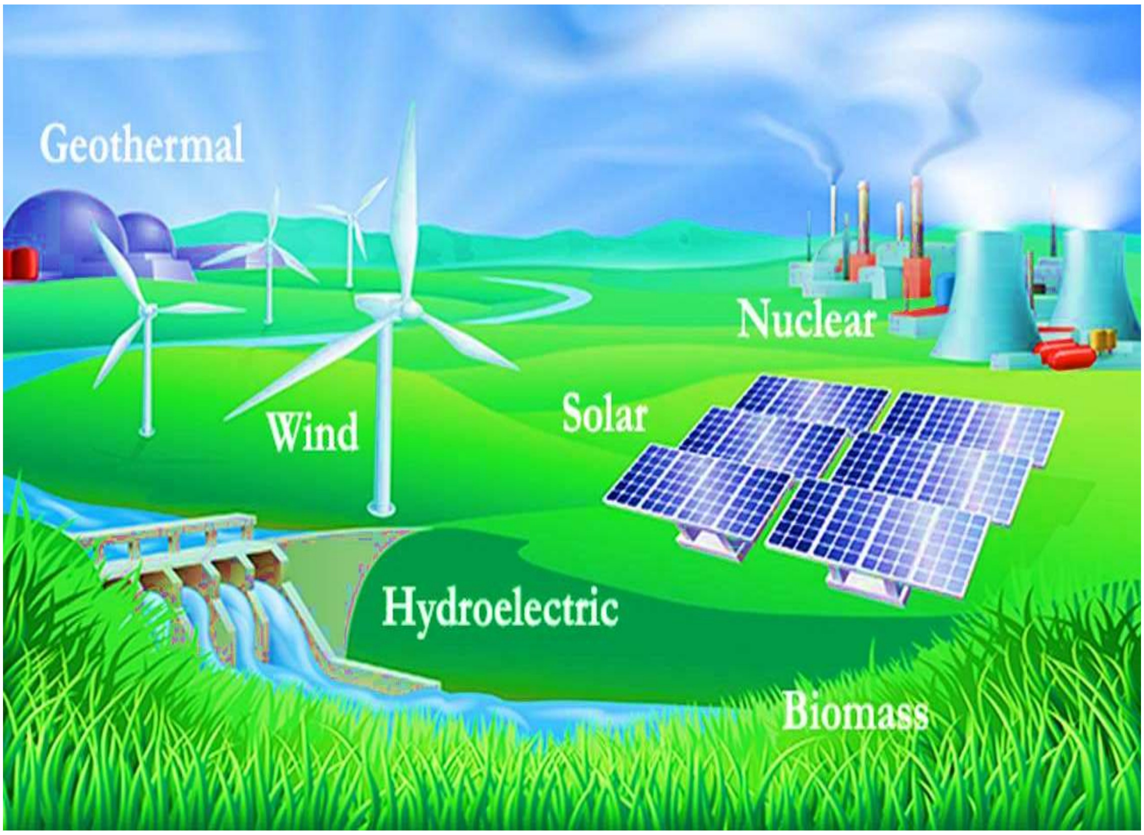


Figure 1.1: Sources of electricity generation

The electricity is not naturally available energy and it has to be generated from numerous natural resources in power plants or power stations. Electricity is generated from numerous sources such as renewable and nonrenewable sources. Nonrenewable sources like combustible fuels, coal etc., and renewable resources like solar, wind, water and nuclear energies are utilized to generate electricity [4] as shown in Fig. 1.1. Also, biomass energy is utilized for electricity generation.

1.1.2 ELECTRICITY TRANSMISSION

Electricity transmission is the procedure of transmitting electric energy to various places for utilization. Initially the large amount of electrical energy is transferred from power stations to small substations for further transmission. So as to attain the terminus i.e., substation, the transmission is generally done in high voltage since the distance and the quantity of electricity is high.

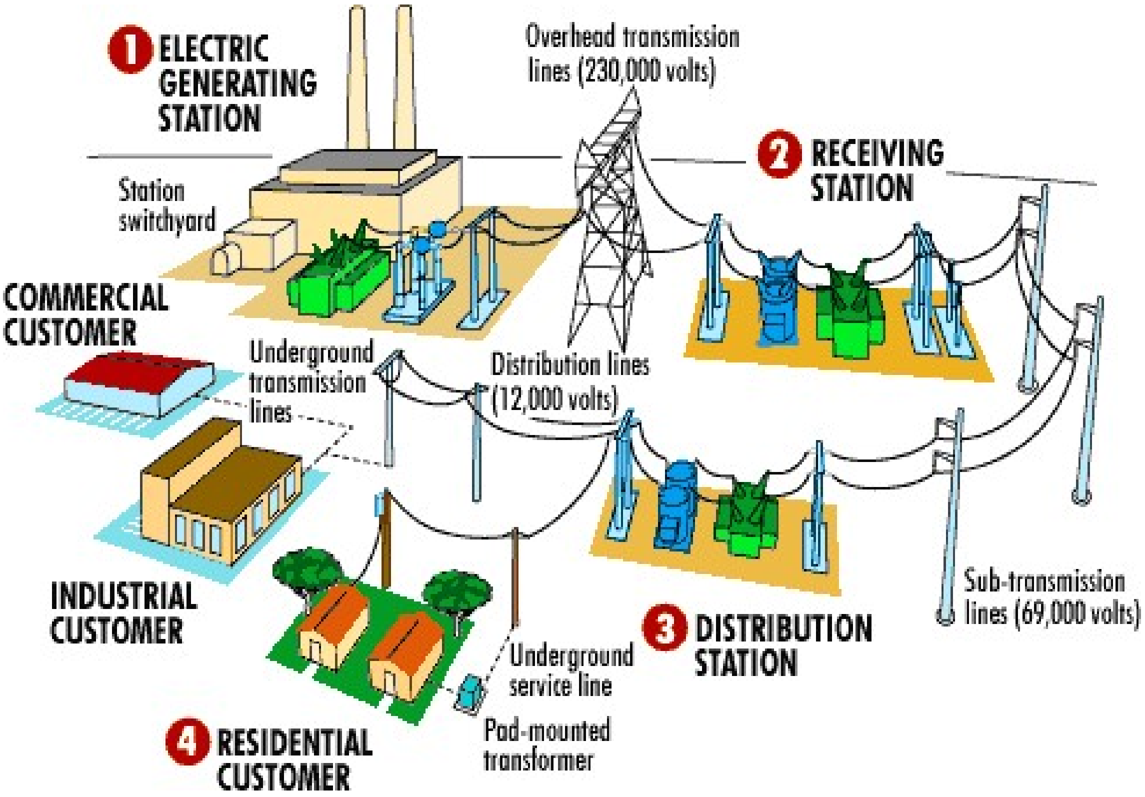


Figure 1.2: Transmission and distribution of electrical power

Overhead lines are utilized for transmitting energy to longer distances generally. In certain areas, underground power transmission is provided mainly in the areas where the population is high. Underground power transmission is efficient since the expenditure of power transmission network installation and its maintenance, less power losses are attained greatly when compared to the overhead power transmission lines [5]. Figure 1.2 shows the transmission and distribution of electrical power.

Sometimes the transmission network is named as grid, though it does not act as a genuine grid for numerous economic reasons. Terminated ways and lines are availed for transmitting electricity from any power station to the load center using multiple ways depending upon its economic way and the expenditure of electricity.

1.2 ELECTRICITY DISTRIBUTION

The terminating procedure in the electric power transmission is electricity distribution. It is the procedure of transmitting electric power from the small substations to individual utilizations. The distribution network utilizes transformers to carry electricity from one place to another. It transmits electrical power at low to medium voltage at a range of 2 to 35 kV [6] as shown in Fig. 1.3.

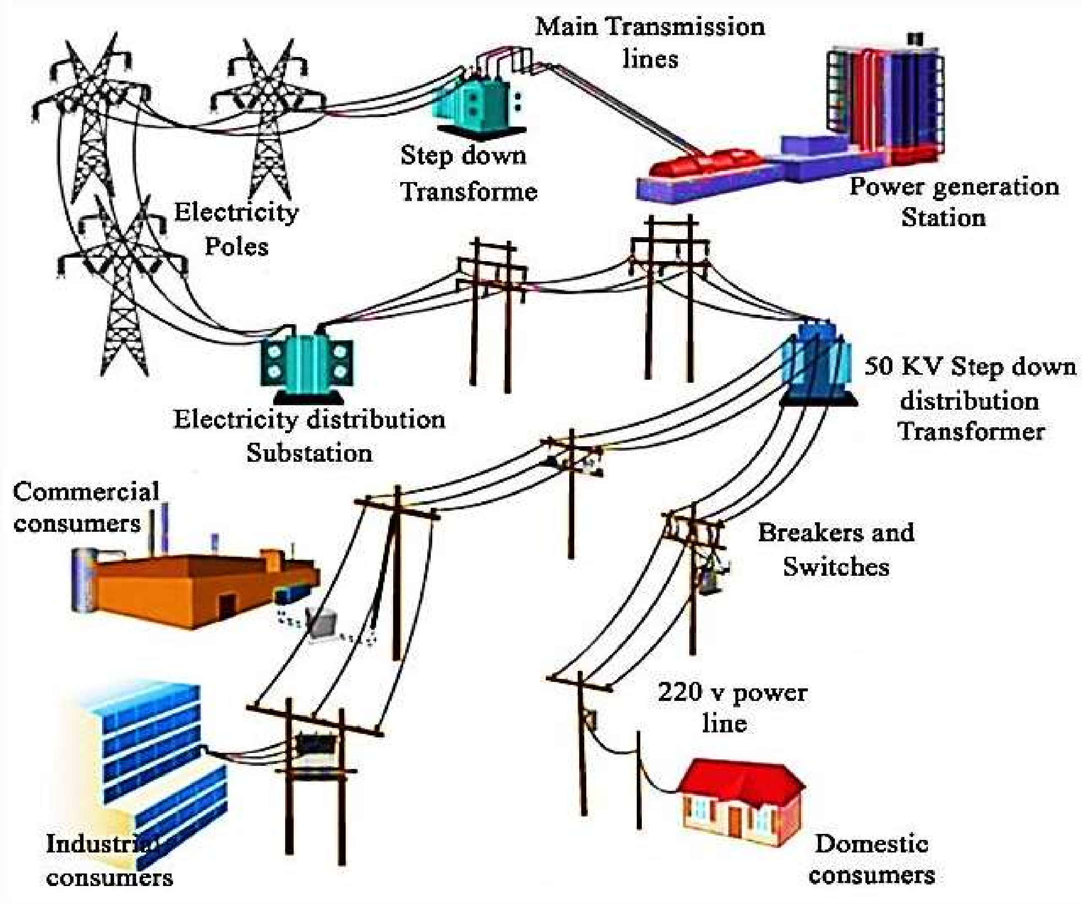


Figure 1.3: Electrical distribution network

Primary distribution lines are utilized to transmit electric power at medium voltage from distribution stations to the location, which is neighboring to the user location. Transformers are used here to lower the voltage suitable for the consumption of various appliances and devices. Certain consumers are provided with electric power through secondary power distribution lines from a single transformer. Secondary distribution lines are connected using service drops for residential and commercial consumers. The consumer remains related straight towards the sub transmission level or primary distribution level only if they demand large quantity of electricity [7].

1.2.1 TYPES OF ELECTRICITY DISTRIBUTION NETWORKS

This primary capacity of an electrical distribution network stays to offer capacity to singular buyer evidences. Distribution of electric power to different buyers should have low voltage. Hence, distribution networks are utilized for distributing electricity. Distribution networks involve subsequent principle constituents:

- Distribution substation
- Primary distribution feeder
- Distribution Transformer
- Distributors
- Service mains

(i) Radial Electricity Distribution Network

In the beginning of electricity distribution network, various feeders centrifugally turned out from the substation and associated with the essential distribution transformer.

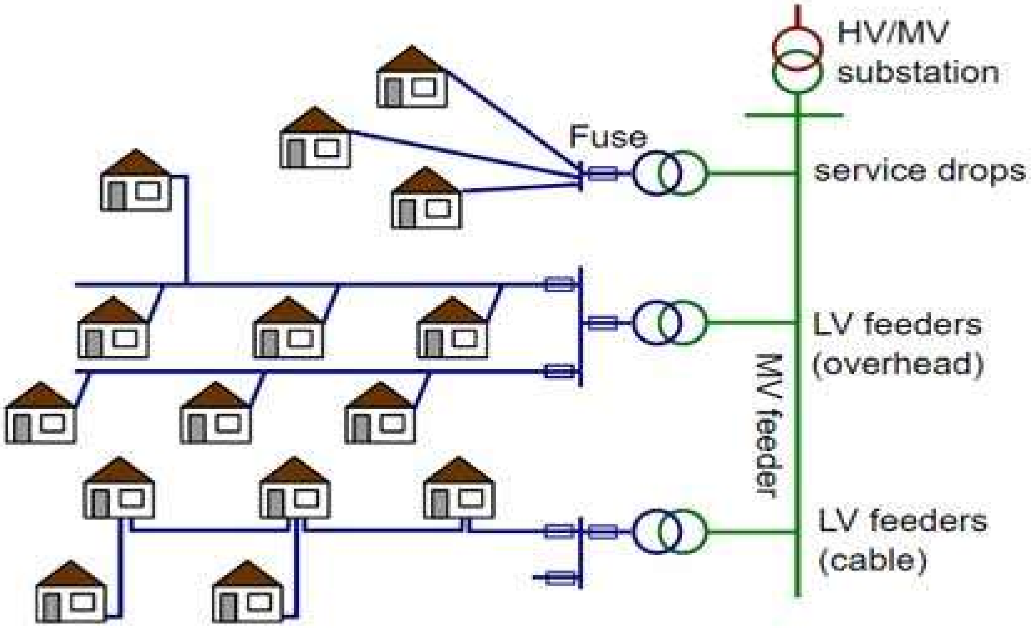


Figure 1.4: Radial electrical distribution network

However, radial electricity distribution network has one major problem, which makes the clients not to receive power while any feeder failure happens since there are no other way to connect the transformer bypassing the faulty feeder. There are chance for failure of transformer also. Moreover, the supplying source is disturbed. In that capacity, the purchaser in the radial electricity distribution network would be in obscurity till the feeder or transformer is repaired. Figure 1.4 shows the radial electricity distribution network.

(ii) Parallel Feeders Distribution Network

The recently stated drawback of a radial network is limited through presenting parallel feeders. This underlying expense network is significantly more as the number of feeders is multiplied. Such network might be used where dependability of the supply is noteworthy for load sharing where the load is greater. Figure 1.5 shows the parallel feeder electricity distribution network.

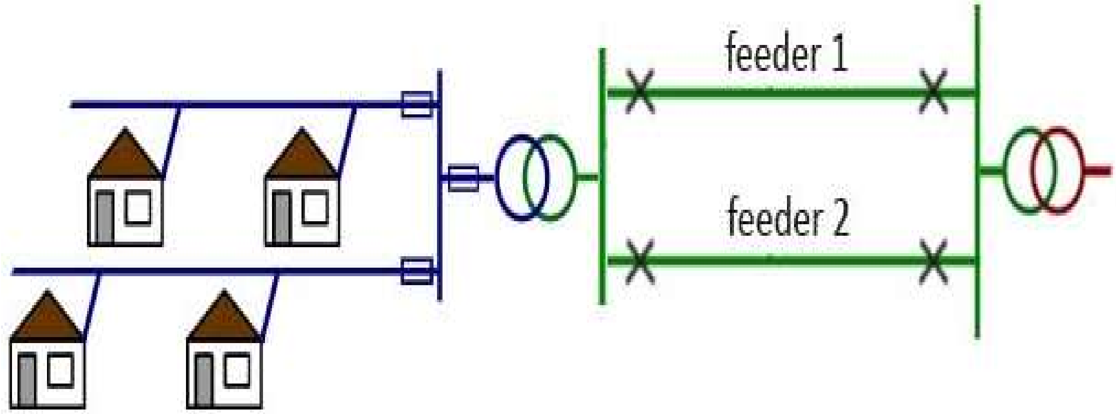


Figure 1.5: Parallel feeders distribution network

(iii) Ring Main Electricity Distribution Network

This low voltage side of radial electricity distribution network can be computed by inducing a KCL and KVL laws. Now one ring system of wholesalers is fed by more than one feeder. For this circumstance, if one feeder is under inadequacy or backing, the ring distributer is as yet supplied by various feeders related with it. The supplying source to the purchasers isn't disturbed despite while any feeder winds up out of organization. Despite that, the ring standard system is in like manner outfitted with different portion withdraws at different sensible core interests. In case any fault occurs on any feeder of the ring, this segment can be separated by opening the related segment isolators on the two sides of the defective zone transformer straightforwardly. Figure 1.6 shows ring electrical power distribution network.

Thusly, supply to the purchasers related with the sound zone of the ring without quite a bit of a stretch is kept up despite while a portion of the ring is under the closure. The number of feeders related with the distribution network depends upon the associated components.

- **Maximum Demand of the System:** If it is higher, a greater number of feeders feed the ring.

- **Total Length of the Ring Main Distributors:** If length is more, more feeders to be integrated with the ring framework to compensate the voltage drop.
- **Required Voltage Regulation:** The number of feeders connected to the ring is also dependent upon the allowable voltage drop of the line.

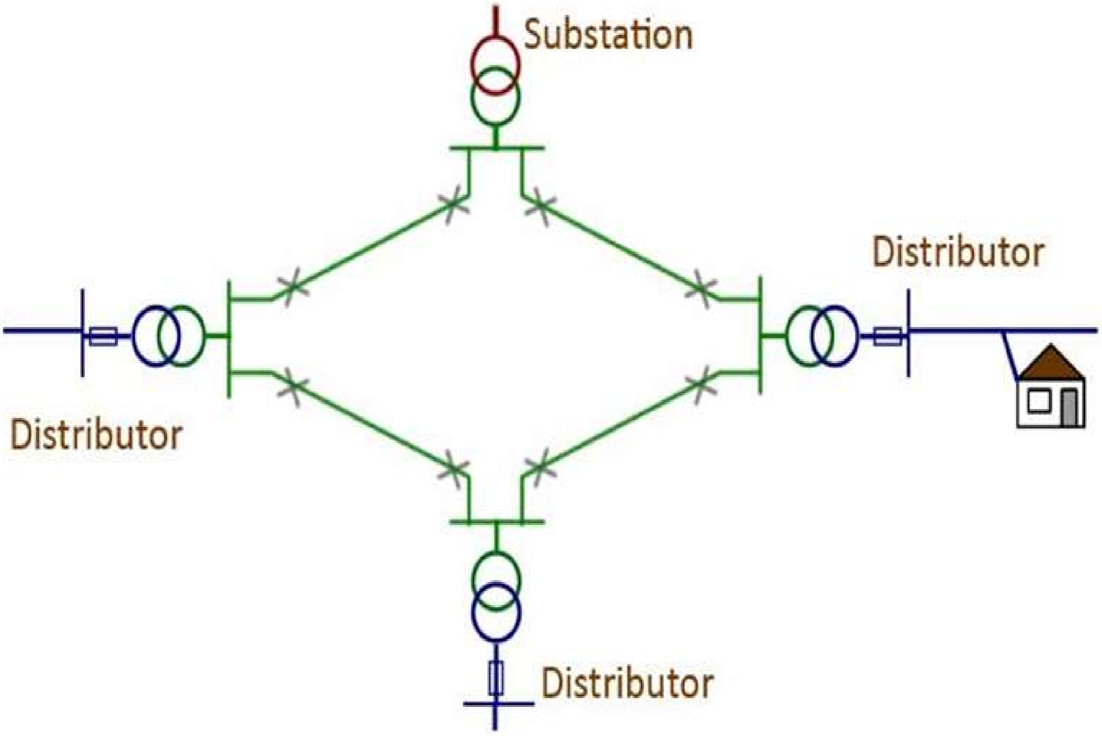


Figure 1.6: Ring electrical distribution network

(iv) Meshed Electrical Power Distribution Network

In transmission and sub transmission networks, typically similar, ring or intersected (work) networks are utilized, which guarantees electric supply provision for clients in case of failure of a transmission line or component. This general standard is that where enormous loads or quantities of clients are included, at that point some type of reserve, as conscious repetition, is incorporated with the system plan, using parallel, coincided or ring type feeders.

1.2.2 POWER DISTRIBUTION NETWORK

A distribution substation is situated close to or inside any city/town /modern territory. It gets power from a transmission network. The high voltage from the transmission line is then ventured somewhere near a stage down transformer to the essential distribution level voltage. Essential distribution voltage is generally 11 kV, yet can run between 2.4 kV to 33 kV relying on purchaser.

A commonplace power distribution network comprises of the following.

- Distribution substation
- Feeders
- Distribution Transformers
- Distributor conductors
- Service mains conductors

Alongside these, a distribution network likewise comprises of switches, security hardware, estimation gear and so forth.

- **Distribution feeders:** The stepped down voltage from the substation is conveyed to distribution transformers by means of feeder conductors. By and large, no tapings are taken from the feeders so that the voltage remains uniform throughout. The principle thought in structuring of a feeder conductor is its current capacity limit.
- **Distribution transformer:** A distribution transformer gives last change in the electric power distribution network. It is fundamentally a stage down 3-stage transformer. Distribution transformer steps down the voltage to 400V/230 V. Here it implies, voltage between line to the neutral is 230 V and line to line voltage is 400 V. In USA and some different nations, 120/240 V distribution network is utilized.
- **Distributors:** Distributor conductor transfers the output from a distribution transformer. Tapings are taken from a main conductor for

power supply to the end customers. The current through a main conductor isn't consistent as tapings are taken at different places all through its length. In this way, voltage drop along the length is the principle thought while planning a merchant conductor.

- **Service mains:** It is a little link, which associates the merchant conductor at the closest post to the buyer's end.

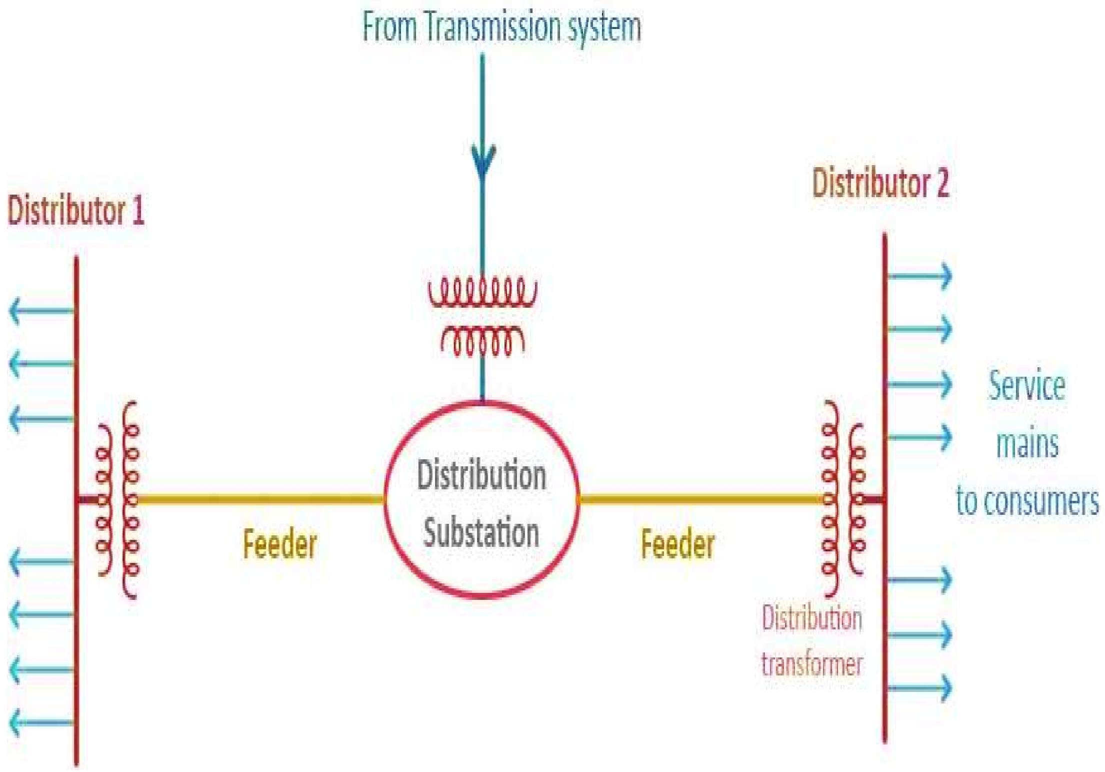


Figure 1.7: Simple radial AC power distribution network

Figure 1.7 shows a simple radial AC power distribution network, which does not show other equipment like circuit breakers, measuring instruments etc. for the simplicity purpose.

(i) Primary Distribution

It is that piece of an AC distribution network, which works at to some degree higher voltages than general private buyer use. Ordinarily utilized essential distribution voltages in many nations are 11 kV, 6.6 kV and 3.3 kV. Essential distribution handles huge purchasers, for example, production lines and businesses. It additionally sustains little substation from where auxiliary distribution is completed. Essential distribution is done by 3-stage, 3-wire network.

(ii) Secondary Distribution

This part legitimately supplies to the private end shoppers. Local buyers are sustained with single stage supply at 230 V (120 V in USA and some different nations). Three stage supplies may likewise be given at 400 V to enormous properties, business structures, little manufacturing plants and so forth. Optional transmission in many nations is completed by 3-stage, 4-wire network.

1.3 OPTIMAL CAPACITOR PLACEMENT AND SIZING

Capacitors in power networks are commonly used to supply reactive power with the end goal of loss minimization and voltage profile improvement. The perfect integration of capacitors is likewise significant in order to guarantee that network power loss and complete capacitor expenses can be decreased. The primary goal of this analysis is to decide optimal arrangement of capacitors in order to reduce the power loss and improve the voltage profile [9]. The utilization of shunt capacitor in distribution feeders has dependably been a significant research zone. It is on the grounds that a segment of power loss in distribution networks could be reduced by adding shunt capacitors to supply a piece of the reactive power required. The advantages of capacitor arrangement in distribution networks are power factor improvement, node voltage improvement, power and energy loss reduction, feeder and network limit discharge just as power quality improvement. The degree of the previously mentioned points of interest of capacitor situation relies upon how capacitors are designated and controlled under conceivable stacking conditions. This implies the advancement issue, to be specific, capacitor situation issue ought to be detailed with the ideal target work, (for example, loss minimization) and different specialized requirements (for example the points of confinement of voltage levels and power flow). From that point onward, the best possible arrangement methods ought to be connected to all by deciding the optimal number, area, type, size and control settings at different sizes of the capacitors to be introduced [10, 11].

The loss minimization in distribution networks has attracted more interesting feature because it improves the performance of distribution network. Studies have demonstrated that as much as 13% of total power generated is spent as loss at the distribution level [12]. To diminish these losses, shunt capacitor banks are introduced on distribution essential feeders. The favorable circumstances with the expansion of shunt capacitors banks are to improve the power factor, feeder voltage profile, power loss decrease and increments accessible limit of feeders. Hence it is essential to discover optimal area and sizes of capacitors in the network to accomplish the previously mentioned goals. Since, the optimal capacitor situation is a confounded combinatorial optimization issue, a wide range of improvement strategies and computations have been proposed earlier.

1.4 LOSS REDUCTION

After deregulation of the electrical power industry, the distribution supply has stayed as a directed restraining infrastructure. Due to the deregulation procedure, distribution utilities are at present confronting expanded weights from investors and administrative experts to improve venture and operational productivity [13]. The conveyance of power from sources to the customer is constantly put with power losses. Power losses in distribution network can represent as much as 13% of the created energy [14].

Such non-irrelevant measure of losses directly affects the budgetary issues and the general proficiency of distribution utilities. Accordingly, strategies for reduction of losses are basic for accomplishing the money related objectives of distribution organizations. Distribution power losses can be classified as technical and non-technical (commercial) losses.

- **Technical losses:** The losses that happens normally and rely on the kind of transmitter utilized, transformer limit, and other part utilized for transmission and distribution of electricity. These losses are inalienable to the distribution of electricity and cannot be dispensed with however can be decreased. These losses are expressed as losses that happens because of warmth dispersal coming about because of current passing through conductors and attractive losses in transformers.

- **Non-technical losses (Commercial losses):** The losses that happens in light of illicit utilization of electricity. These are caused because of error in perusing of meters, theft of power, error of meter and wastefulness in gathering of bills. Non-installment, as the name suggests alludes to situations where clients reject or unfit to pay the bill for their electricity utilization. It is evaluated that electricity robbery costs in our nation is a hefty amount in a year.

  High specialized and non-specialized loss rates may result in [15]:

  (i) Poor regulatory character provided to customers.
  (ii) High cost due to self-defeating or premature speculation.
  (iii) Earnings reduction leading to payment disruptions with all the resulting commodity effects.

Real power losses cause the states' money related burden. Decreasing the losses and achieving a satisfactory dimension will reestablish the certainty of loan specialists and private speculators to urge them to take an interest monetarily in the improvement of the power area. In this manner, the decrease of specialized losses prompts a genuine addition in energy and diminished capital-serious ventures. Again, the reduction of sub-specialized losses does not only improve the organization’s expenditure equality, but also the heap bend by revealing the use of the levy guideline [16].

1.5 RESEARCH GAPS

The detailed literature survey has been presented in Chapter 2. A challenge for power system planners and scientists was the issue of locating and sizing shunt capacitors in distribution networks. In the literature it has been presented these problems, many published papers and reports were discovered. Different methodology formulations were used to address this challenging combinatorial issue. Unbalanced working circumstances and the existence of harmonic sources in the distribution networks complicate the issue of capacitor positioning and sizing further. In many of the research undertaken on the issue of capacitor optimization, these problems have been overlooked. Many methods for solving the issue of capacitor positioning have been created: analytical techniques, numerical programming, methods based on heuristic or artificial intelligence (AI). Heuristic or AI optimization techniques have been commonly used among these methods to address the ideal issue of capacitor positioning. AI is a strong knowledge-based strategy that can solve practical non-linear system. AI can reduce the complexity of mathematics and has a rapid response that can be used to analyze transients. Different capacitor allocation methods are discussed here. Classical techniques have been discovered to be easier but have disadvantages such as slow convergence, and large number of variables requirement. AI techniques, on the other side, are quick and flexible. These techniques are appropriate for both large and nonlinear systems.

1.6 AIM OF THESIS

The goals of the thesis remain as below:

- To develop a fuzzy inference system and hybrid ABC-PSO computation for optimal capacitor placement and sizing in radial distribution network.
- To determine the sensitive nodes of any radial distribution network for optimal capacitor placement for reduction of loss of the network.
- To provide expansion of a distribution network using particle swarm optimization (PSO) and loss reduction of the network.

1.7 PROBLEM STATEMENT

Capacitors are used in distribution networks to provide reactive power compensation to decrease power losses and keep a voltage profile within acceptable boundaries. In radial distribution networks, the ultimate goal is to determine the optimum location and size of the shunt capacitors in order to maximize loss reduction and minimize total cost. The issue is to determine the best shunt capacitor size and location in a radial distribution scheme by minimizing expenses owing to energy failure and installation of the capacitor. The proposed methodology presented in this paper aims at optimizing distribution network technical features by minimizing power losses, maximizing voltage stability and enhancing voltage profiling in a specified radial distribution network.

1.8 ORGANIZATION OF THESIS

The entire thesis will contain the subsequent chapters:

Chapter 1: In this chapter introduction of distribution network, loss reduction will be carried out.

Chapter 2: In this chapter literature survey of load flow, classification and optimal allocation of capacitor allocation and optimization of the electric power distribution network will be introduced.

Chapter 3: In this chapter a problem formulation will be carried out using fuzzy based load flow studies. The load flow will be utilized for computing the real and reactive power flow, voltage of all nodes and a FIS besides hybrid ABC-PSO based optimal capacitor placement and sizing aimed at radial distribution networks is discussed along with its results

Chapter 4: In this chapter an effective design and development of hybrid ABC-CSO based capacitor placement with different objective function and comparison of the results with that obtained by hybrid ABC-PSO algorithm.

Chapter 5: In this chapter the expansion of distribution network is carried out by using PSO algorithm and the size selection of capacitors are carried out by hybrid ABC-CSO algorithm for different loading conditions. The effect of load growth has also been presented.

Chapter 6: In this chapter the overall conclusions of the research work and future possibility of the further research direction have been presented.

CHAPTER-2

LITERATURE STUDY

2.1 LITERATURE SURVEY ON LOAD FLOW ANALYSIS OF RADIAL DISTRIBUTION NETWORK

Murari ***et al.*** [17] displayed a novel load flow computation for AC-DC distribution networks. Four created networks, loads beyond branch [LB] matrix, path impedance [PI] matrix, path drop [PD] grid, slack node to other node drop [SBOBD] matrix and basic network activities are used to get load flow analysis. These networks uncover the system topology and significant data about the conduct of AC-DC distribution network during load flow analysis. Conversely with conventional load flow analysis for HVDC networks, the procedure does not require any lower upper (LU) deterioration, network reversal and forward in reverse substitution of Jacobian lattice. Due to the previously mentioned reasons, the suggested method was computationally proficient. The proposed strategy had been tried to utilize a few contextual analyses of AC-DC distribution networks, which incorporated diverse working methods of different power converters.

Prasanna ***et al.*** [18] illustrated that distribution network load flow studies were different from those of transmission structure, due to its high R/X ratio and radial nature. Several methods had been proposed earlier for doing that distribution load flow studies, but fast load flow algorithms with better results were always needed. That paper presented load flow algorithms for radial as well as weakly meshed distribution networks with and without inclusion of distributed generations and those were based on backward forward sweep method and matrix-based method i.e., bus injection to bus current/ branch current to bus voltage (BIBC/BCBV). Attention was given to number of iterations being taken for convergence, applicability for weakly meshed networks and applicability for distribution networks having distributed generations where distributed generations are modeled as either PQ model or PV model. That paper presented various modeling techniques used for distribution load flow algorithms, which were available in the literature.

Muruganantham ***et al.*** [19] prescribed that the worldwide climatic change was one of the key issues looked by all nations today. Customary power plants were producing undesirable gases to the earth, which was the primary purpose behind the climatic change. Numerous nations had changed their approaches and had expanded their help for green emissions. Huge scale speculations had been arranged towards establishment of Distributed Energy Resources (DER) in the Distribution Network (DN). Among the different DER sunlight-based power was increasingly foreseeable an abundant source of energy. That paper underlined the effect of sunlight-based PV combination in a functional distribution network under consistently factor load design. The load flow analysis was executed through Forward/Backward Sweep (FBS) computation, which was progressively appropriate for a radial network. To get the dynamic conduct of the network, time arrangement investigation was performed. The viability of incorporation of sun-oriented PV was approved in 123-node distribution network. The outcomes uncover the voltage enhancement achieved in the system through incorporation of sunlight-based PV at the chosen locations. The load flow analysis was completed with and without associating sun powered PV in the feeder. The load flow was performed for 24 hours' time venture with various load designs.

Mumtaz ***et al.*** [20] proposed that the micro grid innovation was an alluring alternative towards understanding the developing solicitation of power later on. However, the grid coupled micro grid encounters basic steadiness issues during a deficiency in the primary grid, confinement of the micro grid was the most extreme operational arrangement adjusted. The distributive generation sources are meteorologically dependent thus they are vulnerable to inconsistencies and system overloading. Traditionally, when the microgrid system is implemented many more issues emerge, which should be addressed. That paper proposed the CIGRE benchmark micro grid model, which was a 14-node network that was contained eight close planetary systems with an alternate rating, two battery banks, four synchronous production having diverse power rating, a breeze turbine generator all associated with the fundamental grid. That CIGRE model was 110 kV power network that was created and reenacted in ETAP programming. For electrical power system operation and planning, the load flow analysis is important and essential to investigate the problems in order to increase the safety and reliability of the system. This research focuses on a comprehensive analysis with the help of ETAP software that executes numerical computations of integrated systems at large scale with a stupendous speed. Also, reports were produced, which was useful in executing micro grids. The load flow analysis was carried out by Newton-Raphson method. The outcomes had been approved, which demonstrated that all the examination performed were productive and optimized. The CIGRE Micro Grid Model had been implemented in ETAP programming and the load flow analysis had been carried out to investigate its voltage stability, the power flow both active and reactive among every one of the nodes.

Georgilakis ***et al.*** [21] recommended power flow analysis, which was the basis of power system examination and plan. Power flow analysis was required for different types of investigations, for example, transient steadiness, optimal power flow and possibility studies was talked about. Power flow analysis was a significance method including numerical investigation connected to a power system. In that analysis, iterative strategies were utilized since there was no realized investigative strategy to tackle the issue. In that analysis, iterative systems were utilized due to there was no realized explanatory technique to take care of the issue. In the load flow method nonlinearity came into account. In that paper, a productive method for tackling the load flow issue of a distribution network was proposed. The proposed technique was contrasted with the existing methods.

Shrestha ***et al.*** [22] illustrated the primary distribution network aimed at energy admission to the affected part of 900 MW Upper Karnali Hydropower Project (UKHPP) located in western Nepal. Previously conducted studies identified the optimal network of the primary distribution network for rural electrification of affected area of UKHPP, and analyzed the system's characteristics by developing a network on MATLAB for Static Load Flow Analysis (SLFA) depending upon Newton- Raphson (N-R) method. The SLFA was done based on N-R technique and combination was come to in the third iteration. From that investigation, it was discovered that 2.60378 MW of dynamic power and 2.30945 MVAR of reactive power was required to zap the influenced zone of UKHPP. Additionally, there were 0.054756 MW of real and 0.01641 MVAR of reactive power losses in the network. For result confirmation, the acquired outcomes were checked with the consequence of past MATLAB system utilizing factual analysis at 95% certainty interim of the distinction.

Husain ***et al.*** [23] discussed another proficient strategy for taking care of the load flow issue of a distribution network that based upon the system topology. The fundamental commitment was to suggest an effective load flow technique for radial and weakly meshed distribution networks and to evaluate the influence of load prototypes, various appraisals of X/R ratios, load improvement for further expansion and conflict levels and in addition, to examine the impact of number of loops on weakly meshed distribution networks and moreover provides correlation of radial and weakly meshed distribution networks. The consequences acquired for voltage magnitudes, absolute real and reactive power losses, time of computation, and number of iterations required. Effectiveness of the proposed load flow method had been demonstrated on 33-node radial and meshed distribution networks. In that paper, another effective technique for taking care of the load flow issue of a distribution network was suggested that was ZIP model. That strategy was contrasted with the existing techniques and it had been demonstrated to be predominant in the quantity of cycles, computationally proficient, and the power of union while the arrangement exactness was very much kept up. The ZIP load flow approach was in close concurrence with the current strategies.

Buayai ***et al.*** [24] presented and applied the theoretical structure of the novel integrated arrangement device proposed for Geographic Information Systems (GIS)-dependent distribution network load flow. The PC-based arrangement consolidated the current GIS and distribution load flow's systematic capabilities. It had been used for distribution feeder features to the input data. The load flow analysis was implemented in MATLAB and embedded in a GIS (Arc View) application. That GIS like drawing tool has the capability to partially display a system based on different layers. The preparation capabilities of GIS and the ability of the network to control geo-referenced information and results in different configurations and models made them reasonable for the distribution network planning and task. Different operators were involved in the planning and utilization of the distribution network, thus enabling professionals, services and speculators to become GIS customers. The GIS-dependent distribution network load flow shown in that paper was a perfect tool for conducting the investigation and reviewing the outcome of a guide superimposed on other geographic layers. It was allowed to take a shot at the real network by connecting the output to the load and feeder region. Visual data estimation was that human knowledge could be firmly attached to the number space. It would become a fundamental tool for utility officials and the general population together with the use of energy systems. In addition, it could be combined in an ideal distribution network arrangement.

Muruganantham ***et al.*** [25] clarified that the control portion was in its rapidly developing phase to meet the growing power requirement. The common system had been updated from an uncompensated system to a functioning system with the mixture of Distributed Energy Resources (DER) in the Distribution Network (DN). The system encountered high R/X ratio with high DER infiltration, unpredicted source variety with consistently varied loads. With each of these difficulties, control lattice was resolved to provide customers with high-quality capacity and maintain network security. Load flow studies were important to analyze the system's operation. That paper analyzed the operation attributes of Newton-Rapson (NR) method and Forward/Backwards Sweep (FBS) method with a variable load design. The exhibition of the methods was assessed in a 13-node test feeder.

Idoniboyeobu and Ibeni [26] conducted a research for load flow analysis study of Port Harcourt Town Zone. It was fundamental for arranging, activity, future extension of the system and trade of power between utilities. The examination was done to tackle the issue of successive power blackouts brought about by substantial I^2R losses in the line. Low voltages were experienced at purchasers end just as, poor power factor at load end, over-loading of feeder transformers, lacking size of conductors at buyer's end of the system in Port Harcourt Town, 33 kV distribution network. The application programming called Electrical Transient Analyzer Program (ETAP) was utilized to demonstrate the system's output. It was seen that, the two outcomes acquired were comparative. A 24.6% decrease of the total real power losses was acknowledged after injection of reactive power into the under-voltage network, the network voltage profiles were standardized as saw in results. The outcomes acquired on every feeder would help the network engineer during task and future extension of the system under thought.

2.2 LITERATURE SURVEY ON OPTIMAL CAPACITOR ALLOCATION IN RADIAL DISTRIBUTION NETWORK

Berat [27] described power flow analysis as estimations on characterizing trademark properties of enduring state working circumstance of distribution networks. This study power flow analysis of a power distribution network, under fault conditions was discussed. Three phase-to-ground faults are applied on various points of 9-node distribution network, which was designed under MATLAB/Simulink platform. The outcomes were contrasted with typical working conditions. Power flow analysis is one of the most important computation during both design and operating sections of a power system. In that study, effects of faults on power flow analysis parameters, which were voltage amplitude and phase angle, of a distribution network was investigated. The 9-node distribution network was tested in MATLAB/Simulink platform.

Kannan ***et al.*** [28] presented the issue of capacitor portion for loss reduction in distribution networks in the course of recent decades. That document described the investigation growth and gave an evaluation of the rational thinking and accuracy of the computations of the capacitor position using fuzzy logic. The expectation of that paper was to allocate optimal capacitors and to give specialists and utility architects further knowledge into the decisions of accessible capacitor portion procedures and their individual advantages and disadvantages. That paper arranged a significant number of the capacitor position computations, features their focal points and inadequacies, and gave a down to earth manual for capacitor allotment that utility architects and analysts could utilize.

Tyagi ***et al.*** [29] presented a strategy to reduce the losses of Kotuli town's distribution network in the Uttrakhand (Almora region), India. The field survey was performed to reflect on the state of the feeder and network of delivery. The municipal distribution feeder by and big supplied the lighting and farming loads of the family unit. Exact perceptions had been made and recommendations for usually speaking loss reduction policies prompting further enhancement of the network's by and big skills. After perception in the city it was discovered that there was an irregular distribution network and losses of the network were observed to be exceptionally large and only by altering the distribution transformer position closer to the load center and replace the equal with the energy productive transformer and there was an enormous reduction in the distribution line loss and even the reward was under four years.

Sultana ***et al.*** [30] determined solar oriented power activities and advancements for a nation as enormous as India is troublesome because of the contribution of various empowering agents. The choices of these empowering influences will impact the plan of systems to energize sun-oriented power improvement in India. The present study work basically analyzed Indian sun-oriented energy enhancements that would promote more prominent use in India's intensity and transition scenario to perceive and assess important empowering influences. This work identifies sixteen solar power enablers based on relevant literature and experts′ inputs. That work distinguished sixteen power empowering agents that were sun-oriented depending on applicable writing and inputs from experts. That research would allow policymakers to make detailed decisions about starting and energizing advances in sun-based energy in India.

Mendoza ***et al.*** **[**31] introduced an algorithm based on the methodology of Particle Swarm Optimization (PSO) to fix ideal capacitor allocation and distribution network sizing problems. The objective function was to minimize actual power losses, operating costs, fixed costs and thus improve the quality of voltage. Two PSO algorithms were used in their method, the first one was to determine the optimal allocation of capacitors and the second one was to optimize sizing of capacitors. That algorithm was performed on 34-node and 85-node radial distribution networks. The loads were regarded as steady loads of energy. Results showed the effectiveness of the proposed algorithm based on PSO alternative procedure.

Siddiqui ***et al.*** [32] explained that congestion management was a noteworthy issue because of operational imperatives. Flexible AC Transmission Systems (FACTS) devices could be a choice to control the power flow in congested lines. That paper investigated the utilization of two prevalent FACTS devices, TCSC and STATCOM for power flow control in electrical network and their capacity to decongest the network. It separately suggested the ideal TCSC and STATCOM region to relieve blocking with minimal power losses, voltage regulations and system costs. The proposed technique had been tested on a 14-node network for its adequacy.

2.3 LITERATURE SURVEY ON OPTIMIZATION OF RADIAL DISTRIBUTION NETWORK

Ponnavaikko ***et al.*** [33] solved the electricity distribution network extension planning problem (EDNEPP) using a mixed binary integer programming (MBIP) plan, where the system's enduring state activity with non-straight science articulations was exhibited. The non-straight conditions were linearized using piece-by-piece linearization of nonlinear articulations to ensure computational resemblance of the model. Linearized detailing was verified to ensure optimal response and level of deviation from error. The suggested detailed system model reflected on the choice of establishing new transformers with distinct capacities to efficiently reinforce current transformers at system substations, selecting and developing new substations with feasible fields, re-conducting current feeders in the scheme, developing new feeders with distinct kinds of conductors, losing energy costs. The intrusion expense would comprise a price word called “altruism cost” that was put into the model definition to measure the shoppers’ loss in certainty to influential merchants because of the interfered supply of power that was pervasive in the creation of nations. Two test networks having 23-node and 54-node were used to demonstrate the system model definition's efficiency. Their method launched a mixed binary linear programming (MBLIP) model for the arrangement of the electrical distribution scheme. That would fill in as an important tool for creators and economic experts in the organization of the electric power network, as it was possible to work around that model with steady fundamental management strategies, to obtain an enhanced system, price plan throughout the system network's life expectancy.

Rosell ***et al.*** [34] displayed an enhancement issue, which empowered fulfillment of distribution network administrator demands on adaptability. That was a basic leadership issue for another aggregator type called Smart Energy Service Provider (SESP) to plan adaptable energy assets. That aggregator worked a neighborhood power showcase with high entrance of appropriated energy assets. The enhancement activity issue of SESP was figured as a mixed integer linear programming (MILP) issue and its presentation had been tried by methods for the recreation of experiments in a local market. The novel problem had also been validated in a micro grid laboratory with emulated loads and generation units. The performed tests delivered positive outcomes and demonstrated the adequacy of the proposed arrangement. The coordination of DER into the distribution networks could prompt specialized issues influencing the power quality.

Xie ***et al.*** [35] illustrated that the advancement of the active distribution system (ADS) and multi-micro grids (MGs), expanding quantities of conveyed energy sources were associated with distribution network (DNs) utilizing MGs. DN and MG's challenge held a colossal test to effectively dispatch energy systems. They proposed an autonomous optimization model of the dynamic distribution network with MGs based on the hypothesis of analytical target cascading (ATC) for the strong decentralized and self-sufficient normal for ADS. DNs and MGs were considered to be topics of different intrigues. Given their point-by-point models, it was proposed that the ATC hypothesis decoupled the dispatch of DNs and MGs by displaying the tie-line flow as a pseudo-generator / load, with the objective that MGs and DNs could use their particular assets independently to enhance their activity and monetary benefits. By using chance-compelled programming, different unsafe parts were also regarded. To show the adequacy of network computation, a modified 33-node distribution network and a real territorial DN were focused.

Jeong ***et al.*** [36] presented a consolidated use of Geographic Information System-Multi-Criteria Decision Analysis (GIS-MCDA) and the Fuzzy-Decision-Making Trial and Evaluation Laboratory (F-DEMATEL) strategy to distinguish reasonable and good destinations for biomass offices as far as long haul supportability. The main criteria established in their methodology were demonstrated, evaluated, weighted and allocated to three assemblies of criteria: natural, geophysical and monetary assemblies. In F-DEMATEL's participatory strategy, considerations and their strength statistics were determined as to their impact. After applying the Weighted Linear Combination (WLC), the most reasonable areas were obtained.

Venkatesan ***et al.*** [37] suggested an optimal power flow control technique for Hybrid Renewable Energy Systems (HRESs) such as a combined photovoltaic and wind turbine frame with energy storage. The optimal control technique suggested was the joint execution of the Whale Optimization Algorithm (WOA) as well as the Artificial Neural Network (ANN). Here, the ANN learning method was enhanced by using the WOA optimization method for the core disaster attack job and named as WOANN. In perspective of the dynamic and reactive energy variation in the load side, the suggested WOANN predicts the HRES ' necessary control gain parameters to maintain the energy flow. In order to predict control, acquire parameters, the suggested technique considers demands for power balance such as the availability of sustainable energy sources, the storage situation of the load element, and the demand for load side energy. By using the suggested technique, control flow varieties were restricted between the source side and the load side as well as HRES ' operating expenses in light of week after week and day by day expectation network energy expenses. The suggested method was carried out in the operating phase of MATLAB / Simulink and the viability was dissected by means of the correlation analysis utilizing the current methods.

Kumar ***et al.*** [38] implemented two new computations to explain the optimal placement of capacitors in radial distribution networks in two distinct ways: ideal positioning of fixed capacitor banks (Variable Locations Fixed Capacitor banks-VLFQ) and ideal measurement and positioning of capacitors (Variable Locations Variable Capacitors-VLVQ) for real energy loss minimization and system investment funds boots. The two bio-motivated computations BAT algorithm and Cuckoo Search (CS) algorithm searched for each conceivable region in the network alongside the different capacitor dimensions in which the optimal capacitor sizes were selected as normal dimensions that were market-accessible. The suggested computations were linked to the conventional 34-node and 85-node radial distribution networks in order to verify the practicality. The methodologies suggested were suitable for providing superb agreements with excellent union execution.

CHAPTER-3

OPTIMAL CAPACITOR PLACEMENT USING FIS AND HYBRID ABC-PSO

3.1 INTRODUCTION

About 13% of the all-out electricity production is lost as I^2R loss in the distribution level. Capacitor establishment has demonstrated that it has essentially decreased the power loss and enhanced the voltage profile. Consequently, it will reduce the flow of power from the feeder [39]. Inappropriate placing of the capacitor decreases the advantages of the network and significantly imperils the whole network task regulation [40–42].

So as to find the shunt capacitor in the distribution network, appropriate locations are to be selected, size and number of capacitors is to be introduced, to such an extent that maximum benefits of the system can be achieved at the same time satisfying all the constraints. There are a number of methods available to solve the capacitor installation in distribution network. The main problem in installation of shunt capacitor on radial distribution network lies in how to determine the optimal location and size of the shunt capacitor. As of late numerous techniques and optimization computation have been proposed so as to locate the optimal capacitor position issue. Plant development advancement was presented for optimal assignment of capacitor with the goal of improving voltage profile and decrease of power loss [43].

GA was used to find the optimal measurement at different load concentrations of the fixed and exchanged capacitor [44-47]. Fuzzy based GA was used to determine the optimal dimension with the multi objective of restricting the price of energy and upgrading the network's voltage profile [48]. Direct investigation computations were conducted to locate the appropriate nodes and optimal sizes of the capacitors and were tested on 22-node, 69-node, 85-node radial distribution networks with the objective of expanding net reserve funds and reducing the power deficit [49].The computation of ACO was suggested to clarify the position of the capacitor in the radial distribution network [50]. Devabalaji ***et al.*** [51] suggested the enhancement computation of the bacterial search to place the shunt capacitor in 25-node and 37-node radial distribution networks to reduce the loss of the networks and to enhance the voltage profile of the networks. Antunes ***et al.*** [52] suggested the evolutionary algorithm to integrate the capacitors in radial distribution networks for loss reduction of the networks. Mohammad ***et al.*** [53] presented the Supervisory Control and Data Acquisition (SCADA) with a fuzzy-based system to determine the reasonable capacitor required to upgrade the power factor in accordance with the deliberate parameters. Prakash and Sydulu [54] used particle swarm optimization and decided on the capacitor bank's optimal size to reduce energy loss. Nojavan ***et al.*** [55] proposed a mixed number nonlinear programming method to determine the optimum capacitor location and size to limit the power shortage and expanded the net benefits. All the above suggested methods have achieved encouraging results in solving the capacitor placement in radial distribution network for loss reduction of the radial distribution network. In any case, they additionally have inadequacies in certain regards, for example, computational time in comprehending capacitor and in particular, only light, medium and normal distribution network loads are carried out by each of the researchers. It is noteworthy that the ideal capacitor size will shift with each slight change in load.

The traditional load flow strategies utilized for power systems are as per the following.

1. Gauss-Seidel method with admittance matrix (YGS)
2. Gauss-Seidel method with impedance matrix (ZGS)
3. Newton-Raphson (NR) method
4. Decoupled Newton-Raphson (DNR)

5. Fast Decoupled Newton-Raphson (FDNR)

The above-mentioned methods usually fail to analyze distribution networks, because the admittance matrix (YBus) of the network is sparse and R/X ratio and loading of the feeders is higher. Accordingly, Backward/Forward Sweep (BFS) techniques are normally utilized. BFS strategies needn't bother with Jacobian lattice dissimilar to NR techniques. In any case, ordinary BFS is not helpful for present day dynamic distribution networks. In order to adapt the above circumstances, the main target here to show another operation using the Loss Sensitivity Factor (LSF) method and the Hybrid ABC-PSO computation for the positioning of optimal sized capacitors on the main feeders at the appropriate nodes of the radial distribution networks to reduce power losses and enhance the voltage profile. The proposed system comprises of three phases for the optimal capacitor position issue. They are

1. LSF approach to find the sensitive node,
2. FIS to find the capacitor location and
3. Hybrid ABC-PSO for optimal capacitor sizing.

In the primary stage, LSF approach is utilized to find sensitive nodes of the distribution networks. The capacitor arrangement strategy involves the identifiable evidence of the capacitor position region and the size of the capacitor to be inserted in the distinguished region. A lot of values provided by the Fuzzy Inference System (FIS) to choose the appropriate nodes where the capacitors should be placed. Capacitor area problem is a nonlinear problem and ANFIS approach is selected as a consequence.

3.2 FIS AND HYBRID ABC-PSO BASED OPTIMAL CAPACITOR PLACEMENT AND SIZING

In distribution networks, capacitors are widely used to reduce power losses, enhance the voltage profile and increase the system capacity. The benefits of compensation depend greatly on the placement and size of the added capacitors. A new comparative approach is proposed for the determination of the sensitive nodes on the primary feeders of the radial distribution network for optimal capacitor placement so as to reduce the power loss, energy loss and to improve the voltage profile. Another technique utilizing Loss Sensitivity Factor (LSF) method and Hybrid ABC-PSO computation for the placement of capacitors in radial distribution networks is carried out to reduce the power losses and to increase the voltage profile. The proposed method comprises of three phases for the optimal capacitor placement issue. These are Fuzzy load flow analysis to compute real power loss, reactive power loss and energy loss, LSF method to deal with locating the sensitive node, Fuzzy inference system (FIS) finds the exact locations of capacitors and Hybrid ABC-PSO algorithm decides the optimal capacitor sizing. In the primary stage, Fuzzy load flow analysis to discover real power loss, reactive power loss and energy loss and then LSF approach is utilized to the sensitive node of the distribution networks. The proposed strategy will be tried on various distribution networks and the outcomes will be presented and juxtaposed with other available methods.

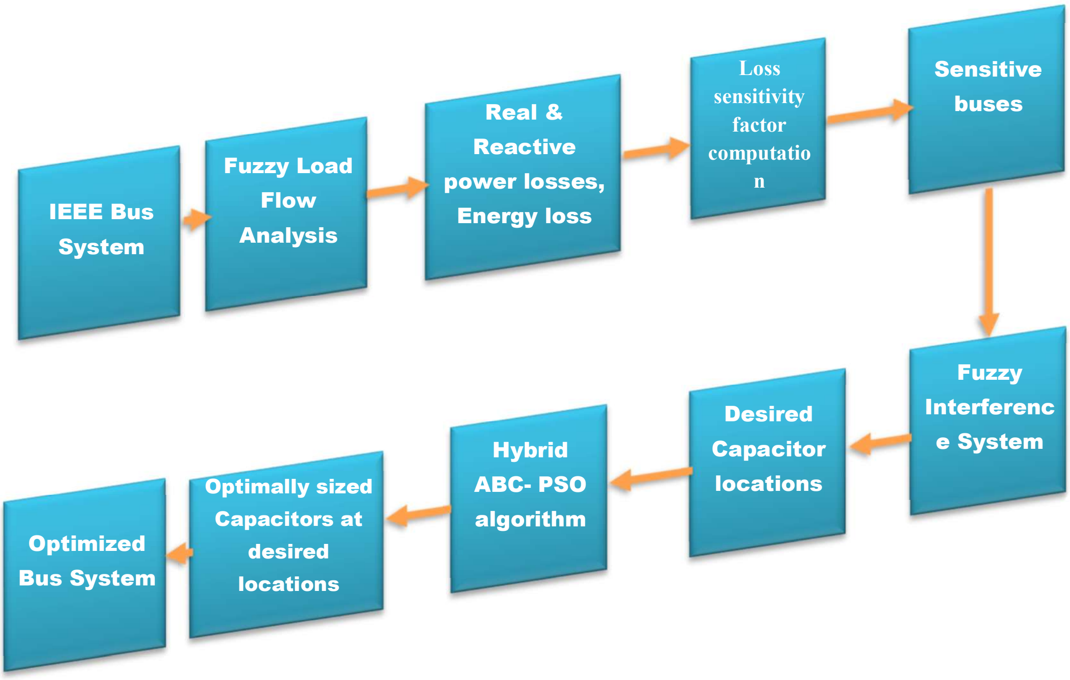


Figure 3.1: Overview of the proposed FIS and hybrid ABC-PSO based optimal capacitor placement and sizing

3.2.1 FUZZY LOAD FLOW ANALYSIS

The load flow analysis ends up supportive for the plan and activity of the radial distributed network (RDN). Anyway, there is a probability of errors because of the regular load flow analysis. In order to bear such errors, fuzzy system was brought into the load flow analysis. The fuzzy load flow analysis employs the fuzzy logic controller that will update the state vector of the system repeatedly. In fuzzy load flow analysis, the crisp input values are fed to the fuzzification process and based on the rules formulated fuzzy output will be obtained and finally they can be defuzzified using some method of centroid computation. The fuzzy logic controller (FLC) utilized for this procedure is shown in Fig.3.2.

3.2.1.1 FUZZY LOGIC

Fuzzy logic is a logic, which manages uncertain worth that lies between [0,1]. The genuine number, which is more genuine, is closer to 1 and closer to 0 on the off chance that it is less valid. The certainty is called level of enrollment of that amount. The articulation about any amount in our everyday life isn't exact. Fuzzy logic is the logic according to the correspondence language about certain amount, which is not exact. Zedeh in 1965 for the first time worked at fuzzy logic [56].

In fuzzy set every one of the components in that set is related with a level of enrollment grade in the middle of 0 to 1. On the off chance that the evaluation is 0, at that point the component does not have a place with that fuzzy set. On the off chance that the evaluation is 0, at that point component clearly have a place with that fuzzy set. The level of enrollment is chosen by participation work, indicated by $\mu_A(x)$, where x is the component of fuzzy set A.

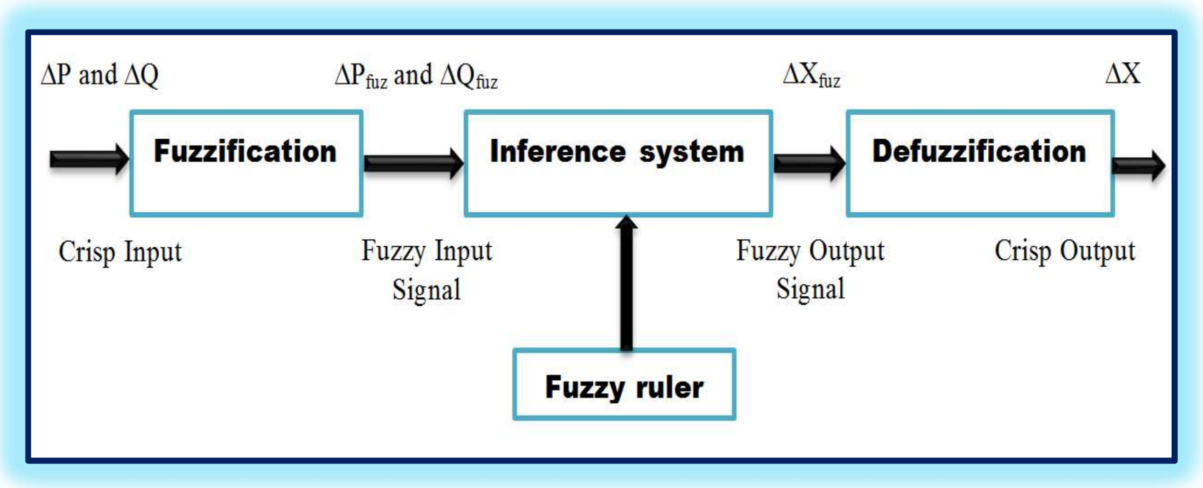


Figure 3.2: Functional block diagram of FLC in fuzzy load flow analysis

Figure 3.2 represents the functional block diagram of FLC in fuzzy load flow analysis. Here, the fuzzy logic controller has fuzzification system, the inference system, fuzzy rule base and defuzzification system. The fuzzification interface merely modifies the inputs in order to interpret them and compare them to the regulations in the fuzzy ruler. The fuzzy ruler retains the understanding of how to best manage the system in the form of a set of regulations. The inference mechanism evaluates which control laws are currently applicable and then chooses what the crisp input should be. The defuzzification interface transforms the inference mechanism's findings into the plant's outputs. After it generates a quantifiable outcome, given fuzzy sets and associated membership degrees, in Crisp logic. It is the method that links a fuzzy set to a fuzzy set. In fuzzy control schemes, it is typically necessary. Defuzzification interprets the Fuzzy sets membership degrees into a particular choice or real value.

3.2.1.2 ANALYSIS OF FAST DECOUPLED LOAD FLOW

Fast load flow decouple technique is the fourth load flow analysis technique that is derived from the Decoupled load flow (DLF) technique that was originally obtained from the Newton Rapson (N-R) load flow strategy. The complex Jacobian matrix of N-R method is simplified into a constant matrix by considering the physical limitations of variables and decoupling properties of real power and voltage phasor angle and reactive power and voltage phasor magnitude.

3.2.1.3 EQUATION OF FUZZY LOAD FLOW

The equation of fuzzy load flow is extracted from Eq. (3.1) and the equation of fuzzy load flow is given by Eq. (3.1).

$$\Delta X = f_x(\Delta F) \tag{3.1}$$

Where, $\Delta X = [\Delta P \Delta Q]^T$ and $\Delta F = [\Delta \delta \Delta V]^T$ and f_x is the FLC task [57]. So for P-δ cycle FLC fuzzy load flow equation is given by Eq. (3.2).

$$\Delta \delta = f_p(\Delta P) \tag{3.2}$$

Q-V cycle FLC fuzzy load flow equation is given by Eq. (3.3).

$$\Delta V = f_Q(\Delta Q) \tag{3.3}$$

The inputs ΔP and ΔQ are the real power mismatch and reactive power mismatch respectively. The output of fuzzy logic controller is ΔX i.e., state variable Δδ and ΔV at that node. Now $\delta^{(i+1)} = \delta^{(i)} + \Delta\, \delta^{(i)}$ and $|V|^{(i+1)} = |V|^{(i)} + \Delta\, |V|^{(i)}$. If ΔP and ΔQ are within tolerance limits, the iteration is stopped and the computed value of P, Q is the actual value of real and reactive power injection at that iteration respectively. Here power mismatches and voltage magnitude are represented in per unit (p.u.) system and voltage angle is represented in degree (deg.).

3.2.1.4 FUZZIFICATION

The contributions to the FLC capacity are ΔP and ΔQ, which are fresh worth. These qualities must be changed over into fuzzy information value of ΔPfuz and ΔQfuz. Input values are moved into relating universe of talk at each cycle by utilizing participation work. Participation capacity might be same or distinctive for various factors. The two quantities are to be fuzzified here. The triangular and Gaussian membership function are used. This will result in four instances that are to be considered with the two membership functions for two crisp inputs ΔPmax or ΔQmax such as [-1, 1].

Both membership functions are divided into 7 zones i.e., each membership function is defined by 7 linguistic factors such as: large positive (LP), large negative (LN), medium positive (MP), medium negative (MN), large positive (LP), small positive (SP) and small negative (SN).

In the fuzzification process the power parameters are converted into per unit parameters as ΔP and ΔQ and then they are fuzzified as ΔP_{Fuz} and ΔQ_{Fuz} respectively with seven etymological factors; large positive (LP), large negative (LN), medium positive (MP), medium negative (MN), small positive (SP), small negative (SN), zero (ZR). They are spoken to in Gaussian capacity. In light of the fuzzy principles created the fuzzy information signals are mapped into the comparing fuzzy output signals. After that the fuzzy output signals are bolstered to the defuzzification procedure in which the revision of the fuzzy output signals are made. The crisp output is obtained by using the centroid of area method within the defuzzifier. The survey of fuzzy load flow was conducted in both node schemes using a flat start condition and a tolerance of 0.001pu (0.1MW / MVAr) for node energy mismatch.

Using the fuzzy load flow analysis, the exact load current and the voltage of each node of the network can be determined. The membership function for the input fuzzy signal is derived from the seven linguistic variables and it is represented as shown in Fig. 3.3 [28].

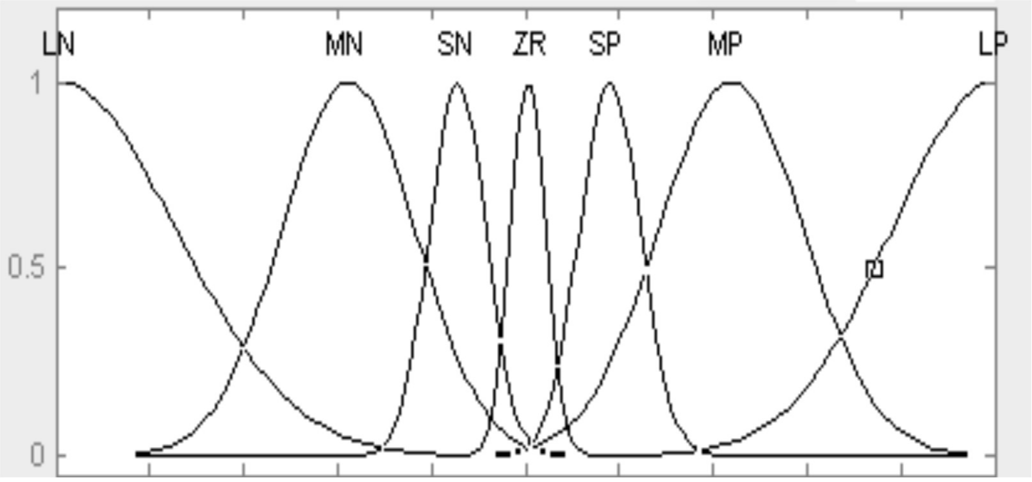


Figure 3.3: Membership function for the input signal

The width and center of the membership function as in Fig. 3.3 is designed as,

The width and center of the membership function as in Fig. 3.3 is designed as, If $\Delta F_{max} = 0.2$ rad,

LN: [$\Delta F_{max}/14$, $-3\Delta F_{max}/4$]: [0.014, -0.15]

MN: [$\Delta F_{max}/14$, $-\Delta F_{max}/2$]: [0.014, -0.1]

SN: [$\Delta F_{max}/14$, $-\Delta F_{max}/4$]: [0.014, -0.05]

ZR: [$\Delta F_{max}/7$, 0]: [0.028, 0]

SP: [$\Delta F_{max}/14$, $\Delta F_{max}/4$]: [0.014, 0.05]

MP: [$\Delta F_{max}/14$, $\Delta F_{max}/2$]: [0.014, 0.1]

LP: [$\Delta F_{max}/14$, $3\Delta F_{max}/4$]: [0.014, 0.15]

Where ΔF_{max} is only the greatest estimation of the information signals ΔP and ΔQ. In the wake of making the enrollment work for the information signals, these are fuzzified into fuzzy factors and the inference procedure will change over the fuzzy factors into fuzzy state factors i.e., fuzzy ouput sign utilizing the accompanying principles.

Rule 1: If ΔF_{fuz} is LN then ΔX_{fuz} is LN

Rule 2: If ΔF_{fuz} is MN then ΔX_{fuz} is MN

Rule 3: If ΔF_{fuz} is SN then ΔX_{fuz} is SN

Rule 4: If ΔF_{fuz} is ZR then ΔX_{fuz} is ZR

Rule 5: If ΔF_{fuz} is SP then ΔX_{fuz} is SP

Rule 6: If ΔF_{fuz} is MP then ΔX_{fuz} is MP

Rule 7: If ΔF_{fuz} is LP then ΔX_{fuz} is LP

3.2.1.5 FUZZY RULES

Since the output ΔX (state vector) is directly proportional to the input location ΔF (power mismatch), the rules are thus formed. For 7 linguistic variable, 7 fuzzy rules are created for one fuzzy input variable at a moment, resulting in a total of 14 fuzzy rules for two fuzzy inputs (ΔP_{fuz}, ΔQ_{fuz}) with respective fuzzy outputs ($\Delta\delta_{fuz}$, $\Delta|V|_{fuz}$).

3.2.1.6 FUZZY OUTPUT

FLC transforms the fuzzy ΔF_{fuz} input signal to the respective fuzzy ΔX_{fuz} output signals. Seven linguistic variables parallel to input fuzzy signals are over-characterized and the input and output connections are direct. Then the ΔF_{fuz} is defuzzified and the crisp output is acquired. ΔX_{max} offers a range of scale mapping that transmits the output signals to the corresponding dissertation development at each iteration based on partial differential equation shown by Eq. (3.4).

$$\Delta X = \left(df_i / dx_i\right)^{-1} \Delta F_{\max} \tag{3.4}$$

The output fuzzy signal are then passed to the defuzzification procedure wherein the remedial activity of the state factors will be performed iteratively. At last the particular load information in the distribution network will be obtained and they are utilized in the accompanying segment for ascertaining the power losses and energy loss in the distribution network.

3.2.1.7 DEFUZZIFICATION

The output of the inference component is in the form of a linguistic or symbolic value, but in the machine controller this type of value is not acceptable. Therefore, the conversion of the fuzzy value into a crisp value requires a component. This converter is called defuzzification. Center-of-area is the most popular defuzzification technique.

The membership function of the output grade is also acquired along with the transformation of the linguistic word. You can obtain a popular grade membership function of the output by multiplying the membership function of the input grade. The membership feature of the output can be expressed as: $\rho out(z) = \rho in(j1)(C) \times \rho in(j2)(C) \times \ldots..\times \rho out(C)$

Where j is the system input variable. The value acquired from the degree membership function is then used in the defuzzification equation.

3.2.2 CANDIDATE NODE SELECTION BASED ON LOSS SENSITIVITY FACTOR APPROACH

The Loss Sensitivity Factor (LSF) is utilized here to locate the sensitive nodes in the distribution network. These sensitive nodes will incredibly decrease the loss in the system when an optimally measured capacitor is put. By choosing these sensitive nodes from the complete number of nodes in the system the general search space for the enhancement issue become diminished. The LSF of each node can be determined from the loss of power happens in each node of the system.

Assume that a distribution line ‘n’ between two nodes having a load impedance of Z(n) and current flow of I(n) and the base voltage level as V [n], the active power loss at the nth line can be determined as by Eq. (3.5).

$$P_l(n) = \frac{|I_n|^2 \operatorname{Re}(Z)}{V[n]^2} = \frac{(P_{ef}{}^2(n) + Q_{ef}{}^2(n))R_n}{V[n]^2} \tag{3.5}$$

Similarly, the reactive power loss can be computed by Eq. (3.6).

$$Q_l(n) = \frac{|I_n|^2 \operatorname{Im}(Z)}{V[n]^2} = \frac{(P_{ef}{}^2(n) + Q_{ef}{}^2(n))X_n}{V[n]^2} \tag{3.6}$$

Where $P_{ef}(n)$ = Total effective active power supplied beyond the node '*n*' and

$Q_{ef}(n)$ =Total effective reactive power supplied beyond the node '*n*' .

The system energy loss is computed using the value of total real power loss and it is given by Eq. (3.7).

$$\text{Energy loss } E_{loss} = \sum_{n=1}^{k} P_{tot.loss} T_n \tag{3.7}$$

Where T_n = Time duration of the nth load.

The factor K_e is utilized to change over the energy loss into cost value. The expense related with the energy assets is determined from the energy loss and is given by the Eq. (3.8).

$$\text{Cost of loss} = \mathrm{K_e} \sum_{n=1}^{k} P_{tot.loss} T_n \tag{3.8}$$

Where K_e = Energy cost (Rs/kWh) and $P_{tot.loss}$ = Total power loss

From the estimations of active and reactive power losses the estimations of LSF for comparing the nodes can be determined as given by Eq. (3.9) and Eq. (3.10) respectively.

$$\frac{\partial P_l}{\partial Q_{ef}} = \frac{2 \times Q_{ef}(n) \times R_n}{(V[n])^2} \tag{3.9}$$

$$\frac{\partial Q_l}{\partial Q_{ef}} = \frac{2 \times Q_{ef}(n) \times X_n}{(V[n])^2} \tag{3.10}$$

Among these two estimations of LSF, Eq. (3.9) will be considered for the choice of sensitives nodes. For the nodes in the system their loss sensitivity factors determined utilizing Eq. (3.9) are organized in the descending order and the values are put away as a vector at the node position n, for example, 'bp[i]'. At that point the values put away in the vector bp[i] will be standardized dependent on the standardization work as given by Eq. (3.11).

$$Norm(i) = V[i]/0.95 \tag{3.11}$$

Where $V[i]$ is the base voltage of the i^{th} node in the network. The normalization function will decide, which node needs the reactive compensation based on a limit. Here the nodes with Norm [i] less than a particular value are referred to as the sensitive nodes and these nodes are selected as the candidate nodes for the capacitor placement, which will be stored in a vector of candidate nodes. The nodes with *Norm* (i) greater than the limit do not need compensation and these nodes will not be included in the candidate node vector. After that the most appropriate candidate nodes, which will reduce the power loss in considerable amount can be selected based on the Fuzzy Inference System. The FIS approach for the capacitor placement is explained in the following section.

3.2.3 FUZZY INFERENCE SYSTEM (FIS) FOR CAPACITOR PLACEMENT

A fuzzy Inference System (FIS) is a system that uses fuzzy set theory to map input values and output values. In this method, the FIS is used to find the most appropriate candidate nodes in which the capacitors will be placed to compensate the power loss in the radial distribution network. The FIS employs set of rules and membership functions where a decision matrix is formed initially based on the fuzzy membership functions in order to find the suitable capacitor locations. The membership functions are formed for the fuzzy variables such as power loss index and voltage which are shown in the following Table 3.1 [28].

Table 3.1: Fuzzy membership functions

<table>
<tr><th colspan="6">Membership functions for Power loss index</th></tr>
<tr><th>Variable</th><th>Low</th><th>Low-Medium</th><th>Medium</th><th>High-Medium</th><th>High</th></tr>
<tr><td>Power Loss Index (PLI)</td><td><0.25</td><td>0.00-0.50</td><td>0.25-0.75</td><td>0.50-1.00</td><td>>0.75</td></tr>
<tr><th colspan="6">Membership functions for Voltage</th></tr>
<tr><th>Variable</th><th>Low</th><th>Low-Normal</th><th>Normal</th><th>High-Normal</th><th>High</th></tr>
<tr><td>Voltage</td><td><0.94</td><td>0.92-0.98</td><td>0.96-1.04</td><td>1.02-1.08</td><td>>1.1</td></tr>
</table>

The corresponding decision matrix for the membership functions is shown in the following Table 3.2 [28] in which the fuzzy variables are described by the fuzzy terms as low, low-medium/normal, medium/normal, high and high-medium/normal.

Table 3.2: Decision matrix for determining the suitable capacitor locations

AND		**Voltage**				
		Low	**Low-Normal**	**Normal**	**High-Normal**	**High**
PLI	**Low**	Low-Medium	Low-Medium	Low	Low	Low
	Low-Medium	Medium	Low-Medium	Low-Medium	Low	Low
	Medium	High-Medium	Medium	Low-Medium	Low	Low
	High-Medium	High-Medium	High-Medium	Medium	Low-Medium	Low
	High	High	High-Medium	Medium	Low-Medium	Low-Medium

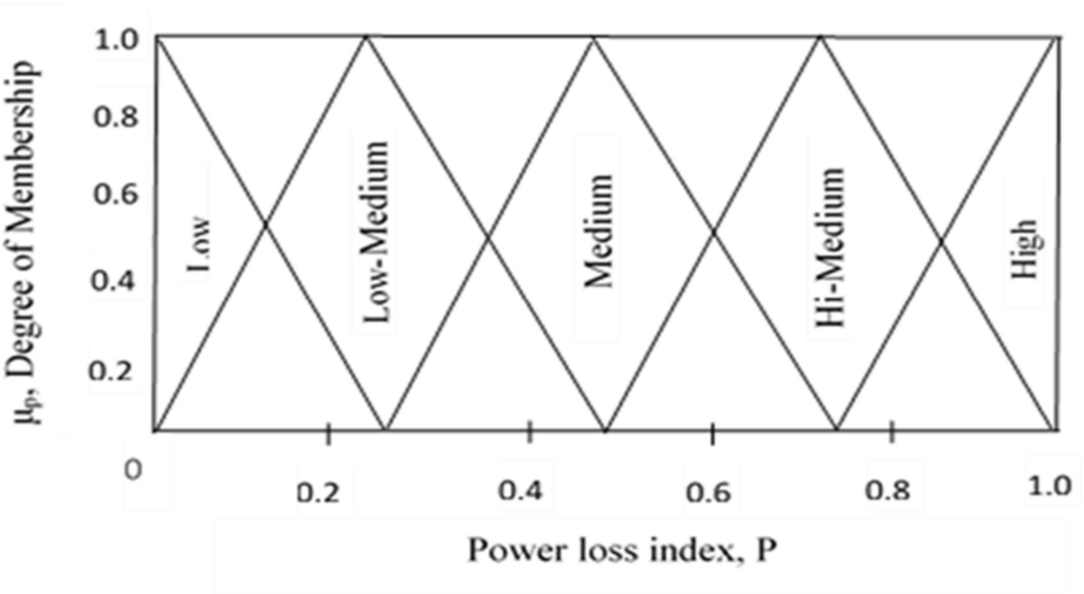
Among the fuzzy variables the power loss index (PLI) is the normalization of power loss of the corresponding node ‘n’, which is normalized as for the base (i.e., zero) and greatest loss decrease (i.e., one) and it very well may be determined by utilizing Eq. (3.12).

$$Power\ Loss\ Index\,(PLI) = \frac{loss\ reduction\,(n) - loss\ reduction\,(\mathrm{min})}{loss\ reduction\,(\mathrm{max}) - loss\ reduction\,(\mathrm{min})} \tag{3.12}$$

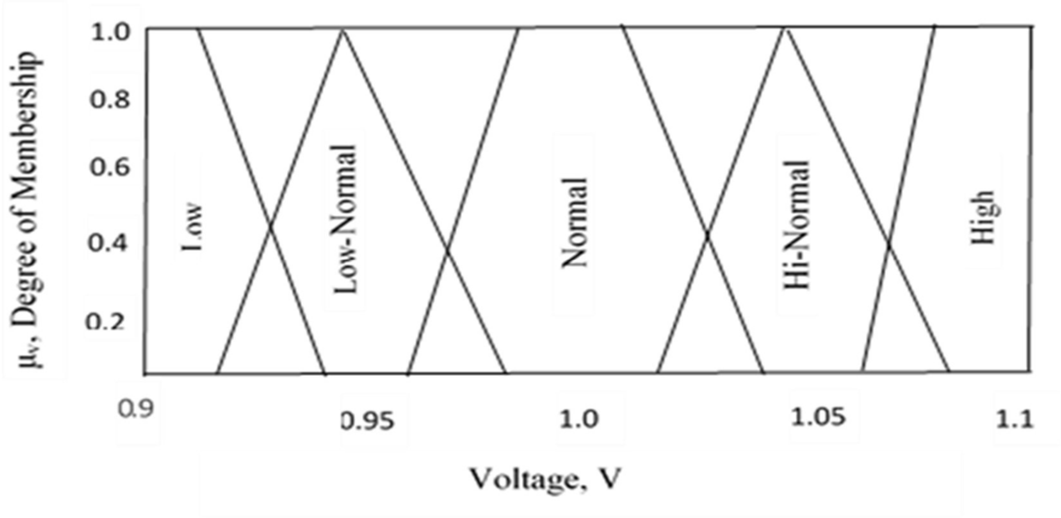
For the specific value of the PLI and the voltage for the desired node utilizing the decision matrix, the fuzzy rules are determined. For example, if a node with PLI = 0.48 and voltage = 0.94, at that point the relating fuzzy guidelines produced will be,

1. If power loss index is low-medium AND voltage is low-normal then capacitor reasonableness is low-medium.
2. If power loss index is medium AND voltage is low-normal then capacitor suitability is medium.

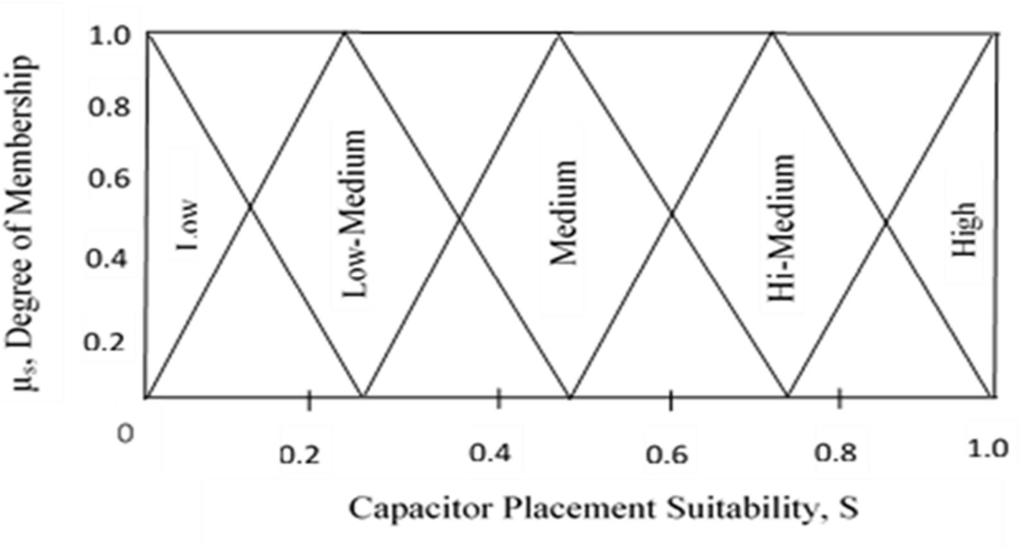
The exact capacitor locations can be found from the diagram of membership functions, which are illustrated in Fig. 3.4 [28].



(a) Power loss index membership functions



(b) Voltage membership functions



(c) Capacitor placement suitability membership functions

Figure 3.4: Membership functions

The capacitor suitability of index is given by Eq. (3.13).

$$S = \frac{\int \mu_s(Z).Z\,dZ}{\int \mu_s(Z)\,dZ} \tag{3.13}$$

Where $\mu_s(Z)$ = Distribution function of capacitor placement suitability and Z = Point at which the membership function is determined.

The distribution function of capacitor placement suitability of node i for the set of k fuzzy rules using the max-prod impedance method is computed by Eq. (3.14).

$$\mu_s(i) = \max_k [\mu_p(i).\mu_v(i)] \tag{3.14}$$

Where $\mu_p(i)$ and $\mu_v(i)$ are the membership functions of power loss index (PLI) and voltage respectively. This capacitor suitability of index will be determined for every single node in the candidate node vector and the nodes having the highest value of capacitor suitability index will be chosen for placing the capacitor. At that point the optimal size of the capacitor can be resolved utilizing the hybrid ABC-PSO algorithm.

3.2.4 CAPACITOR SIZING WITH HYBRID ABC-PSO ALGORITHM

After finding the appropriate capacitor placements, the optimal size of the capacitors which will reduce the power loss to a minimum value and increase the voltage profile can be solved using the Hybrid ABC-PSO algorithm.

3.2.4.1 HYBRID ABC-PSO ALGORITHM

Artificial Bee Colony (ABC) algorithm and Particle Swarm Optimization (PSO) algorithm are the notable algorithms that will mimic the insect behavior in problem modeling and solution. Here both the ABC and PSO algorithms are hybridized in order to select the most appropriate capacitor sizes to be placed at the candidate nodes resulting from the FIS approach. The ABC algorithm initially picks the random values of capacitor sizes and afterward computes the power loss for the selected capacitor sizes. The ABC algorithm has the three phases and these are employed bees and scout bees. Each stage will refresh the size of the capacitors and the most exceedingly awful arrangement results toward the finish of the last stage can be enhanced with the utilization of the PSO algorithm. The contribution for the ABC computation will be the arbitrary estimations of capacitor sizes. By and large the size of the capacitors for the radial distribution network will be in the scope of 0-4050 kVAr and the accompanying computation will give the optimal capacitor sizes. The computation will proceed until the base power loss got with the most reasonable size of capacitors. Therefore, the principle goal of the ABC-PSO algorithm in this technique is to limit the all-out power loss and the energy loss and it is given by Eq. (3.15).

$$Fitness\ \ function = Min\left[\sum_{n=1}^{N}\{P_l(n)+Q_l(n)\}+\sum_{i=1}^{3}\{T_nP_{t,n}\}\right] \tag{3.15}$$

In Eq. (3.15) the first two terms in the summation denotes the total power loss in the candidate nodes and the second term denotes the energy losses in the candidate nodes after capacitor placement.

a) The Analogies of hybrid ABC-PSO algorithm with Capacitor sizing Problem is given below:

The analogies used in the hybrid combination of ABC-PSO algorithm with respect to the capacitor sizing problem are presented in Table 3.3.

Table 3.3: Analogies of the proposed algorithm regarding capacitor sizing problem

Analogy	Capacitor sizing problem
Food source in ABC	Random value of capacitor sizes
Food source positions in ABC	Fitness values for the corresponding capacitor sizes
Fitness value	Total power loss and energy loss after placing the capacitors as given in Eq. (3.15).
Particles (Qc)	Capacitor sizes with worst fitness values
Distance vector (*pp*)	Capacitor size in kVAr
Velocity Vector (*v*)	Change in Capacitor Size in kVAr
Pbest	Best capacitor size ever of every individual particle
Gbest	Best capacitor size ever among all individual particles globally
Inertia Factor (*w*)	Amount of change in capacitor sizes

Table 3.4 shows the parameters and their values used in the ABC-PSO algorithm.

Table 3.4: Parameters and its values used in ABC-PSO

Parameters	Values
Random value of capacitor sizes	Randomly selected numbers
Fitness value	0.19
Particles (Qc)	12 kVAr
Distance vector (*pp*)	0.183 kVAr
Velocity Vector (*v*)	0.178 kVAr
Pbest	0.198 kVAr
Gbest	0.179 kVAr
Inertia Factor (*w*)	0.192 kVAr

Based on the Table 3.3, ABC-PSO algorithm will be performed and the steps are illustrated in the next section.

b) The steps in the Hybrid ABC-PSO algorithm are shown below.

Step 1: Initialize the random values of capacitor sizes as food source positions.

Step 2: Each employed bee produces a new food source in their food source site and exploits the better source.

Step 3: Each onlooker bee selects a source depending on the quality of her solution, produces a new food source in selected food source site and exploits the better source.

Step 4: Determine the source to be abandoned and allocate its employed bee as scout for searching new food sources.

After finishing Step 4, PSO algorithm will be performed to replace the worst solutions with better values.

Step 5: Initialize a population of particles with random positions.

Step 6: Compute the fitness value for the given objective function for each particle.

Step 7: Set present particles as “P_{best}”.

Step 8: Add velocity to initial particles in order to obtain new set of particles.

Step 9: Find fitness value for each new set of particles.

Step 10: Compare each particle’s fitness value to find new “P_{best}” between the two set of particles.

Step 11: Find minimum fitness value by comparing two set of particles and corresponding particle is “G_{best}”.

Step 12: Update velocity for next iteration using the below formula,

$$v = w \times [a(P_{best} - pp) + b(G_{best} - pp)];$$

$$pp = pp + v;$$

Step 13: The iteration of PSO is repeated until the convergence is made.

Step 14: Memorize the best food source found so far.

Step 15: Repeat the steps 2- 14 until the stopping criterion is met.

The combination of ABC-PSO computation yields the best optimal capacitor sizes to be set at the selected candidate nodes. The resulting loss of power after integrating the optimally sized capacitors will be reduced and voltage profile of the system will be improved. The proposed method has been tested on 69-node and 34-node radial distribution networks.

3.3 RESULTS AND DISCUSSION

In this work two radial distribution networks for setting and estimating the capacitors optimally have been selected for utilizing Fuzzy load flow analysis, Loss Sensitivity Factor, Fuzzy Inference System and Hybrid ABC-PSO computation. The proposed technique is actualized on in the system with the System Configuration of Intel core i3 processor, 4GB RAM and Windows 8 Operating network and the performance of the proposed method has been tested on 69-node and 34-node radial distribution networks.

3.3.1 69-NODE RADIAL DISTRIBUTION NETWORK

Figure 3.5 shows the single line diagram of 69-node radial distribution network having base values 12.66 kV and 100 MVA. The line data and node data have been presented in **Appendix-A**.

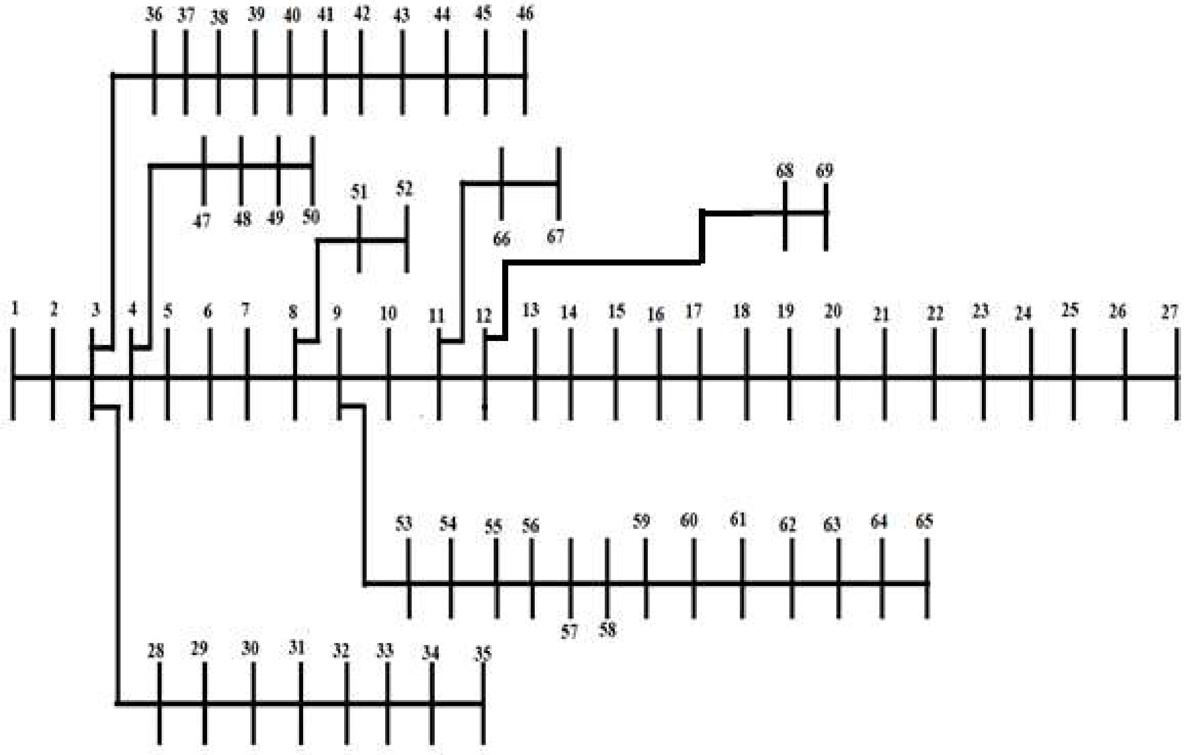


Figure 3.5: 69-node radial distribution network

The optimal dimensioned capacitors in 69-node radial distribution network are planned to be computed. The base case voltage and LSF values for the nodes of 69-node radial distribution network has been given in Table 3.5.

With this LSF values of the RDN these are normalized using the Eq. (3.11) to get the sensitive nodes in the in the node. The normalization value thus obtained for the 69-node is 4.0020e+03. Using this normalization value, the sensitive nodes in the node found out using the loss sensitivity factor approach. Next the most appropriate nodes are selected using the Fuzzy Inferencing system. The sizes of the capacitors to be put at these nodes are selected by the Hybrid ABC-PSO algorithm. The sizes of the capacitors have been presented in Table 3.6.

Table 3.5: Base case Voltage (p.u.) and LSF values of each node of 69-node radial distribution network

Node Number	Voltage (p.u.)	LSF	Node Number	Voltage (p.u.)	LSF
6	0.99008	0.0000	37	0.99975	0.0011
7	0.98079	0.0000	39	0.99954	0.0005
8	0.97858	0.0000	40	0.99954	0.0000
9	0.97744	0.0001	41	0.99884	0.0000
10	0.97245	0.0013	43	0.99851	0.0001
11	0.97134	0.0412	45	0.99841	0.0005
12	0.96819	0.0100	46	0.99841	0.0024
13	0.96526	0.0000	48	0.99855	0.0267
14	0.96237	0.0002	49	0.99470	1.2870
16	0.95897	0.0017	50	0.99416	1.1107
17	0.95807	0.0087	51	0.97855	0.0000
18	0.95808	0.0126	52	0.97854	0.0000
20	0.95732	0.0000	53	0.97466	0.0000
21	0.95684	0.0694	54	0.97142	0.0001
22	0.95683	0.0000	55	0.96694	0.0000
24	0.95660	0.0015	59	0.92477	0.0378
26	0.95637	0.0000	61	0.91234	2.4445
27	0.95637	0.0003	62	0.91205	0.0002
28	0.99997	0.0007	64	0.90977	0.0024
29	0.99985	0.0012	65	0.90919	0.0019
33	0.99973	0.0000	66	0.97129	0.0000
34	0.99901	0.0003	67	0.97129	0.0000
35	0.99895	0.0001	68	0.96786	0.0003
36	0.99999	0.0026	69	0.96786	0.0012

The subsequent power losses, minimum voltage (p.u.), energy loss and cost have been presented in Table 3.7. Table 3.8 shows the outcomes after compensation of 69-node radial distribution network by proposed method, ABC and PSO algorithms. Figure 3.6 shows the voltage profile of the uncompensated network, after placement of optimal sized capacitors by using ABC-PSO, ABC and PSO algorithms. Figure 3.7 shows the comparison of optimal sized capacitors obtained by proposed method, ABC algorithm and PSO algorithm. Figure 3.8 shows the comparison of total real power loss after integration of optimal sized capacitors in 69-node radial distribution network by the proposed method, ABC algorithm and PSO algorithm respectively.

Table 3.6: Optimal size of capacitors to be integrated in 69-node radial distribution network

Node Number	Capacitor Size (kVAr)
11	126
13	93
17	145
21	117
28	94
39	104
45	96
Total kVAr	871

Table 3.7: Outcomes of 69-node radial distribution network before and after compensation

Parameters	Before Capacitor placement	After Capacitor placement
Real Power loss (kW)	224.96	143.63
Reactive Power loss (kVAr)	114.15	56.30
Minimum voltage (p. u.) [Node No.]	0.90919 [65]	0.95867
Energy loss (kWh)	1950403.2	1245272.1
Cost ($)	2215658.0352	1414629.1056

Table 3.8: Outcomes of compensated 69-node radial distribution network obtained by proposed method, ABC and PSO algorithms

Method	Maximum real power loss (kW)	Minimum Voltage (p.u.)	Node Number
Proposed Method	143.63	0.95867	65
ABC Algorithm	148.65	0.93693	65
PSO Algorithm	150.98	0.928465	65

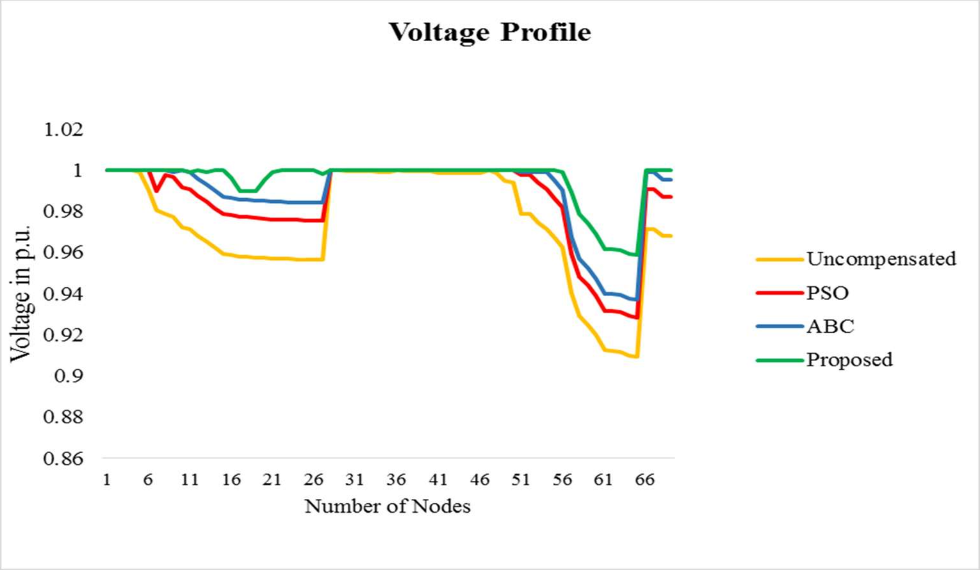


Figure 3.6: Voltage profile of 69-node radial distribution network before and after placement of capacitors

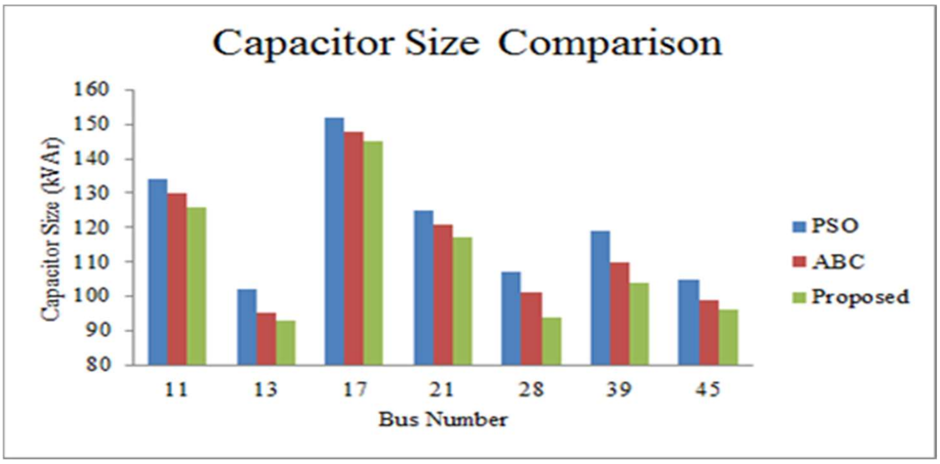


Figure 3.7: Comparison of capacitor sizes to be integrated in 69-node radial distribution network

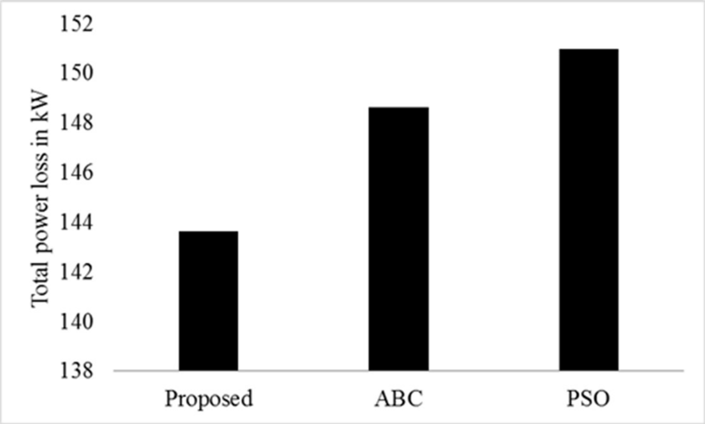


Figure 3.8: Comparison of total power loss of the compensated 69-node radial distribution network obtained by proposed method, ABC and PSO algorithms

Optimal capacitor sizes are distinguished dependent on the CSI values from FIS approach. From the Table 3.6, it is realized that the losses in the system have been reduced impressively after integration of optimal sized capacitors at the appropriate nodes.

3.3.2 34-NODE RADIAL DISTRIBUTION NETWORK

Figure 3.9 shows the single line diagram of 34-node radial distribution network having base values 11 kV and 100 MVA. The line data and node data have been presented in **Appendix-B**.

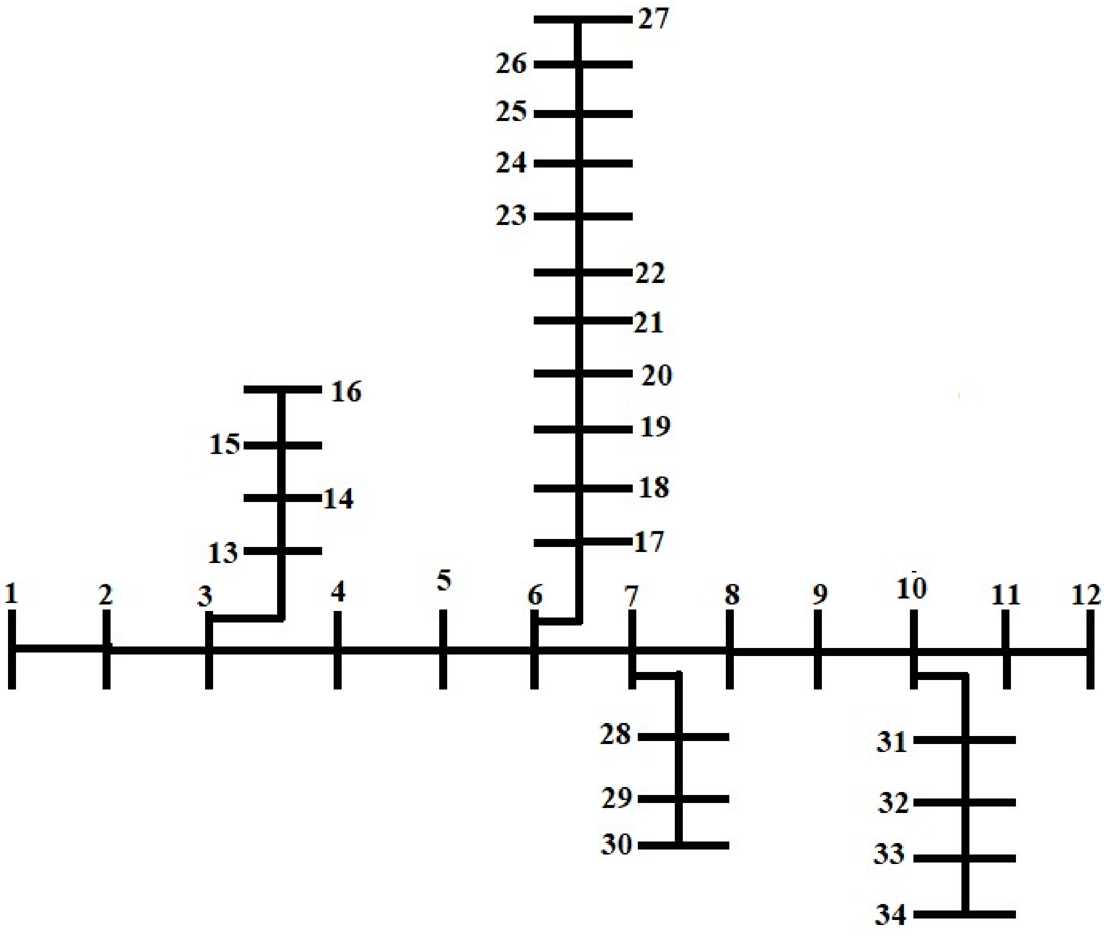


Figure 3.9: 34-node radial distribution network

Table 3.9 shows the base case voltage and LSF values of 34-node radial distribution network.

Along with these LSF values of 34-node radial distribution network are normalized for obtaining the sensitive nodes of the network. The normalized values in this way obtained for the 34-node radial distribution network is 5.9014e+04. Utilizing this normalization value, the sensitive nodes in the network are obtained by utilizing the loss sensitivity factor method. Next the most proper nodes are chosen utilizing the FIS. The optimal sized capacitors are to be put at these nodes are obtained by the Hybrid ABC-PSO algorithm.

Table 3.9: Base case voltage and LSF values of 34-node radial distribution network

Node Number	**Voltage (p.u.)**	**LSF**	**Node Number**	**Voltage (p.u.)**	**LSF**
1	1.00000	0.1733	18	0.96223	0.0001
2	0.99419	0.0000	19	0.95812	0.1661
3	0.98934	0.1661	20	0.95487	0.1697
4	0.98215	0.0547	21	0.95196	0.1552
5	0.97657	0.1516	22	0.94873	0.1552
6	0.97035	0.0000	23	0.94605	0.1625
7	0.96650	0.0000	24	0.94348	0.1625
8	0.96446	0.1805	25	0.94224	1.9494
9	0.96194	0.1300	26	0.94185	0.1300
10	0.96086	0.0041	27	0.94164	0.0830
11	0.96035	1.9494	28	0.96624	0.0130
12	0.96023	0.0000	29	0.96624	0.0041
13	0.98871	0.0830	30	0.96586	0.0062
14	0.98842	0.0032	31	0.96043	0.0043
15	0.98838	0.0127	32	0.96017	0.0032
16	0.98838	0.0073	33	0.95990	0.0021
17	0.96593	0.0036	34	0.95990	0.0021

The sizes of the capacitors have been presented in Table 3.10. The subsequent power losses, minimum voltage (p.u.), energy loss and cost have been presented in Table 3.11. Table 3.12 shows the outcomes after compensation of 34-node radial distribution network by proposed method, ABC and PSO algorithms. Figure 3.10 shows the voltage profile of the uncompensated network, after placement of optimal sized capacitors by using ABC-PSO, ABC and PSO algorithms. Figure 3.11 shows the comparison of optimal sized capacitors obtained by proposed method, ABC algorithm and PSO algorithm. Figure 3.12 shows the comparison of total real power loss after integration of optimal sized capacitors in 34-node radial distribution network by the proposed method, ABC algorithm and PSO algorithm respectively.

Table 3.10: Optimal size of capacitors to be integrated in 34-node radial distribution network

Line Number	Capacitor Size (kVAr)
2	147
6	121
7	105
12	130
Total kVAr	503

Table 3.11: Outcomes of 34-node radial distribution network before and after compensation

Parameters	Before Capacitor placement	After Capacitor placement
Real Power loss (kW)	221.67	157.489
Reactive Power loss (kVAr)	142.5	67.05
Minimum voltage (p. u.) [Node No.]	0.94164 [27]	0.95568
Energy loss (kWh)	1994100	1365429.63
Cost ($)	2265297.6	1551128.06

Table 3.12: Outcomes of compensated 34-node radial distribution network obtained by proposed method, ABC and PSO algorithms

Method	Total Power loss (kW)	Minimum Voltage (p.u.)	Node number
Proposed Method	157.489	0.95568	27
ABC Algorithm	209.5612	0.9504	27
PSO Algorithm	216.9465	0.9496	27

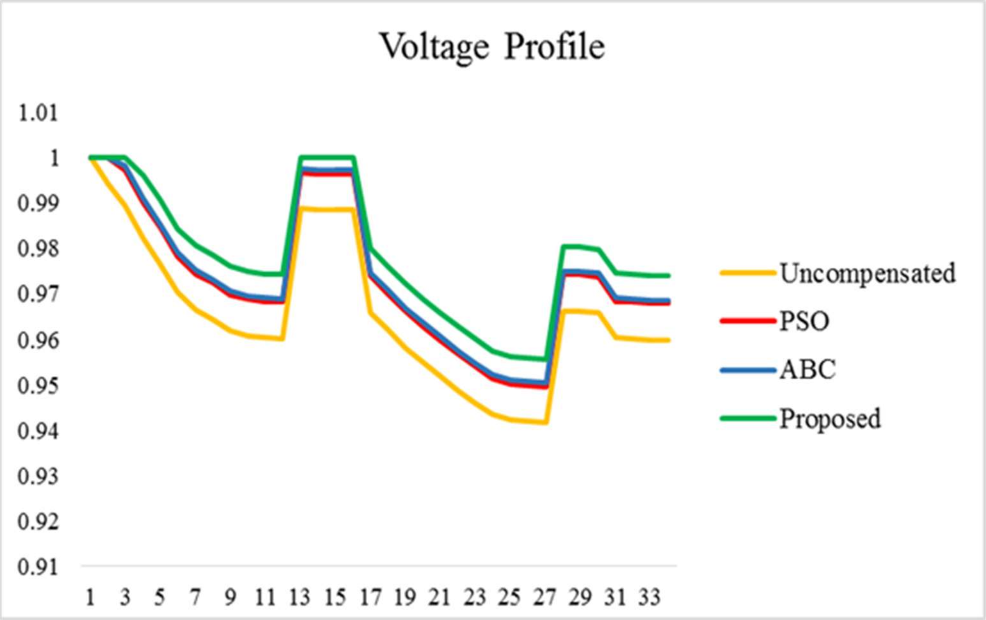


Figure 3.10: Voltage profile of 34-node radial distribution network before and after placement of capacitors

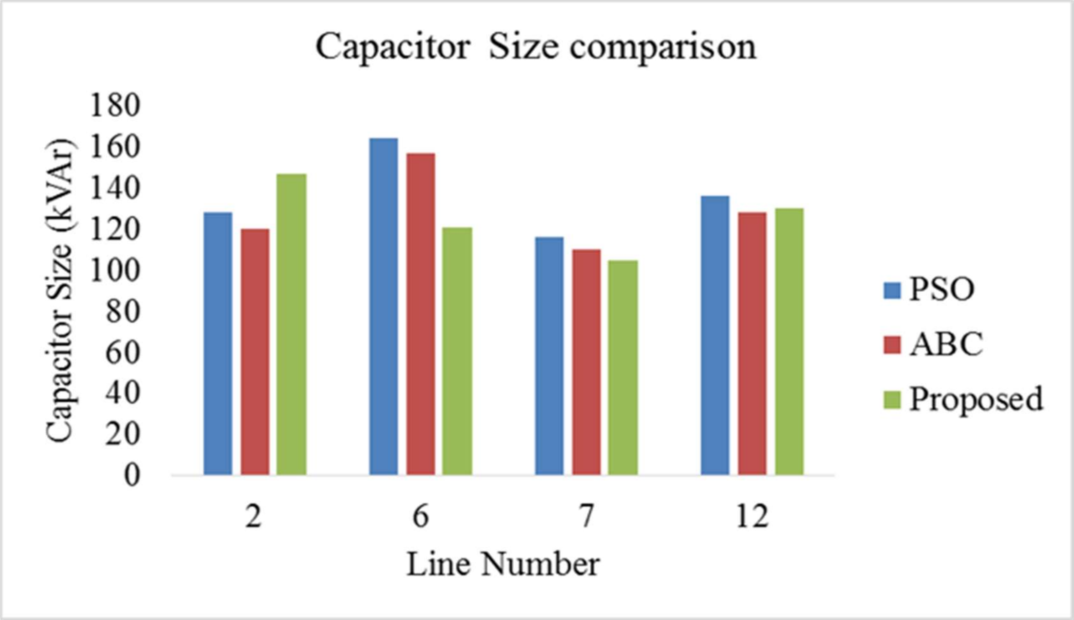


Figure 3.11: Comparison of capacitor sizes to be integrated in 34-node radial distribution network

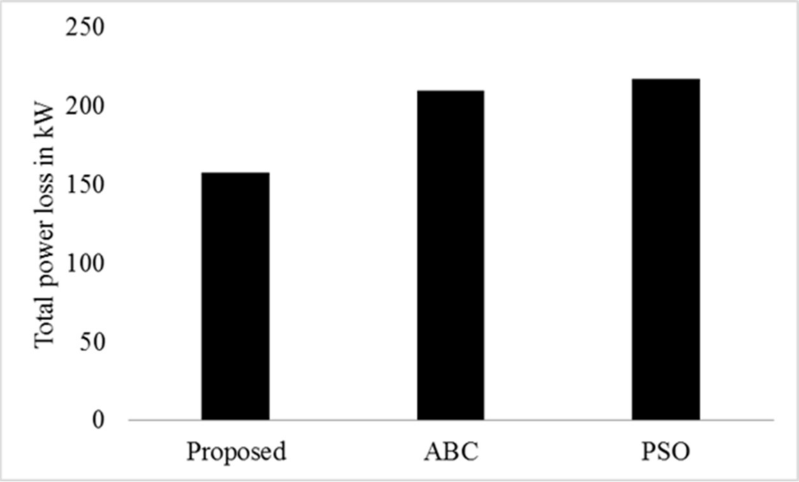


Figure 3.12: Comparison of total power loss of the compensated 34-node radial distribution network obtained by proposed method, ABC and PSO algorithms

Henceforth, the outcomes computed by the proposed system are appeared and contrasted with its improved presentation by contrasting with the ABC computation and PSO computation. The examination outcomes were specified as Fig. 3.6, Fig. 3.7, Fig. 3.8, Fig. 3.10, Fig. 3.11 and Fig. 3.12. From the presentation investigation it can be concluded the advancement of proposed network for the ideal situation and measuring of capacitor in radial distribution network.

3.4 CONCLUSIONS

This chapter presents the optimal capacitor placement in radial distribution network using hybrid ABC-PSO algorithm. The sensitive nodes are computed by using hybrid loss sensitive factor. The appropriate nodes are picked up from the sensitive nodes using Fuzzy Inference System (FIS). The outcomes obtained by the proposed method have also been compared with the outcomes obtained by ABC algorithm and PSO algorithm using the same objective function and FIS system for 69-node and 34-node radial distribution networks.

CHAPTER-4

HYBRID ABC-CSO BASED CAPACITOR PLACEMENT

4.1 INTRODUCTION

Albeit the previously presented technique provides good results, it has certain disadvantages such as premature convergence, weak local search ability. Moreover, it failed to predict the future loads. The motivation of this chapter is to extend the previous chapter using different hybrid optimization algorithm. The optimization algorithm used in sizing of capacitor should be an efficient algorithm because the real power and reactive power losses are dependent on the sizing of capacitors to be integrated at appropriate locations. If the real power and reactive power losses are reduced, it means the cost related to energy losses will be low.

Distribution network planning and development is the most significant component of electricity planning network. The principle reason for the electricity distribution network planning and development is the reliability improvement of the system, and ensure costs of customer to a minimum output. The basic capacity of the electrical system is to provide and fulfill the electricity to clients. Investigation and deliberation a conceivable arrangement to extend the distribution network of every zone to support the energy utilization will be expanded [59]. Distribution Networks are developing extensive and being extended too far, prompting higher system losses and poor voltage regulation, the requirement for an efficient distribution network has to be obtained.

Various methodologies have already been utilized to reduce the losses, for example, optimal utilization of electrical equipments, optimal utilization of loading at the transformers, reconfiguration, and optimal capacitor positioning, optimal placement of Distributed Generation (DG) and removal of harmonics. Among all this, capacitor banks are widely included in distribution network for power factor correction, loss decrease and voltage profile change [60]. An aberrant point of interest of capacitor placement is seen as a decrease in the measure of VAR requirement needed at higher voltage levels on transmission systems. They likewise help in keeping up the voltage profile inside acceptable limits. The measures of profit that can be procured by putting the capacitors depend predominantly on how the capacitors are set on the distribution network [61].

The general capacitor placement problem comprises of determining the location, type, size and control settings at different load levels of the capacitors to be installed. The objective is to minimize the energy losses while considering capacitor establishment costs [62]. It is known that the CPP (Capacitor Placement Problem) is a hard-combinatorial optimization issue, particularly in light of the fact that real distribution networks are generally substantial and the profits of installing capacitors in one piece of the system are proliferated to different parts. Subsequently, successful location studies ought to take into thought the entire distribution network [66]. Several researchers have considered the problem of optimal capacitor placement utilizing different optimization methods. For instance, reference [63] portrays a crossover strategy drawn upon the Tabu Search approach, extended with features taken from other combinatorial approaches, for example, GA and simulated annealing, and from practical heuristic methodologies. Some others have considered capacitor placement in power systems in the presence of harmonics [64]. In [65] the problem of capacitor placement has been solved in distribution networks.

A versatile optimization strategy Firefly Algorithm (FA) has been recommended for handling the optimal capacitor position problem suitably [66]. Another two procedures named Ant Colony Search Algorithm (ACSA) and Particle Swarm

Optimization (PSO) algorithm serves for tackling the reconfiguration issue of ideal feeder, the position of optimal capacitor problem as well as the issue deliberates the mix of these problems. The above two recent works provide appropriately good results [67, 68]. A method considering the presence of harmonics in the system, which avoids impairment to electrical equipment of both the electric utility and customers have been discussed [69-73].

In power system, optimal location of capacitor has a significant part in reducing the overall losses incurred in distribution network as presented in the previous chapter.

A new methodology for determining the sensitive nodes on the essential feeders of the radial distribution network to optimally place the capacitor in order to reduce the losses of the system, and to enhance the voltage profile is proposed. The presented an algorithm for placement of capacitors in the radial distribution networks to improve the voltage profile is Hybrid ABC-CSO algorithm. The proposed procedure consists of four stages.

1. Fuzzy Based Load Flow Analysis
2. Capacitor Location by Fuzzy Expert System (FES)
3. Capacitor sizing based on Hybrid Artificial Bee Colony- Cuckoo Search Optimization

The proposed method will work as the fuzzy analysis of load flow that will compute the real power and reactive power losses and energy losses. The capacitor placement methodology includes the identification of location for capacitor placement and the size of the capacitor. The position of capacitor is estimated by using Fuzzy Expert Systems. The sizing of capacitor is computed by using Hybrid ABC-CSO algorithm.

4.2 PROPOSED METHODOLOGY FOR OPTIMAL CAPACITOR LOCATION AND SIZING

The Hybrid ABC-CSO algorithm for placing the capacitors in radial distribution networks for enhancing the voltage profile is presented. The proposed method is worked as the fuzzy load flow analysis that computes the active power and reactive power losses and energy losses. The capacitor placement methodology includes the detection of location to set the capacitor and the dimension of the capacitor to be introduced at the recognized area. The position of capacitor is estimated by using Fuzzy Expert Systems. A lot of guidelines are characterized to decide the appropriateness of a node for capacitor establishment. Next, sizing of capacitor is computed by using an optimization algorithm called Hybrid ABC-CSO. The proposed architecture is displayed in Fig. 4.1.

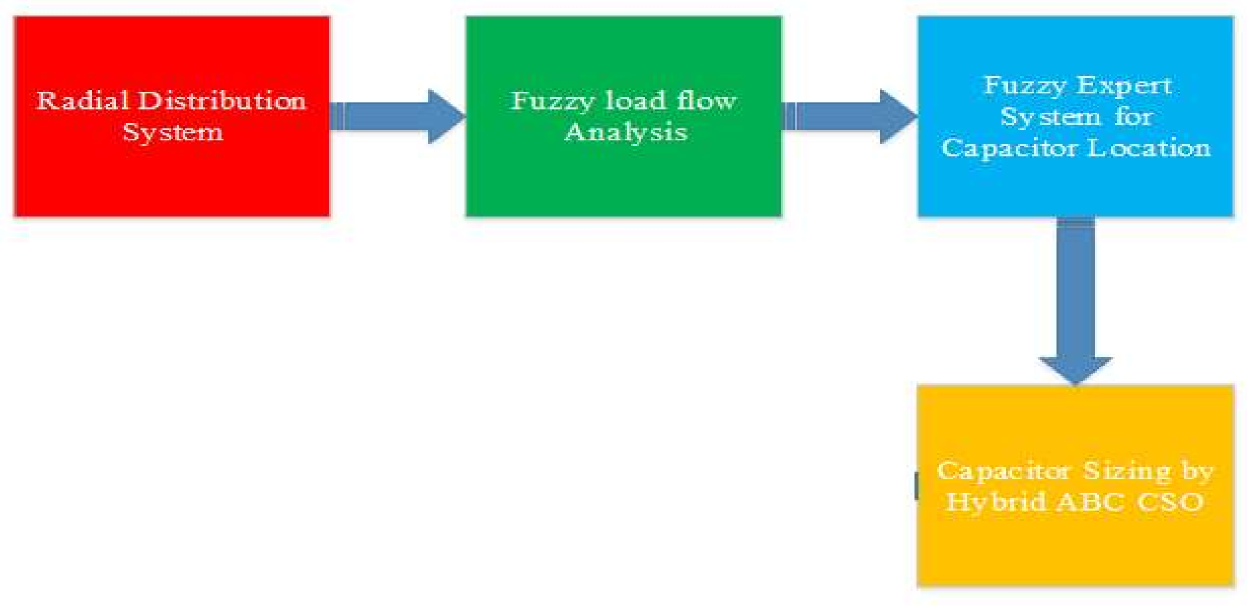


Figure 4.1: Proposed system for optimal capacitor sizing

4.2.1 FUZZY LOAD FLOW ANALYSIS

The mathematical model of a single branch system of a radial distribution network is shown in Fig. 4.2.

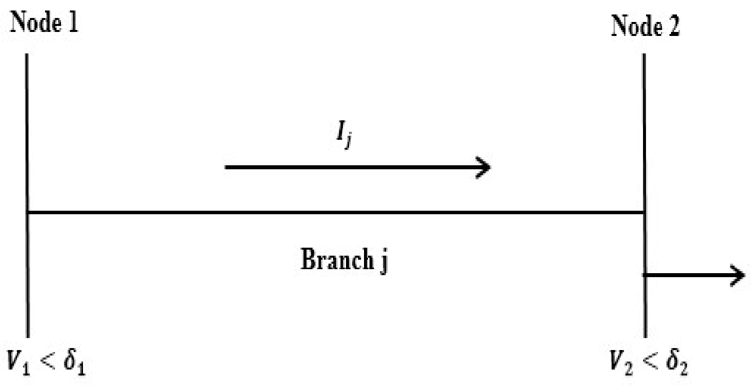


Figure 4.2: Mathematical model of single branch system

In Fig.4.2,

Node 1 and node 2 are sending-end and receiving-end nodes,

I_j represents current flowing through the branch j,

V_1 and V_2 are the magnitude of voltages at node 1 and node 2 respectively and

δ_1 and δ_2 are the angles of V_1 and V_2 respectively.

From the Fig.4.2, the current flowing through branch j is computed by Eq. (4.1).

$$I_j = \frac{V_1\angle\delta_1 - V_2\angle\delta_2}{Z_j} \tag{4.1}$$

The expression of power is given by Eq. (4.2).

$$P_2 - jQ_2 = V_2^* \times I_j \tag{4.2}$$

where $Z_j = R_j + jX_j$, where $R_j \; and \, X_j$ is the resistance and reactance of branch j

P_2 provides the addition of real power of all beyond node 2 and real power of the node 2 itself and the summation of the real power losses of all branches beyond node 2.

Q_2 provides the addition of reactive power of all beyond node 2 and reactive power of the node 2 itself and the summation of the reactive power losses of all branches beyond node 2.

From Eq. (4.1) and Eq. (4.2),

$$V_2 = \sqrt{B_j - A_j} \tag{4.3}$$

where,

$$A_j = P_2 \times R_j + Q_2 \times X_j - 0.5 \times (V_1)^2$$
$$B_j = \sqrt{\left(A_j^2 - \left(Z_j^2 \times \left(P_2^2 + Q_2^2\right)\right)\right)}$$

The real and reactive electricity loss of branch j is measured using Eq. (4.4) and Eq. (4.5) respectively.

$$P_{j(Loss)} = \frac{R_j \times \left[P_2^2 + Q_2^2\right]}{V_2^2} \tag{4.4}$$

$$Q_{j(Loss)} = \frac{X_j \times \left[P_2^2 + Q_2^2\right]}{V_2^2} \tag{4.5}$$

These estimations are done progressively till the convergence criteria is accomplished, i.e., the distinction in voltage between the previous iteration and the existing iteration is smaller to a certain value, for each node. That is

$$\max\left|V(old) - V(new)\right| < \varepsilon \tag{4.6}$$

where,

V (old) is the voltage obtained in previous iteration,

V (new) is the voltage obtained in present iteration and

$\mathcal{E}$ is the maximum allowable variation of voltage.

In spite of the fact that the data gathered by deterministic strategies for estimation are reliable, the conceivable errors can simply be normal. In order to tolerate such errors fuzzy method was incorporated into the load flow analysis. The fuzzy load flow analysis employs the FLC that will update the state vector of the system repeatedly. In fuzzy load flow analysis, the crisp input values are fed to the fuzzy procedure and dependent on the standards figured fuzzy output will be obtained. Lastly, these can be defuzzified utilizing some strategy for centroid estimation. The FLC utilized in this procedure is represented in the accompanying Fig.4.3.

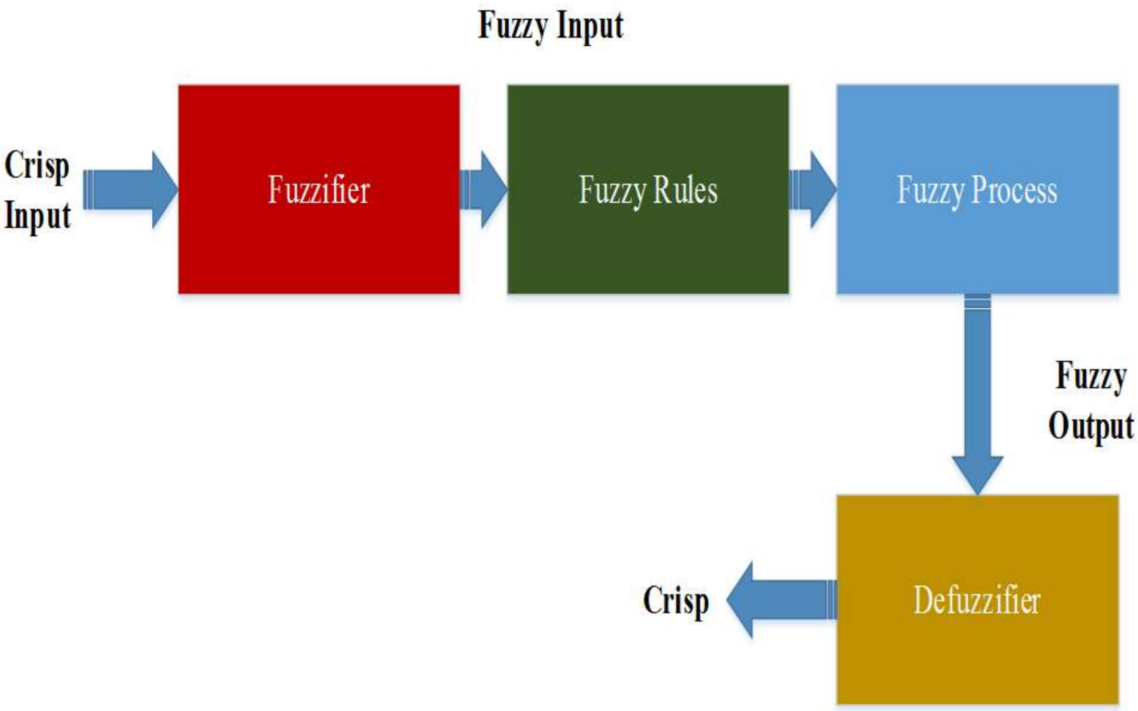


Figure 4.3: Block diagram of FLC

In the fuzzification procedure the power parameters are changed over into per-unit parameters as ΔP and ΔQ then they are fuzzified as ΔPFuz and ΔQFuz separately with seven semantic factors; large negative (LN), medium negative (MN), small negative (SN), zero (ZR), small positive (SP), medium positive (MP), large positive (LP). They are spoken to in Gaussian capacity. In view of the fuzzy guidelines created the fuzzy information sign are mapped into the comparing fuzzy yield signals. After that the fuzzy output signals are fed to the defuzzification process in which the correction of the fuzzy output signals is made. The crisp output is obtained by using the centroid of area method within the defuzzifier. The fuzzy load flow study has been carried out in both the bus systems using flat start condition and for bus power mismatch tolerance of 0.001pu (0.1MW/ MVAr). The output fuzzy signals are then passed to the defuzzification process in which the corrective action of the state variables will be performed iteratively. The method to select the location of capacitor has already been presented in Chapter 3. The equations needed for detecting the sensitive nodes are given below.

4.2.2 CAPACITOR LOCATION BY FUZZY EXPERT SYSTEM (FES)

By the max–prod implication method of inference, the resultant affiliation role of every fuzzy law is scaled to the least affiliation value of all the predecessors. Similarly, the last combined affiliation task is the result of the merger of entire scaled resultant affiliation tasks of the fuzzy rules. By this inference method, the capacitor appropriateness affiliation task, μ_s of node i for k fuzzy comments is given by Eq. (4.7).

$$\mu_s(i) = \max_k \left\lfloor \mu_p(i) \cdot \mu_v(i) \right\rfloor \tag{4.7}$$

Here μ_p and μ_v are the enrollment elements of power loss list and voltage individually. When the appropriateness enrollment capacity of a node is resolved, it must be defuzzified so as to figure the node's reasonableness positioning. The centroid technique for defuzzification has been chosen. This procedure of defuzzification revelations the focal point of locale of the enrollment work. In this manner, the capacitor situation reasonableness list is determined by:

$$S = \frac{\int \mu_s(x).xdx}{\int \mu_s(x)dx} \tag{4.8}$$

Where $\mu_s(x)$= Distribution function of capacitor placement suitability and

x = Point at which the membership function is maximum.

Therefore, the capacitor appropriateness of file will be determined for every single node and the busses having most elevated estimation of capacitor reasonableness list will be chosen for putting the capacitor.

4.2.3 CAPACITOR SIZING BASED ON HYBRID ARTIFICIAL BEE COLONY- CUCKOO SEARCH OPTIMIZATION

Artificial Bee Colony and Cuckoo Search Optimization algorithms are the well-known evolutionary algorithms that will mimic the insect or bird's behavior in problem modelling and solution. Here, combined Artificial Bee Colony and Cuckoo Search Optimization algorithm are used in order to select the most appropriate capacitor sizes to be placed at the selected buses obtained from fuzzy expert system approach. The ABC computation initially picks the irregular estimations of capacitor sizes. The ABC computation comprises of three stages. These are utilized honey bees, passerby honey bees and scout honey bees. Each stage will refresh the size of the capacitors and the most noticeably awful arrangement results toward the finish of the last stage can be upgraded with the utilization of the CSO computation. The contribution of the computation will be arbitrary estimation of capacitor sizes. This computation will be proceeded until the base power loss acquired with the most appropriate size of capacitors. In this manner the ABC-CSO computation appraises the size of the capacitor by using the objective function given by Eq. (4.9).

$$S = C_e \sum_{j=1}^{L} T_j P_{j(Loss)} + \sum_{i=1}^{N_L} \left(C_{cf} + C_c Q_{ci} \right) \tag{4.9}$$

where $P_{j(Loss)}$ =Power loss at jth load level, Q_{ci} =Reactive power injection from capacitor to node i, S=Savings, T_j =load duration, N_L =No. of capacitor location, L = No. of load level, C_e=Capacitor Energy cost of losses, C_{cf} =Capacitor installation cost and C_c=Capacitor marginal cost.

a) The Analogies of hybrid ABC-CSO algorithm with Capacitor Sizing Problem is given below:

The analogies used in the hybrid grouping of ABC-CSO algorithm with respect to the capacitor sizing difficult are given in the Table 4.1. Table 4.2 shows the parameters and its values used in ABC-CSO algorithm.

Table 4.1: Analogies of the proposed algorithm regarding capacitor sizing problem

Analogy	**Capacitor sizing problem**
Nourishment source in ABC	Random value of capacitor sizes
Nourishment source positions in ABC	Fitness values for the corresponding capacitor sizes
Suitability value	Total power loss and energy loss after placing the capacitors.
Suitability function F_j	Capacitor sizes with worst fitness values
Position (P_a)	Replacing the worst one with the best
γ, β, ran	Arbitrarily generated numbers from 0 to 1
New cuckoo X_i	New capacitor size
Step size α	Step size parameter related to the scale of the problem
Best nourishment source	Best value of capacitor size

Table 4.2: Parameters and its values used in ABC-CSO

Parameters	Values
Random value of capacitor sizes	Randomly selected numbers
Suitability value	0. 185µm
Suitability function F_j	0.178 kVAr
Position (P_a)	0.198 kVAr
γ, β, ran	0.2,0.5,0.8
New cuckoo X_i	0.179 kVAr
Step size α	32
Best nourishment source	0.182 kVAr

Based on the Table 4.1, ABC-CSO algorithm will be performed and the steps are illustrated in the next section.

b) The steps involved in the Hybrid ABC-CSO are

- Stage 1: Initialize the arbitrary estimations of capacitor sizes as nourishment source positions.
- Stage 2: Each utilized honey bee creates another nourishment source in their sustenance source location and the best source is exploited.
- Stage 3: Every passerby honey bee chooses a source contingent upon the nature of her answer, yields another nourishment source in chosen sustenance source location and the best source is adventured.
- Stage 4: Define the source to be relinquished and assign the honey bee utilized as a spy to search for new sources of sustenance.

  After this step CSO algorithm will replace the worst solutions with better values.
- Stage 5: Initialize an arbitrary populace of host homes.

- Stage 6: Obtain a cuckoo chaotic ally using toll flight conduct.

$$X_i(t+1)=X_i(t)+\alpha\oplus Levy(\lambda),\alpha>0$$

$$Levy(\lambda)=t(-\lambda),1<\lambda<3$$

$$stepsize\ \alpha = ran * step$$

$$step=\frac{U}{V^{1/\beta}}$$

$U = N*\sigma$ and $V = N$

$$\sigma=\left[\frac{\gamma(1+\beta)\sin\left(\frac{\pi*\beta}{2}\right)}{\gamma\left(\frac{1+\beta}{2}\right)*(\beta)*\left(2^{\frac{\beta-1}{2}}\right)}\right]^{\frac{1}{\beta}}$$

Where γ, β and *ran* are the random values range from 0 to 1.

- Stage 7: Appraise the suitability function (say F_i)
- Stage 8: Obtain a fresh host home and compute its suitability function say F_j
- Stage 9: If $F_i<F_j$, Substitute j with fresh answer else let j be the answer.
- Stage 10: Consent a portion of P_a of the foulest home by fabricating fresh ones at fresh positions utilizing Levy flights
- Stage 11: Retain the finest answers.
- Stage12: Rank the arrangements and locate the present best.
- Stage 13: Memorize the best nourishment source found up until this point.
- Stage 14: Repeat the means 2-13 until the halting model meet.

The mixture of Hybrid ABC-CSO procedure produces the finest ideal capacitor dimensions to be positioned at the selected nodes. The hybrid ABC-CSO algorithm pseudo code is thus represented where the capacitor size is given based on the ABC algorithm and also it estimates the size of the capacitor for providing an objective function. The fitness values are given based upon the levy flight behavior in the CS computation. The process is repeated until a better solution is obtained. By this hybrid algorithm the optimal size of the capacitor is achieved. Though there are many optimization algorithms available for the capacitor placement, the hybrid algorithm is proposed because it provides a better result of estimating the fitness value better than the other optimization algorithm. It also uses the fuzzy membership function to provide the better solution with the help of the objection function.

4.3 SIMULATION OUTPUTS AND DISCUSSIONS

Here the proposed method for placing and sizing of capacitors utilizing fuzzy load flow analysis, FES, hybrid ABC-CSO in a radial distribution network were implemented and their results are presented.

System Outline:
Operating System: Windows 8
Processor: Intel Core i3
RAM: 4 GB

The proposed method is performed 69-node and 34-node radial distribution networks.

4.3.1 69-NODE RADIAL DISTRIBUTION NETWORK

Figure 4.4 shows the 69-node radial distribution network having base values of 12.66 kV and 100 MVA. The line data and load data have been given in **Appendix-A**.

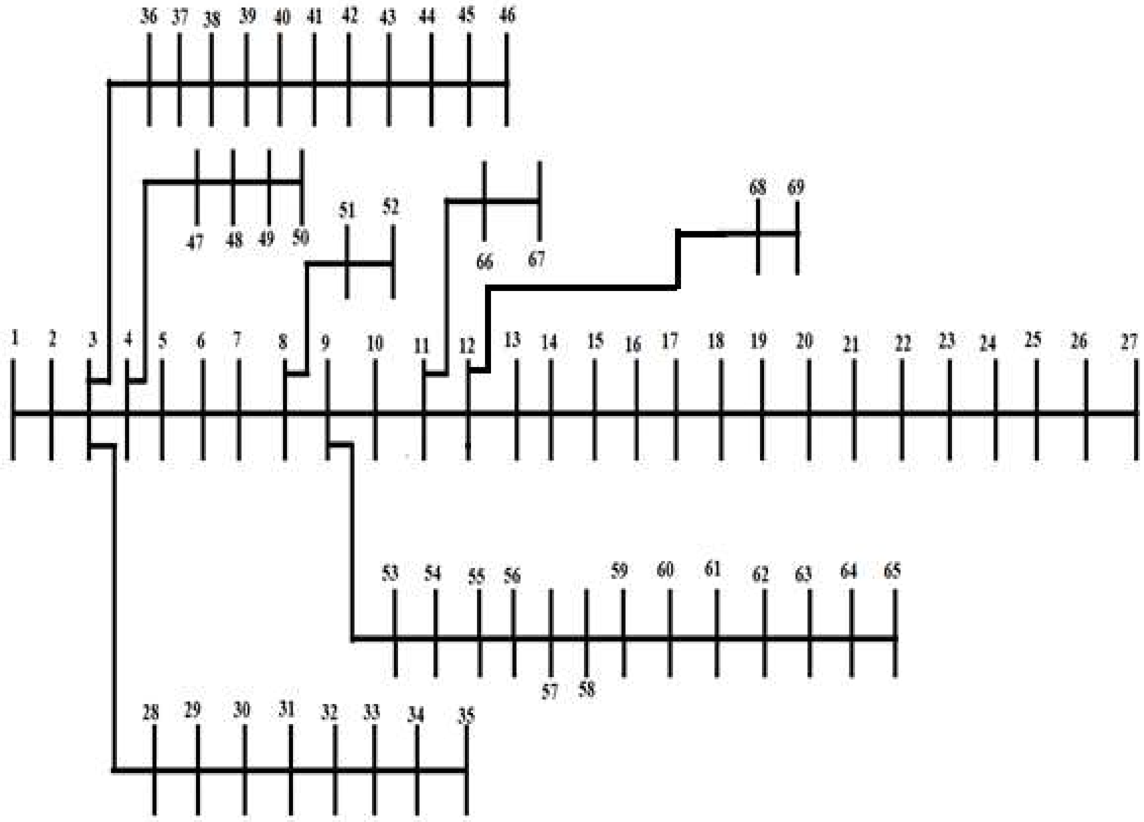


Figure 4.4: 69-node radial distribution network

Table 4.3 presents the voltage magnitude (p.u.), power loss index obtained by FES output. The minimum voltage is found at node number 65 and its p.u. value is 0.9019.

Table 4.4 shows the optimal sizes of capacitors to be integrated at the nodes 11,13,17,21,28,39 and 45 having values in kVAr of 118,86,113,109,90,99 and 88 respectively. Total capacitor size is 723 kVAr.

Table 4.5 shows the outcomes of 69-node radial distribution network in terms of real power loss (kW), reactive power loss (kVAr), minimum voltage (p.u.), energy loss (kWh), cost ($) and capacitor cost ($).
Table 4.6 shows the outcomes of the compensated 69-node radial distribution network obtained by the proposed method, ABC-PSO algorithm, ABC algorithm and PSO algorithm.

Figure 4.5 shows the voltage profile of 69-node radial distribution network before and after integration of capacitors using proposed method, ABC-PSO algorithm, ABC algorithm and PSO algorithm.

Figure 4.6 shows the comparison of capacitor sizes to be integrated in this network obtained by the proposed method, ABC-PSO algorithm, ABC algorithm and PSO algorithm.

Figure 4.7 shows the comparison of real power loss of the compensated 69-node radial distribution network obtained by the proposed method, ABC-PSO algorithm, ABC algorithm and PSO algorithm.

Table 4.3: Voltage, power loss and output of fuzzy expert system values for the 69-node radial distribution network

Node No.	**Voltage (p.u.)**	**Power Loss Index**	**Suitability Index (FES Output)**	**Node No.**	**Voltage (p.u.)**	**Power Loss Index**	**Suitability Index (FES Output)**
6	0.99008	0.0003	0.0807	37	0.99975	0.0000	0.0801
7	0.98079	0.0077	0.0965	39	0.99954	0.6658	0.7200
8	0.97858	0.0154	0.1111	40	0.99954	0.0001	0.0801
9	0.97744	0.0066	0.0958	41	0.99884	0.0000	0.0800
10	0.97245	0.0071	0.1403	43	0.99851	0.0001	0.0801
11	0.97134	0.6050	0.6089	45	0.99841	0.6681	0.7156
12	0.96819	0.0445	0.2075	46	0.99841	0.0003	0.0807
13	0.96526	0.6023	0.6011	48	0.99855	0.0005	0.0812
14	0.96237	0.0026	0.2469	49	0.99470	0.0083	0.0976
16	0.95897	0.0170	0.2500	50	0.99416	0.0090	0.0900
17	0.95807	0.5986	0.5991	51	0.97855	0.0081	0.0977

18	0.95808	0.0202	0.2501	52	0.97854	0.0008	0.0824
20	0.95732	0.0004	0.2500	53	0.97466	0.0012	0.0930
21	0.95684	0.5899	0.5985	54	0.97142	0.0074	0.1589
22	0.95683	0.0021	0.2500	55	0.96694	0.0078	0.2238
24	0.95660	0.0121	0.2500	59	0.92477	0.0818	0.3396
26	0.95637	0.0061	0.2500	61	0.91234	0.0410	0.2303
27	0.95637	0.0061	0.2500	62	0.91205	0.0314	0.2907
28	0.99997	0.6584	0.7365	64	0.90977	0.2201	0.4611
29	0.99985	0.0000	0.0800	65	0.90919	0.0591	0.3191
33	0.99973	0.0001	0.0802	66	0.97129	0.0051	0.1610
34	0.99901	0.0002	0.0803	67	0.97129	0.0051	0.1610
35	0.99895	0.0001	0.0801	68	0.96786	0.0088	0.2119
36	0.99999	0.0000	0.0800	69	0.96786	0.0088	0.2119

Table 4.4: Optimal size of capacitors to be integrated in 69-node radial distribution network

Node Number	**Capacitor Size (kVAr)**
11	118
13	86
17	133
21	109
28	90
39	99
45	88
Total kVAr	723

Table 4.5: Outcomes of 69-node radial distribution network before and after compensation

Factors	**After Capacitor placement**	**Before Capacitor placement**
Real Power loss (kW)	135.97	224.96
Reactive Power loss (kVAr)	39.36	114.15
Minimum voltage (p.u.) [Node No.]	0.96101 [65]	0.90919
Energy loss (kWh)	1239652.9	1950403.2
Cost ($)	1391789.23	2215658.0352
Capacitor Cost ($)	2169	-

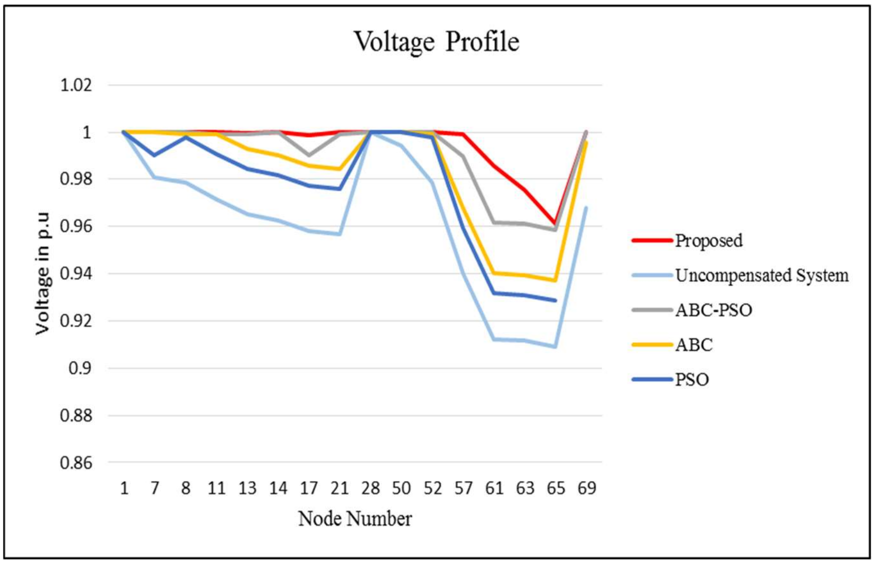


Figure 4.5: Voltage profile of 69-node radial distribution network before and after capacitor placement

Table 4.6: Outcomes of compensated 69-node radial distribution network obtained by proposed method, ABC-PSO, ABC and PSO algorithms

Technique	Total real power loss (kW)	Min. Voltage (p.u.)	Node No.
Proposed Method	135.97	0.96101	65
ABC-PSO Algorithm	143.63	0.95867	65
ABC Algorithm	148.65	0.93693	65
PSO Algorithm	150.98	0.928465	65

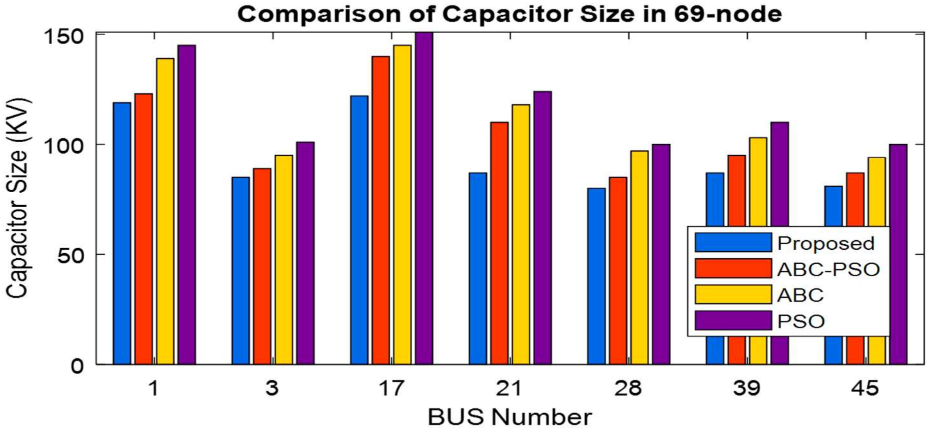


Figure 4.6: Comparison of capacitor sizes to be integrated in 69-node radial distribution network

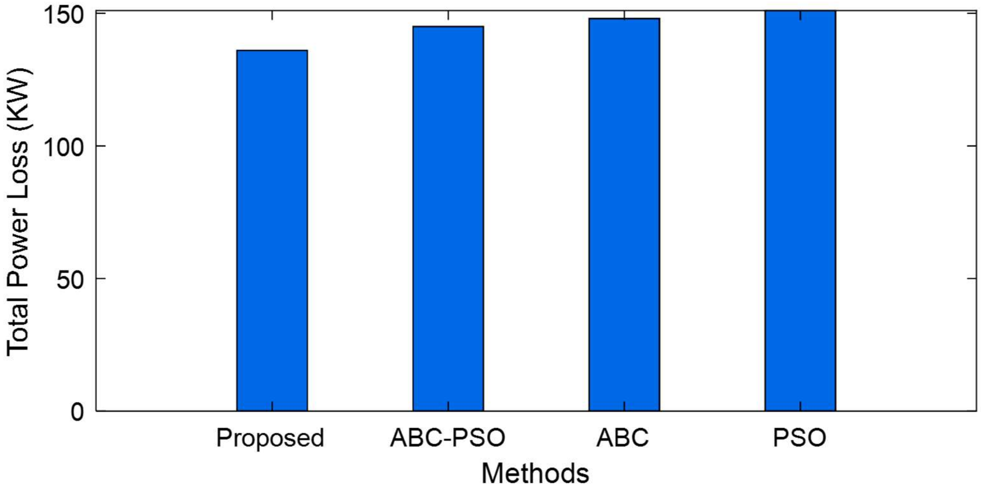


Figure 4.7: Comparison of total power loss of the compensated 69-node radial distribution network obtained by proposed method, ABC-PSO, ABC and PSO algorithms

4.3.2 34-NODE RADIAL DISTRIBUTION NETWORK

Figure 4.8 shows the 34-node radial distribution network having 11 kV and 100 MVA as the base value. The line data and load data are presented in **Appendix-B**.

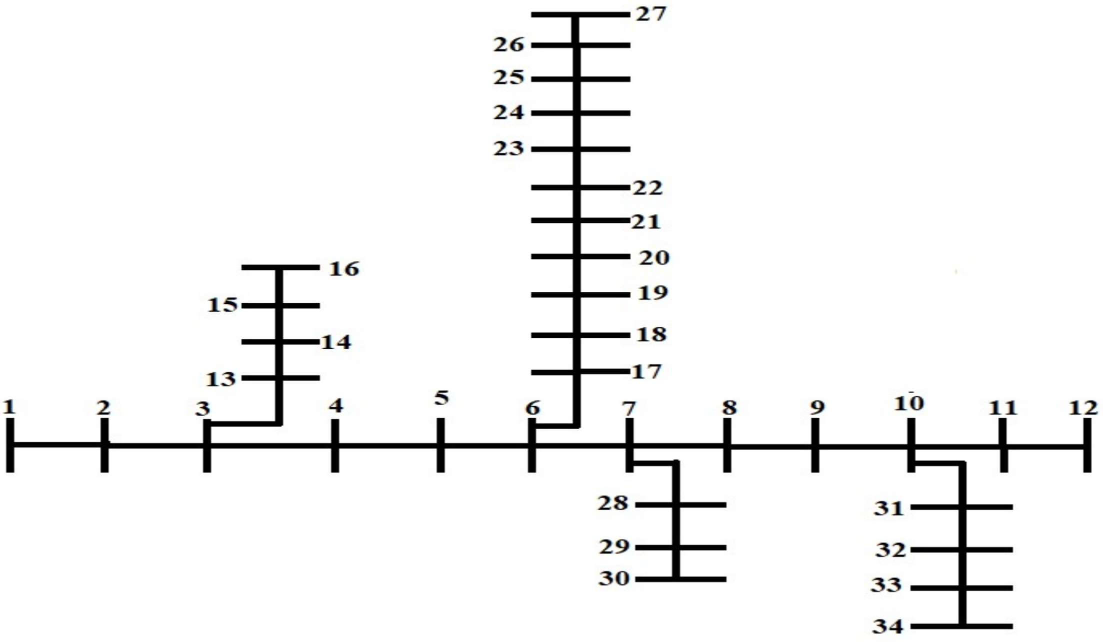


Figure 4.8: 34-node radial distribution network

The resultant voltage attained from the fuzzy load flow analysis and the yield of FES for the nodes in 34-node radial distribution network was provided in Table 4.7 where the least voltage esteem identified is 0.94164 p.u.

Table 4.7 presents the voltage magnitude (p.u.), power loss index obtained by FES output. The minimum voltage is found at node number 27 and its p.u. value is 0.94164.

Table 4.8 shows the optimal sizes of capacitors to be integrated at the nodes 2,6,7 and 12 having values in kVAr of 136,114,101 and 125 respectively. Total capacitor size is 476 kVAr.

Table 4.9 shows the outcomes of 34-node radial distribution network in terms of real power loss (kW), reactive power loss (kVAr), minimum voltage (p.u.), energy loss (kWh), cost ($) and capacitor cost ($).

Table 4.10 shows the outcomes of 34-node radial distribution network obtained by the proposed method, ABC-PSO algorithm, ABC algorithm and PSO algorithm.

Figure 4.9 shows the voltage profile of 34-node radial distribution network before and after integration of capacitors using proposed method, ABC-PSO algorithm, ABC algorithm and PSO algorithm.

Figure 4.10 shows the comparison of capacitor sizes to be integrated in this network obtained by the proposed method, ABC-PSO algorithm, ABC algorithm and PSO algorithm.

Figure 4.11 shows the comparison of real power loss of the compensated 34-node radial distribution network obtained by the proposed method, ABC-PSO algorithm, ABC algorithm and PSO algorithm.

.

Table 4.7: Voltage, power loss and output of fuzzy expert system values for the 34-node radial distribution network

Node No.	Voltage (p.u.)	Power Loss Index	Suitability Index (FES Result)	Node No.	Voltage (p.u.)	Power Loss Index	Suitability Index (FES Result)
1	1.00000	0.0000	0.0800	18	0.96223	0.5239	0.4853
2	0.99419	0.7579	0.7500	19	0.95812	0.5979	0.4842
3	0.98934	0.0000	0.0800	20	0.95487	0.5571	0.4562
4	0.98215	0.2834	0.2500	21	0.95196	0.5602	0.4500
5	0.97657	0.3848	0.3240	22	0.94873	0.5719	0.4610
6	0.97035	0.0000	0.6111	23	0.94605	0.5225	0.4554
7	0.96650	0.0000	0.6852	24	0.94348	0.5698	0.4902
8	0.96446	0.5874	0.0537	25	0.94224	0.5920	0.4943
9	0.96194	0.5307	0.4210	26	0.94185	0.6003	0.4023
10	0.96086	0.0000	0.2495	27	0.94164	0.6050	0.4089
11	0.96035	0.3938	0.3901	28	0.96624	0.1896	0.2371
12	0.96023	0.6584	0.64270	29	0.96624	0.1908	0.2371
13	0.98871	0.0552	0.1655	30	0.96586	0.1914	0.2380
14	0.98842	0.0567	0.1670	31	0.96043	0.1623	0.2497
15	0.98838	0.0570	0.1674	32	0.96017	0.1637	0.2500
16	0.98838	0.0096	0.1002	33	0.95990	0.1644	0.2500
17	0.96593	0.5591	0.4842	34	0.95990	0.1646	0.2500

Table 4.8: Optimal size of capacitors to be integrated in 34-node radial distribution network

Node Number	**Capacitor Size (kVAr)**
2	136
6	114
7	101
12	125
Total kVAr	476

Table 4.9: Outcomes of 34-node radial distribution network before and after compensation

Parameters	**Before Capacitor placement**	**After Capacitor placement**
Real Power loss (kW)	230	149.156
Reactive Power loss (kVAr)	142.5	61.46
Minimum voltage (p.u.) [Node No.]	0.94164 [27]	0.9615
Energy loss (kWh)	1994100	1216401.56
Cost ($)	2265297.6	138183.17
Capacitor Cost ($)	-	1428

Table 4.10: Outcomes of compensated 34-node radial distribution network obtained by proposed method, ABC-PSO, ABC and PSO algorithms

Method	**Total Power loss (kW)**	**Minimum Voltage (p.u.)**	**Node number**
Proposed	149.156	0.96150	25
ABC-PSO	157.489	0.95568	27
ABC	209.5612	0.95040	27
PSO	216.9465	0.94960	27

The comparison of the capacitor sizes and power loss of the network between the projected as well as prevailing approaches are shown in the Fig.4.10 and Fig.4.11.

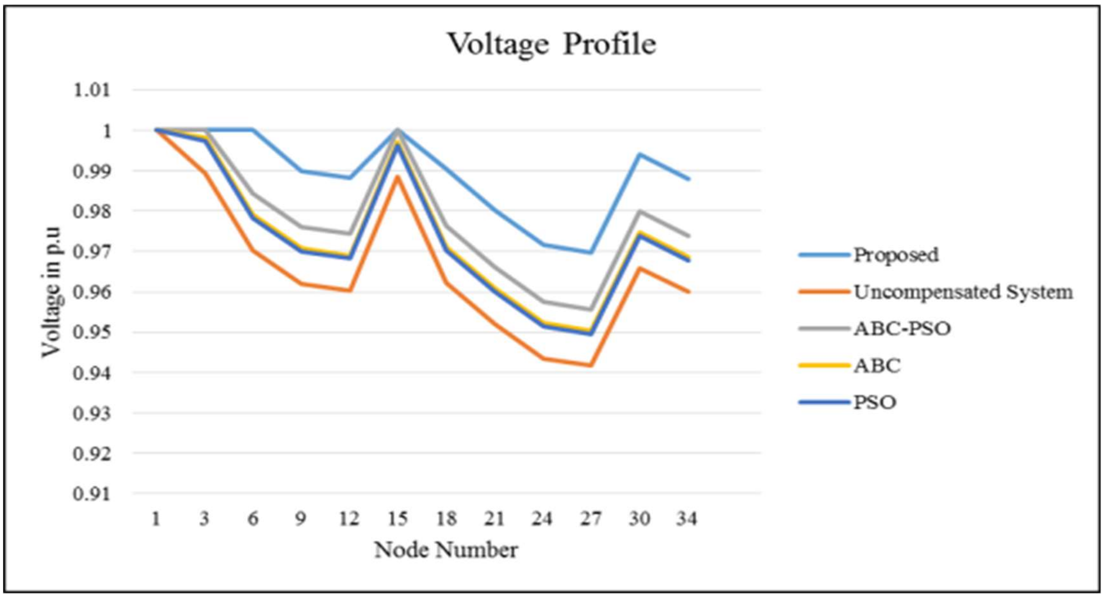


Figure 4.9: Voltage Profile of 34-node radial distribution network before and after capacitor placement

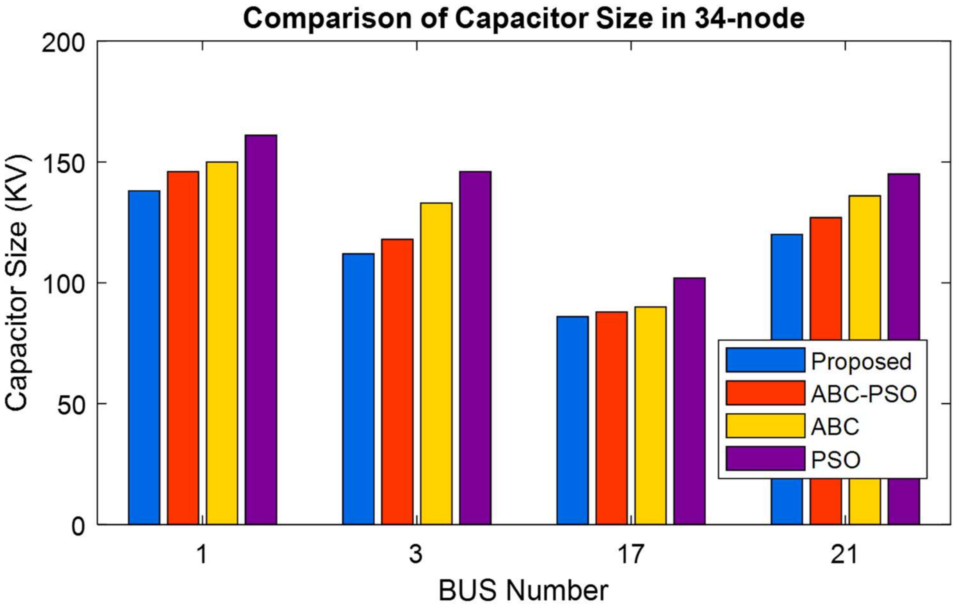


Figure 4.10: Comparison of capacitor sizes to be integrated in 34-node radial distribution network

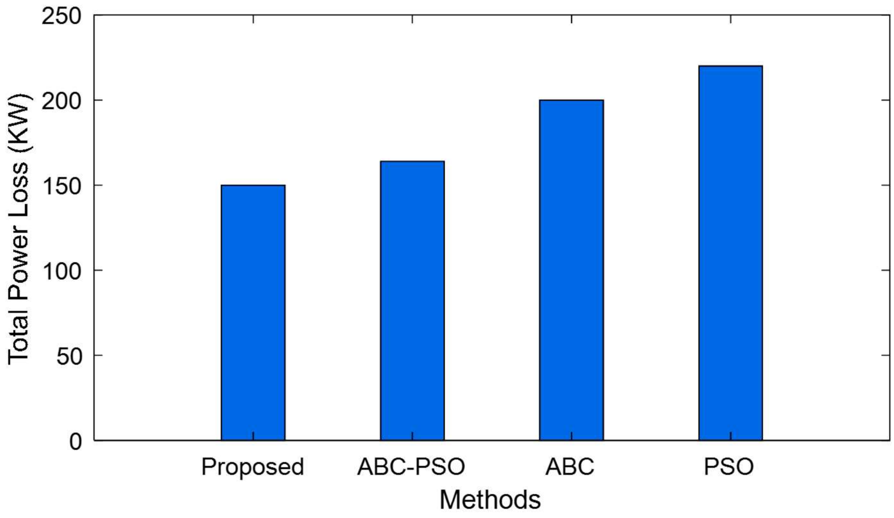


Figure 4.11: Comparison of total power loss of the compensated 34-node radial distribution network obtained by proposed method, ABC-PSO, ABC and PSO algorithms

Apart from the comparisons given for a 34-node radial distribution network, Table 4.11 shows the comparison of the proposed method with other available methods for this network.

Table 4.11: Comparison of total power loss of the compensated 34-node radial distribution network obtained by the proposed method, BSO [43] and BFO [51]

Methods	**Total Power Loss (kW)**
Proposed Method	149.156
BSO [43]	210.840
BFO [51]	160.600

Thus, the mathematical models BSO (Backtracking Search Optimization algorithm) and the BFO (Bacterial foraging Optimization Algorithm) are explained in the graph illustrated in Fig. 4.12.

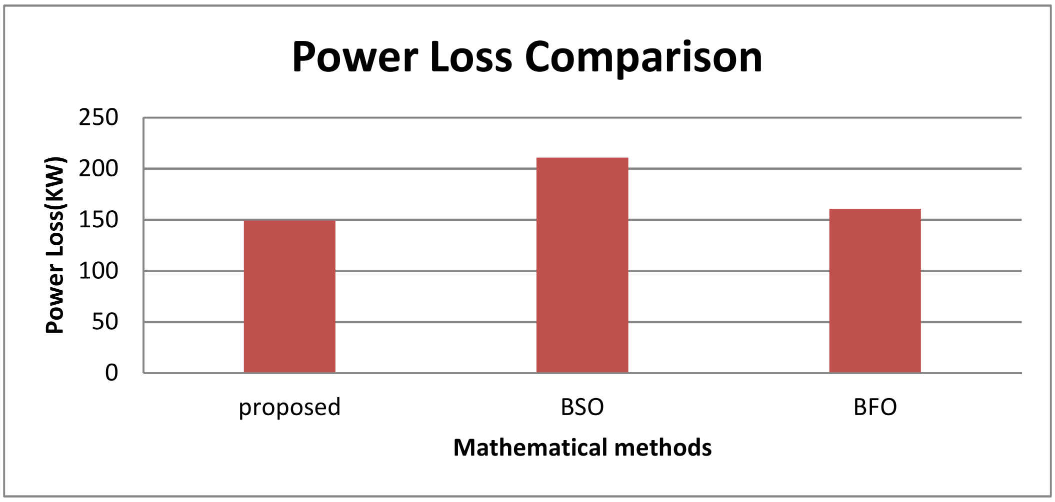


Figure 4.12: Comparison graph for power loss obtained by the proposed method with other methods

4.4 CONCLUSIONS

In this chapter the sizes of capacitors have been decided by using hybrid ABC-CSO algorithm. The appropriate nodes have been selected using FES. The proposed method has been tested on 69-node and 34-node radial distribution networks. The outcomes obtained by the proposed method have also been compared with ABC-PSO, ABC and PSO algorithms and other two existing algorithms [43,51]. The proposed method gives better results compared to these algorithms.

CHAPTER-5

OPTIMAL PLANNING AND PLACEMENT OF CAPACITOR IN DISTRIBUTION NETWORK

5.1 INTRODUCTION

The primary goal of extending the distribution network is to expand the structure of the distribution network to generate enhanced energy demand. Therefore, the expansion of the distribution network involves installing new substations, replacing old feeders and assembling new feeders to feed new nodes. Accordingly, the objective function for extending the distribution network problem can be created as follows. In this suggested technique, an earlier developed, fuzzy-based load flow assessment has been used to compute node voltages, actual energy loss, reactive power loss, etc.

Stable increment in power requirement upon distribution network because of characteristic development of a service domain or through incitement of energy business sector is a major test to scheduling designers and hence the network is versatile without abusing service quality. Load growth in network results into either extra consumption for fresh substation expansion or the current substation limit expansion [78]. Current day-to-day energy systems in latest memory are more strongly loaded to take care of the increasing demand, and one of the major problems linked to such a concentrated scheme is voltage breakdown or voltage instability. The voltage breakdown is depicted by a mild variation in the functioning of the system indicate owing to the development of loads in such a path, to the point that the voltage magnitude decreases continually until a sharp shift occurs [79]. The problem of voltage breakdown could only be explained as the energy system's inability to supply the reactive power needed or as a consequence of the system itself's excessive absorption of the reactive power [80]. In view of its prediction, aversion and basic corrections to ensure stable operation, the problem of voltage instability or breakdown has turned into a problem of amazing interest to utilities. As of late, the load demand in distribution networks are forcefully expanding because of financial and ecological weights. The working conditions are subsequently closer to the voltage stability limits [81].

In addition, distribution networks experience incessant particular load changes. As of late, the voltage stability (VS) of radiated distribution network was examined and different voltage stability indices have been created [82-84]. Capacitor banks were usually implemented in distribution networks to provide reactive power bolstering. The reactive reward measure given is all that much identified with the capacitors' positions in the feeders for distribution. Detecting the region, size, number and type of capacitors to be placed is incredibly central as it reduces energy and energy losses, extends the feeders ' available limit and enhances the feeder voltage profile [85]. In [86], PSO is used to select the optimal distribution and size of capacitors near harmonic sources, taking into account the instability. Another ideal supply-based building of microgrids in intelligent distribution networks was suggested in [87]. Two distinct strategies, one considering the linearized type of the equality limitations of the probabilistic optimization model and one in light of the point estimate strategy, were tried and looked at. In [88] it has been proposed to take care of the issue utilizing Cuckoo Search algorithm (CSA). A discrete adaptation of CSA is consolidated with a radial distribution power flow (RDPF) computation. To incorporate the vicinity of harmonics, the created method was coordinated with a harmonic power flow (HPF) computation.

The issue of picking ideal areas and dimensions of shunt capacitors in distribution networks is solved [89]. Various strategies for taking care of this issue in perspective of reducing losses were recommended in literatures [89-92]. Computations for improving voltage stability of transmission networks through ideally placing the capacitor [93, 94]. A connection among voltage stability and loss reduction were produced and the idea of boosting voltage stability by minimizing the loss has been delineated [95, 96]. From these it can be watched that numerous researches have done on optimal placement of capacitors in distribution networks without thought of distinctive loading condition. Though, these methods are fused for effectual scheduling of the network.

This chapter provides expansion of a distribution network through particle swarm optimization (PSO) by considering the objectives like power loss, short circuit capacity as well as energy not supplied function. Then from the obtained modified or expanded distribution network then we optimally place capacitor by using hybrid ABC-CSO algorithm by considering different loading conditions.

5.2 PROPOSED METHODOLGY FOR PLANNING OF DISTRIBUTION NETWORK

A new methodology is proposed for planning of distribution network with optimal location of capacitor under diverse loading conditions for reducing power losses as well as for enhancing the voltage profile. Initially expansion of planning of distribution network is done before carrying out planning of capacitor. A Hybrid Artificial Bee Colony (ABC)-Cuckoo Search Optimization (CSO) based capacitor placement under diverse loading conditions is used here. Under these different loading conditions, the required capacitive reactive power is computed to minimize power losses and increase the voltage profile. Then finally, the impact of load development on distribution network is analyzed before and after capacitor placement. The architecture of proposed method is shown in Fig. 5.1.

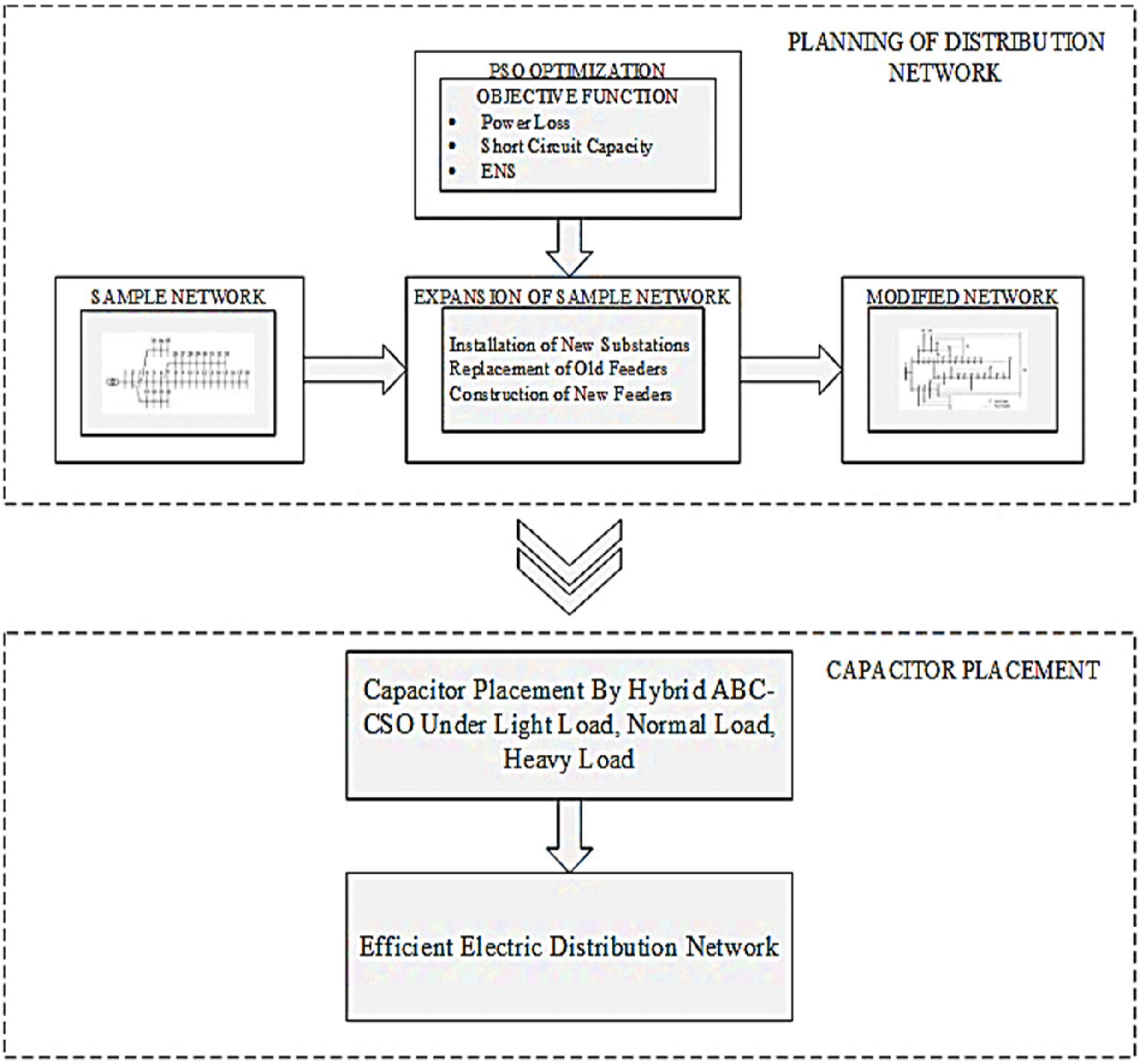


Figure 5.1: Architecture of the proposed method

Figure 5.1 clearly shows the process of projected technique, primarily, we are expanding the existing distribution network by installing new substations, replenish the ancient feeders, erection of fresh feeders based on investment and operation cost, power and voltage stability index by using Particle Swarm Optimization (PSO). Then, in the resultant modified network by using Hybrid ABC-CSO the optimal sized capacitors are allocated by ABC-PSO algorithm to provide the reactive power support as well as for enhancing the voltage profile with minimal power losses and to obtain an efficient electrical distribution network.

5.2.1 EXPANSION OF DISTRIBUTION NETWORK

The main objective of expanding the distribution network is to expand the distribution network structure to produce increased demand for energy. Expanding the distribution network therefore relates to installing new substations, replacing old feeders and assembling new feeders to feed new nodes. Accordingly, the objective function can be developed as follows for expanding the distribution network issue. In this proposed method, fuzzy based load flow analysis developed earlier has been used and it is used to compute the node voltages, real power loss, reactive power loss etc.

5.2.1.1 OBJECTIVE FUNCTIONS

The objective function for expansion of distribution network problem consists of three objectives and these are power losses, short circuit capacity, and energy not supplied.

A. Power Losses: Losses are dependent on line resistance and heat losses are generally referred to as currents. Our goal is to minimize complete power losses due to modifications in the distribution network given by Eq. (5.1).

$$P_{Loss} = \sum_{t=1}^{N_s} \sum_{k=1}^{N_b^t} \left(R_k^t \times \left| I_k^t \right|^2 \right) = F_1 \tag{5.1}$$

where N_s *and* N_b^t represent number of stages in planning and number of all branches respectively. R_k^t and I_k^t represent the resistance and current of k^th^ branch in the t^th^ stage respectively.

B. Short Circuit Capability: Improving the distribution network's brief circuit ability is one of the major issues in the planning of the distribution scheme. The short circuit capacity is directly related to node voltage strength at substation. If the short circuit capacity is high, it means that the node is capable of linking more loads. If the short circuit capability of the network is low, it means that the network is weak. The short circuit capability of node is computed by using Eq. (5.2).

$$S_{sc} = \frac{E}{Z} \tag{5.2}$$

where E is the equivalent voltage source and Z is impedance of node. Minimum short circuit capacity to ensure voltage stability of node which is given by using Eq. (5.3).

$$S_{sc\min} = \frac{2S_L(1+\sin\theta)}{E} \tag{5.3}$$

where $S_L = \sqrt{P_L^2 + Q_L^2}$ and θ is the angle of power factor, and S_L, P_L, Q_L represent apparent, real and reactive power of node. The relationship among short circuit capacity and voltage stability is given when the voltage of node is steady if $\left(\left(S_{sc\min} - S_{sc}\right)/S_{sc}\right) < 0$ and it is unstable when $\left(\left(S_{sc\min} - S_{sc}\right)/S_{sc}\right) > 0$. Therefore, voltage stability of node based on short circuit capacity is given by Eq. (5.4).

$$VS_{SCC} = \frac{2S_L Z(1+\sin\theta)}{E^2} \tag{5.4}$$

Therefore, the objective function is given by Eq. (5.5).

$$F_2 = Min\left[\sum_{t=1}^{N_s} \frac{1}{N_b^t} \sum_{i=1}^{N_b^t} VS_{SCC}^t\right] \tag{5.5}$$

C. Energy Not Supplied: Maximum energy outages in transmission and distribution networks are caused by faults. Energy not supplied (ENS) based upon the topology of distribution network and active power compensation into each node. Thus, expansion of distribution network problem is to be carried to optimize reliability like minimization of ENS as given by Eq. (5.6).

$$F_3 = ENS = \sum_{t=1}^{N_s} \sum_{j=1}^{N_b^t} P_i \sum_{i,j\in V, j\neq i} \left(U_j + U_j^{'}\right) \tag{5.6}$$

where U_j and $U_j^{'}$ are the administration inaccessibility identified with reparation time of all branches associated with node and administration inaccessibility associated with the rebuilding period of entire divisions associated with node I, separately. The overall objective function is given by Eq. (5.7).

$$F = Min[F_1 + F_2 + F_3] \tag{5.7}$$

5.2.1.2 PROBLEMS CONSTRAINTS

There are many constraints in distribution expansion planning, which are given below:

- Voltage Restrictions

$$V_{\min} \leq V^i \leq V_{\max} \qquad i = 1,2,3,\ldots,N_b$$

- Capacities of feeders sections

$$S_j^F \leq S_{j-cap}^F, \qquad \forall j \in F$$

- Capacities of substations

$$0 \leq S_i^{SS} \leq S_{i-cap}^{SS} \qquad \forall i \in S$$

- Radial Structure of Network

5.2.1.3 OPTIMIZATION BY PSO

Particle swarm optimization (PSO) is a stochastic optimization algorithm, which mimics animal social behaviors such as flocking of birds and the methods by which they find food sources. The algorithm starts by initializing a population of particles in the normalized search space with random positions *x* and random velocities *υ*, which are constrained between zero and one in each dimension. A particle position vector is converted into a candidate solution vector in the problem space through a mapping. Here equation (5.7) is regarded as the fitness of the corresponding particle. Updating the position and velocity of particles is performed by using Eq. (5.8).

$$v_i^{k+1} = wv_i^k + c_1 rand_1 \times \left(pbest_i - u_i^k \right) + c_2 rand_2 \times \left(gbest_i - u_i^k \right) \tag{5.8}$$

$$u_i^{k+1} = u_i^k + v_i^{k+1} \tag{5.9}$$

where v_i^k is velocity of agent i at reiteration k

w is weighting function

c_1 and c_2 are the comparative masses of the personal best function and global best function respectively.

rand is arbitrary integer among 0 and 1,

u_i^k is present location of element i at reiteration k,

$pbest_i$ is *pbest* of element i and

$gbest_i$ is *gbest* of the cluster.

The loading task is computed by utilizing the Eq.(5.10).

$$w = \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter \tag{5.10}$$

where $w_{\max}$ and $w_{\min}$ are the maximum and least mass, $iter_{\max}$ and $iter$ are maximum and present iteration value. The algorithmic stages are presented in Fig.5.2.

Step 1: *Initialize the particles randomly.*
Step 2: *Appraise the fitness function for every element using the equation (5.7).*
Step 3: *Fix the current elements as "pbest".*
Step 4: *Increase speed to the original elements to acquire a fresh set of elements.*
Step 5: *Evaluate the suitability esteem to every fresh group of elements.*
Step 6: *Match every individual element's suitability esteem for identifying the fresh "pbest" among 2 group of elements.*
Step 7: *Discover the least suitability esteem through matching 2 group of elements and matching element as "gbest".*
Step 8: *Modernize the position and speed of each particle by using equation (5.8) and (5.9).*
Step 9: *Iteration of PSO is reiterated till conjunction is completed.*

Figure 5.2: Steps involved in PSO

The resultant expanded distribution network is then used for optimal placement of capacitor, which is given in next section.

5.2.2 CAPACITOR PLACEMENT BY HYBRID ABC-CSO

Here, the capacitor's location is identified by utilizing sensitivity analysis and sizing of capacitor is done by Hybrid Artificial Bee Colony-Cuckoo Search (ABC-CSO) optimization algorithm. The loss sensitivity factor chooses the node that have highest reduction of loss after the placement of capacitor. Thus, the nodes can be used as capacitor placement candidate nodes. This node computation will decrease the optimization search room. Deliberate a line associated with an impedance among two busses i and j of R+jX connected to a load $P_{eff} + jQ_{eff}$. The real power loss of the line is expressed by Eq.(5.11).

$$P_{Loss}(j) = \frac{\left(P_{eff}^2(j) + Q_{eff}^2(j)\right)R}{\left(V(j)\right)^2} \tag{5.11}$$

And the reactive power loss of the line is expressed by Eq.(5.12).

$$Q_{Loss}(j) = \frac{\left(P_{eff}^2(j) + Q_{eff}^2(j)\right)X}{\left(V(j)\right)^2} \tag{5.12}$$

where $P_{eff}(j)$ and $Q_{eff}(j)$ are the total real power and reactive power provided reactively beyond node j. The LSFs have now been computed by using Eq. (5.13) and Eq. (5.14).

$$\frac{\partial P_{Loss}}{\partial Q_{eff}} = \frac{\left(2Q_{eff}(j)R\right)}{\left(V(j)\right)^2} \tag{5.13}$$

$$\frac{\partial Q_{Loss}}{\partial Q_{eff}} = \frac{\left(2Q_{eff}(j)X\right)}{\left(V(j)\right)^2} \tag{5.14}$$

The LSF given in the above Eq. (5.13) is computed from load flow analysis. The LSF estimate collected is organized in descending order and the corresponding node amounts are saved as $b_p(i)$ a vector for the node. The descending order of vector components provides the sequence from which compensation nodes are obtained. The uniform voltage sizes are computed from these vectors by deliberating the magnitudes of the base voltage provided by the vector given by Eq. (5.15).

$$N(i) = \left|V(i)\right| / 0.95 \tag{5.15}$$

Where $V[i]$ is the base voltage of the i^{th} node in the network. *N(i)* selects which node needs reactive compensation. The node with value of *N(i)<1.0* picked as candidate nodes for settlement of capacitor. These nodes are saved in node vector. LSF decides that node needs compensation or not. The value of *N(i)>1.0* that kind of node doesn't desire to compensate and it will not be included in node vector.

In the proposed method, the hybrid ABC-CSO algorithm for finding the optimal capacitor size has been used. Artificial Bee Colony and Cuckoo Search Optimization algorithms are the well-known evolutionary algorithms that imitate the conduct of insects or birds in modeling and solving problems. In this case, the combined ABC and CSO algorithm are used to select the most appropriate capacitor dimensions to be positioned on the selected nodes obtained from the analysis of loss sensitivity. Basic working of this optimization is the behavior of bees finding food surrounding the hive. In general, the bees are divided into three main groups that were engaged bees, watcher bees and spy bees. Every groups have diverse goals and task in search of food. In the proposed technique, each stage will update the size of the capacitors and the most noticeably terrible arrangement results toward the finish of the last stage can be enhanced with the utilization of the CSO computation. The contribution of the computation will be irregular estimation of capacitor sizes. This computation will be proceeded until the base power loss got with the most appropriate size of capacitors. Therefore, the ABC-CSO computation evaluates the size of the capacitor by limiting the beneath target work represented by Eq. (5.16).

$$S = C_e \sum_{j=1}^{L} T_j P_{j(Loss)} + \sum_{i=1}^{N_L} \left(C_{cf} + C_c Q_{ci} \right) \tag{5.16}$$

where $P_{j(Loss)}$ =Loss of power at jth load level, Q_{ci} =Reactive power injection to node from capacitor, S = Investments, T_j = loading period, N_L =No. of capacitor location, L = Number of load level, C_e = Capacitor Energy price of losses, C_{cf} = Capacitor fixing price and C_c =Peripheral price of capacitor. The basic steps involved in ABC-CSO is shown in Fig. 5.3.

Step:1 *Arbitrary esteem of capacitor dimensions are initialized as food source position*

Step:2 *In their food source site, employed bee generates a fresh food source and makes better use of it.*

Step:3 *Onlooker bee chooses a source based on the quality of its solution, generates a fresh source of food in a chosen source of food and exploits the better source.*

Step:4 *Fix the source to be removed and assign its bee to search for fresh sources of food.*

Step:5 *CSO based Scout Bee Phase Begins.*

Step:6 *Initialize arbitrary populace of host nests.*

Step:7 *Attain a cuckoo arbitrary by levy flight behavior*

$$X_i(t+1)=X_i(t)+\alpha\oplus Levy(\lambda),\alpha>0$$
$$Levy(\lambda)=t(-\lambda),1<\lambda<3$$

Step:8 *Estimate its suitability function (F_i).*

Step:9 *Now obtain a new host nest and compute the suitability function (F_j).*

Step:10 *If $F_i<F_j$, replenish j by fresh answer else j be the answer.*

Step:11 *Left a portion of P_a of bad nest by fabricating fresh ones at fresh location utilizing levy flights.*

Step:12 *Provide the best solutions.*

Step:13 *Rank the solutions and find the current best.*

Step:14 *Remember the greatest food source detected so far.*

Step:15 *Rehash the above steps till criteria achieved.*

Figure 5.3: Steps involved in ABC-CSO for sizing of capacitor

In terms of time, the load demand at the distribution substation fluctuates. Distribution feeders are midnight and quickly loaded in the first portion of the day at midnight and are loaded strongly during the moment available. Additionally, greater load demand outcomes in reduced voltage magnitude at the substation's most remote end and greater energy losses. Similarly, light load demand results in high voltage magnitude at the substation's most remote end and small energy losses. The voltage size variety inside ±5 % is allowable according to universal standard. By infusing required measure of shunt reactive power, voltage profile can be enhanced and along these lines the power losses will diminish. It implies the reactive power provided by capacitors is corresponding to loading conditions. Three different loading conditions i.e., light (50% of full load), normal (100% of full load) and peak load (130% of full load).

5.2.3 ANALYSIS OF IMPACT OF LOAD GROWTH

Due to the development of fresh load, the load on a feeder is increasing. A feeder can bring additional load on or as far as possible on the assumption of its ability. Due to present conveying capability, i.e., heat restriction or voltage regulation, feeder capacity is computed. Once the feeder capacity exceeds it is necessary to create new substation or extension of the current substation by expanding the new feeder. Because of expansion in load demand network encounters

- Node Voltage Deviation
- Voltage Stability Index
- Active and Reactive power demand

A. Node voltage deviation: Node voltage is one of the most important indicators of safety and power quality. The shift in voltage magnitude leads to bad electrical network implementation. The voltage deviation can be depicted by Eq. (5.17).

$$V_D = \sum_{i=1}^{N_b} \frac{|V_{Rat} - V_i|}{V_{Rat}} \tag{5.17}$$

where V_{Rat} is the system's base voltage in p.u., V_i is the genuine voltage of the i^{th} node. To the extent that it can meet the requirements of voltage regulation or heat limit, a feeder may require additional loads.

B. Voltage Stability Index: In this suggested technique, the computation of voltage stability index power flow formula is used. The index of voltage stability at the node computed by using Eq. (5.18).

$$VSI(m2) = |V(m1)|^4 - 4.0\{P(m2)x(jj) - Q(m2)r(jj)\}^2 - 4.0\{P(m2)r(jj) + Q(m2)x(jj)\}|V(m1)|^2 \tag{5.18}$$

where *VSI(m2)* = index of voltage stability of nodule *m2(m2 = 2,3 ,.., N*$_b$*), r(jj)* = resistance of division *jj, x(jj)* = reactance of division *jj, V(m1)* = voltage at nodule *m1, V(m2)* = voltage at nodule *m2, P(m2)* = entire genuine power load nourished over node *m2, Q(m2)* = entire reactive power load nourished over node *m2.*Circumstance for steady action of the outward distribution network is $VSI(m2) \geq 0$, for $m2 = 2,3,...,N_b$. The node where $VSI(m2)$ is least is the most delicate to voltage breakdown.

C. Active and reactive power demand: The active power and reactive power demand for some year is specified using Eq. (5.19) and Eq. (5.20) respectively.

$$P_L(k) = P_L(0)(1+G)^{\alpha k} \tag{5.19}$$

$$Q_L(k) = Q_L(0)(1+G)^{\alpha k} \tag{5.20}$$

where G is the yearly load development proportion, $P_L(k)$ =genuine power load at kth year, $Q_L(k)$ =reactive power load at kth year, $P_L(0)$ =genuine power load at base year, and $Q_L(0)$ =reactive power load at base year. Generally, load progression is derived from arithmetical records accessible for the concerned distribution network. The α value based upon the sort of load associated with the network. In this proposed method, we analyze the load growth on constant load.

5.3 SIMULATION RESULTS AND DISCUSSIONS

In this proposed method, we are expanding or modifying existing distribution network for optimal placement of capacitor by using PSO and Hybrid ABC-CSO algorithms in 33-node radial distribution network.

System Outline:

Operating System: Windows 8

Processor: Intel Core i3

RAM: 4 GB

In this method, for the expansion of distribution network for capacitor placement, the 33-node radial distribution network depicted as Figure 5.4 and the load data and line data are available in [97]. This test system has 32 nodes, 5 tie switches, 2 feeder substation and 32 sectionalizing switches. Three additional new loads points are added, which is shown in Table 5.1. In this, 15 existing branches can be upgraded and there are 12 routes available for installing new branches, which are presented as Table 5.2. The system data of this network is given in **Appendix-C.**

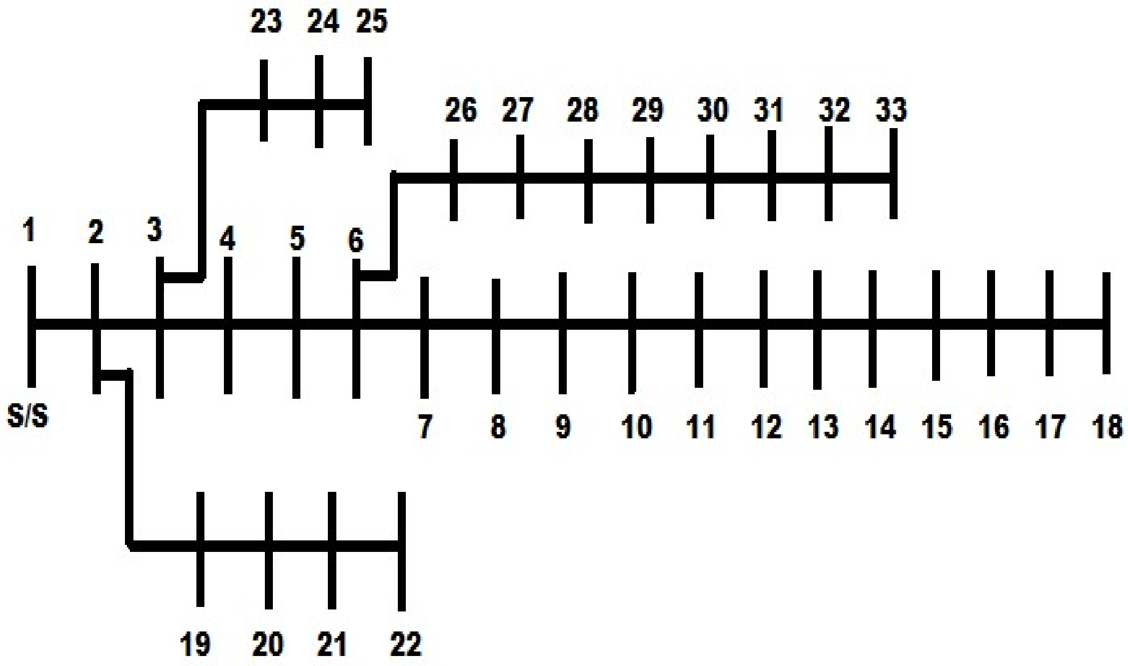


Figure 5.4: 33-node radial distribution network

Table 5.1: New Nodes Information

Node No.	**Real Power (kW)**	**Reactive Power (kVAr)**
34	320	270
35	110	50
36	180	60

Table 5.2: Available routes for new branches

From Node	To Node	Resistance (Ω)	Reactance (Ω)	U_j Resistance (Ω)	U'_j Reactance (Ω)
19	34	0.09	0.18	0.5	0.08
20	34	0.13	0.18	0.7	0.07
21	34	0.09	0.27	0.9	0.05
22	34	0.18	0.23	1	0.05
23	35	0.09	0.18	0.6	0.02
24	35	0.09	0.27	0.8	0.04
25	35	0.13	0.18	0.7	0.01
26	35	0.18	0.23	0.1	0.05
21	36	0.18	0.23	1	0.07
22	36	0.09	0.18	1	0.07
23	36	0.09	0.27	1	0.04
24	36	0.13	0.18	0.8	0.03

By using PSO based on the three objective functions like power losses, short circuit capacity, and energy not supplied with constraints we will get an optimized new modified distribution network which is shown in Fig.5.5.

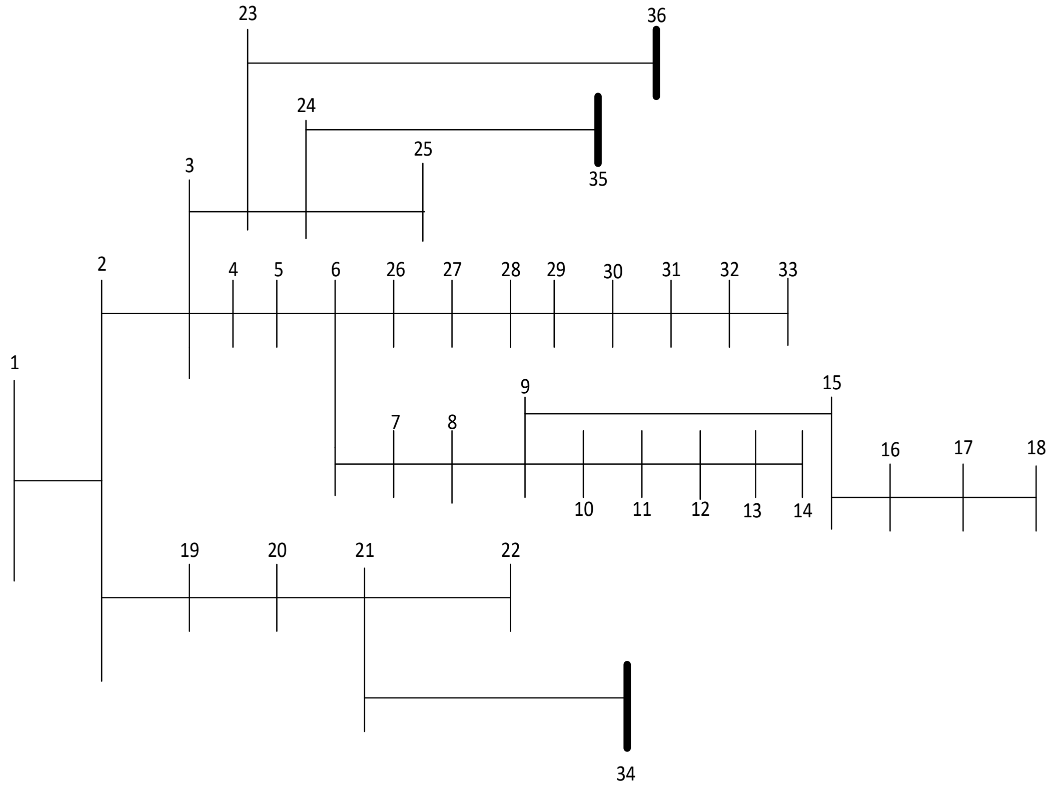


Figure 5.5: Modified 33-node distribution network

The load data and line data for the 33-node modified distribution network is given in Table 5.3 and Table 5.4.

Table 5.3: Load data for Modified 33-node Network

Node No.	P_L (kW)	Q_L (kVAr)	Node No	P_L (kW)	Q_L (kVAr)
2	100	60	20	90	40
3	90	40	21	90	40
4	120	80	22	90	40
5	60	30	23	90	50
6	60	20	24	420	200
7	200	100	25	420	200
8	200	100	26	60	25

9	60	20	27	60	25
10	60	20	28	60	20
11	45	30	29	120	70
12	60	35	30	200	600
13	60	35	31	150	70
14	120	80	32	210	100
15	60	10	33	60	40
16	60	20	34	320	270
17	60	20	35	110	50
18	90	40	36	180	60
19	90	40			

Table 5.4: Line data for Modified 33-node Network

Sending end node	Receiving-end node	R(Ω)	X(Ω)	Sending-end Node	Receiving end Node	R(Ω)	X(Ω)
1	2	0.0922	0.047	19	20	1.5042	1.3554
2	3	0.493	0.2511	20	21	0.4095	0.4780
3	4	0.366	0.1864	21	22	0.7089	0.9373
4	5	0.3811	0.1941	3	23	0.4512	0.3083
5	6	0.816	0.707	23	24	0.898	0.896
6	7	0.1872	0.9188	24	25	0.896	0.7011
7	8	0.7118	0.2351	6	26	0.203	0.1034
8	9	1.03	0.74	26	27	0.2842	0.1447

9	10	1.044	0.74	27	28	1.059	0.9337
10	11	0.1966	0.065	28	29	0.8042	0.7006
11	12	0.3744	0.1298	29	30	0.5075	0.2585
12	13	1.468	1.155	30	31	0.9744	0.963
13	14	0.5416	0.7129	31	32	0.3105	0.3619
9	15	0.3744	0.1298	32	33	0.341	0.5302
15	16	0.7463	0.545	21	34	0.09	0.27
16	17	1.289	1.721	24	35	0.09	0.27
17	18	0.732	0.574	23	36	0.09	0.27
2	19	0.593	0.2511				

The modified network and its data mentioned above is now used for optimal placement of capacitor by ABC-CSO under different load conditions. Here three types of load normal load, light load and peak load are considered. The outputs of the 33-node distribution network are shown in Table 5.5.

Table 5.5: Outputs of 33-node distribution system using proposed method under diverse load circumstances

Parameters	**Light Load**		**Normal load**		**Peak load**	
	Before Capacitor placement	**After Capacitor placement**	**Before Capacitor placement**	**After Capacitor placement**	**Before Capacitor placement**	**After Capacitor placement**
Power loss (kW)	78.9869	53.8475	231.502	151.7633	601.324	410.95
Minimum node voltage (p. u.)	0.9583	0.9678	0.9131	0.9341	0.8528	0.8818
Capacitor Location	-	12,24,30	-	12,24,30	-	12,24,30
Capacitor Size	-	150,100, 600	-	400, 550, 900	-	550,100, 1050
Energy Cost ($/kWh)	41515.514	28302.2442	121677.451	79766.8181	316055.999	215995.32
Capacitor Cost ($)	-	2550	-	5550	-	5100

The effect of load growth on different system parameters is shown in Table 5.6.

Table 5.6: Impact of Load Development on diverse Parameters

Parameters	**Base Case**	**First Year**	**Second Year**	**Third Year**	**Fourth Year**	**Fifth Year**
Active Power Load (MW)	4.325	4.645	4.993	5.367	5.769	6.201
Reactive Power Load (MVAr)	2.680	2.881	3.097	3.329	3.578	3.846
Min. Voltage (p.u.)	0.9214	0.9024	0.8914	0.8835	0.8758	0.8647
Voltage Deviance	1.6471	1.7787	1.9347	2.1674	2.3485	2.5468
Min. Voltage Solidity Index (p.u.)	0.6847	0.6636	0.6411	0.6173	0.5919	0.5650

Obviously, feeder can take charge growth up to the second year from this table. This is because in the subsequent year the base voltage size is 0.8914 which is near to the minimum permissible voltage limit. In the third year, the voltage cutoff is neglected, which is below the allowable containment point of the foundation. This issue emerges because of load development. Rate voltage deviation is growing with the year and in the fifth year it reaches up to 2.5468.

It is obvious from Fig. 5.6 that because of load development voltage extent at every node step by step diminishes with the quantity of years. Essentially, from Fig. 5.7, it is seen that the base voltage dependability list decreases with load development.

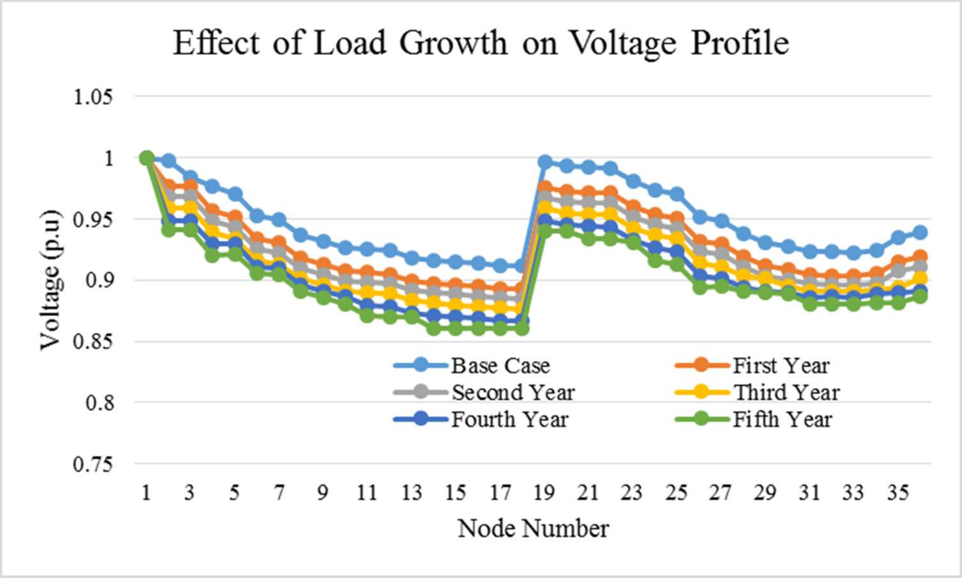


Figure 5.6: Impact of load development on voltage profile

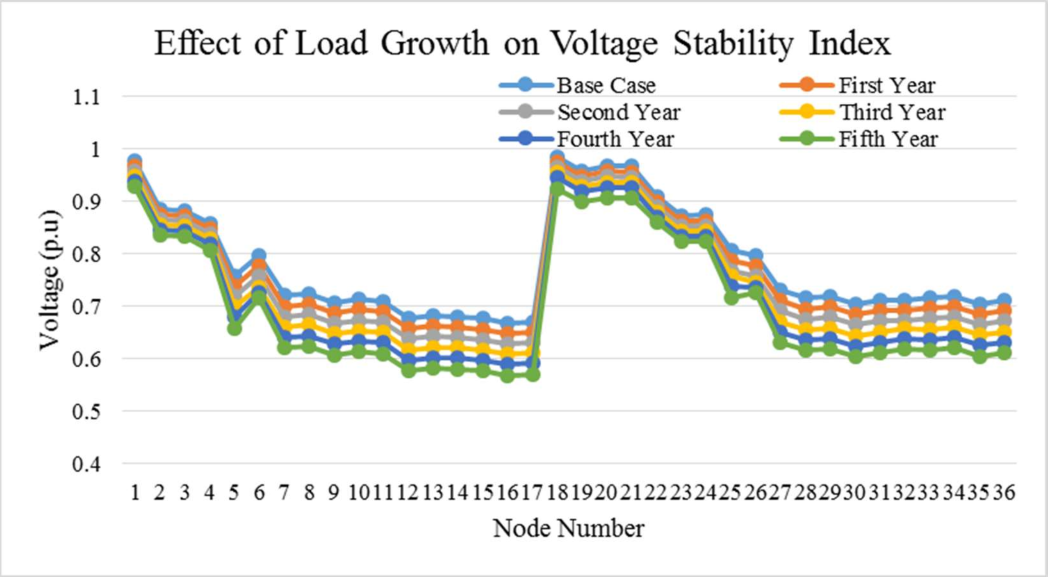


Figure 5.7: Influence of Load development on index of voltage stability

A. ***Node voltage Deviation:*** The node voltage deviations with various capacitors for distinct years are shown in Table 5.7, evidently increases in voltage deviation with load expansion each year. It is further evident from Table 5.7 that there is an enormous reduction in voltage deviation when distinct number capacitors are regarded with the establishment of separate number of capacitors.

Table 5.7: Voltage Deviation for Different Year

Load Growth	Voltage Deviation				
	Without Capacitor	With Capacitor			
		One Location	Two Location	Three Location	Four Location
Year 1	1.8574	1.0678	1.0325	1.0147	0.9798
Year 2	2.1058	1.1947	1.1015	1.0014	0.9846
Year 3	2.2546	1.2647	1.2104	1.1719	1.1547
Year 4	2.4047	1.3247	1.2647	1.2147	1.1912
Year 5	2.5349	1.4314	1.3417	1.3149	1.2945

B. ***Voltage Stability Index:*** It is to be noticed that base estimation of voltage stability improves a lot with the integration of capacitor. In addition, when numerous numbers of capacitor are optimally put, the base estimation of voltage soundness record improves altogether, which is obvious from the four-capacitor case introduced in Fig. 5.8 with the expansion in load development.

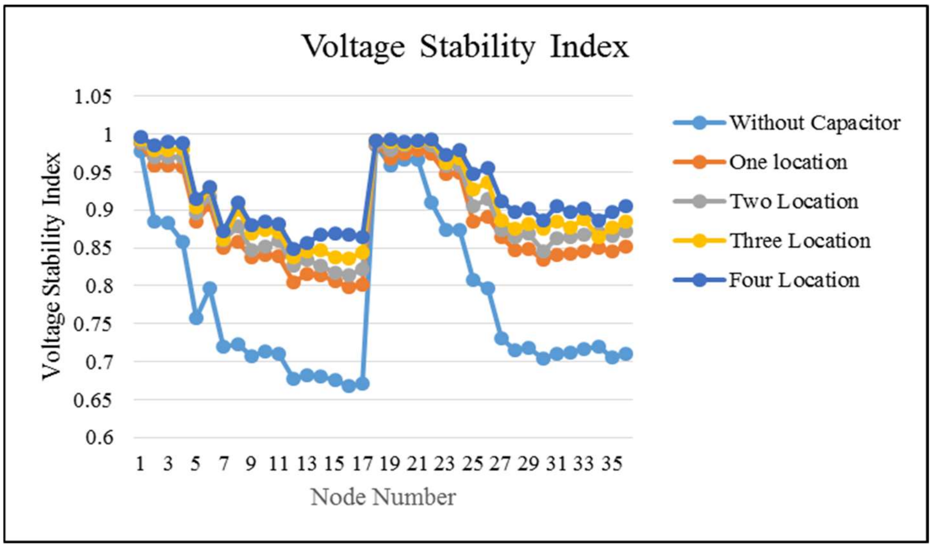


Figure 5.8: Development in voltage stability index after capacitor placement in view of load development in second year

5.4 CONCLUSIONS

An efficient planning of distribution network with optimal location of capacitor under diverse loading conditions for reducing power losses as well as for enhancing voltage profile have been presented. Initially expansion of planning of 33-node radial distribution network is done before carrying out planning of capacitor. This proposal presents a new methodology using Hybrid Artificial Bee Colony (ABC)-Cuckoo Search Optimization (CSO) based capacitor placement under light, normal and peak load conditions. Under these different loading conditions, the required capacitive reactive power is computed to minimize power losses and improve the voltage profile. Then finally, the impact of load development on distribution network is analyzed afore and afterward placing the capacitor. The proposed methodology has been executed on MATLAB working platform and outcomes has been scrutinized. The simulation outputs specify that the proposed methodology is suitable for efficient scheduling of radial distribution network. The effect of load growth in capacitor placement has also been considered using modified 33-node radial distribution network.

CHAPTER-6

OVERALL CONCLUSIONS AND FURURE SCOPES OF RESEARCH WORK

6.1 OVERALL CONCLUSIONS

Initially we proposed a technique for reducing the power loss and to enhance the voltage profile of the radial distribution network utilizing the optimally estimated capacitors at the nodes is proposed, which have greatest loss decrease when the optimal capacitors are integrated at the appropriate nodes. The fuzzy load flow analysis has been utilized to compute the total power loss of the system. The Fuzzy Inferencing System have been used to pick up the appropriate nodes from the sensitive nodes and the hybrid ABC-PSO algorithm has been used to compute the optimal sizes of the capacitors. The proposed method has been tested on 69-node and 34-node radial distribution networks and the execution is differentiated and analyzed and the present strategies for capacitor course of action. The results showed that the proposed technique gives favored results over the present methodologies. As an expansion, another methodology for capacitor placement issue has been exhibited. The FES method is suitable for choosing the appropriate nodes to integrate the capacitors. The hybrid ABC-CSO algorithm has been used to find the optimal sizes of the capacitors to be integrated. The simulation results obtained show the improvements for the parameters such as the power, voltage, energy, capacitor cost etc. The comparisons are made with the existing algorithms such as the ABC-PSO, PSO (Particle Swarm Optimization), ABC and also with the other mathematical model such as the BSO and BFO.

Hence the obtained results show remarkable improvements in all the parameters when comparing with the existing methods. The simulation results indicate that the proposed approach effectively allocates the capacitor in the distribution compared to other methods. Finally, an efficient planning of distribution network with optimal location of capacitor under diverse loading conditions for reducing power losses as well as for enhancing voltage profile have been presented. Initially expansion of planning of distribution system is done before carrying out planning of capacitor. This proposal presents a new methodology using Hybrid Artificial Bee Colony (ABC)-Cuckoo Search Optimization (CSO) based capacitor placement under light, normal and peak load conditions. Under these different loading conditions, the required capacitive reactive power is computed to minimize power losses and improve the voltage profile. Then finally, the impact of load development on distribution network is analyzed before and after placing the capacitor. The proposed methodology has been executed on MATLAB working platform and outcomes has been scrutinized. The simulation outputs specify that the proposed methodology is suitable for efficient scheduling of radial distribution network.

6.2 FURURE SCOPES OF RESEARCH WORK

The following are the future scope of works:

- Model predictive controllers would be used in the future to determine appropriate candidate nodes for capacitor placement in a distribution network.
- The same procedure can be carried out on unbalanced radial distribution networks.
- The hybrid algorithm like ABC-BAT can also be tested in balanced and unbalanced radial distribution networks.

REFERENCES

[1] Blythe, A. R., Blythe, T. and Bloor, D. “Electrical properties of polymers”, Cambridge university press, 2005.

[2] Krishna, A. and Pillai, G. "Voltage Stability and Reactive Power Sharing in Microgrids with Distributed Rotational and Electronic Generation", Feedback, Vol, 3, p. 8.

[3] Mosteiro-Romero, M., Krogmann, U., Wallbaum, H., Ostermeyer, Y., Senick, J.S. and Andrews, C.J. "Relative importance of electricity sources and construction practices in residential buildings: A Swiss-US comparison of energy related life-cycle impacts", Energy and Buildings, Vol. 68, pp. 620-631, 2014.

[4] Rudkevich, A. "On the supply function equilibrium and its applications in electricity markets", Decision Support Systems, Vol. 40, No. 3-4, pp. 409-425, 2005.

[5] Sundqvist, T. and Söderholm, P. "Valuing the environmental impacts of electricity generation: a critical survey", The Journal of Energy Literature, 2002.

[6] Brunekreeft, G., Neuhoff, K. and Newbery, D. "Electricity transmission: An overview of the current debate", Utilities Policy, Vol.13, No. 2, pp. 73-93, 2005.

[7] Gers, J.M. and Holmes, E.J. "Protection of electricity distribution networks", Vol. 47. IET, 2005.

[8] Joskow, P.L. "Incentive regulation in theory and practice: electricity distribution and transmission networks." In Economic Regulation and Its Reform: What Have We Learned? ", pp. 291-344. University of Chicago Press, 2014.

[9] Sirjani, R., Mohamed, A. and Shareef, H. "System using Harmony Search Algorithm", Journal of Applied Sciences, Vol. 10, No. 23, pp. 2998-3006, 2010.

[10] Choi, J. Y. and Swaminathan, M. "Decoupling Capacitor Placement in Power Delivery Networks Using MFEM", IEEE Transactions on

Components Packaging and Manufacturing Technology, Vol. 1, No. 10, pp. 1651-1661, 2011.

[11] Mendes, A., Franca, P.M., Lyra, C., Pissarra, C. and Cavellucci, C. "Capacitor placement in large-sized radial distribution networks", IEE Proceedings-Generation, Transmission and Distribution, Vol.152, No. 4, pp. 496-502,2005

[12] Rao, R. S., Narasimham, S.V.L. and Ramalingaraju, M. "Optimal capacitor placement in a radial distribution network using plant growth simulation algorithm", International Journal of Electrical Power & Energy Systems, Vol. 33, No. 5, pp. 1133-1139, 2011.

[13] Kleinberg, M.R., Miu, K., Segal, N., Lehmann, H. and Figura, T.R. "A Partitioning Method for Distributed Capacitor Control of Electric Power Distribution Systems", IEEE Transactions on Power Systems, Vol. 29, No. 2, pp.637-644, 2014.

[14] Bernardon, Daniel Pinheiro, Vinicius Jacques Garcia, Adriana Scheffer Quintela Ferreira, and Luciane Neves Canha. "Multicriteria distribution network reconfiguration considering subtransmission analysis", IEEE Transactions on Power Delivery, Vol. 25, No. 4, pp. 2684-2691,2010.

[15] dos Sanyos, C.M.P. "Determination of Electrical Power Losses in Distribution System", IEEE PES Transmission and Distribution Conference and Exposition Latin America, Venezuela, pp. 1-5, 2006.

[16] Ibrahim, E. S. "Management of loss reduction projects for power distribution systems", Electric Power Systems Research, Vol. 55, No. 1, pp. 49-56, 2010.

[17] Murari, K. and Padhy, N.P. "A Network-Topology-Based Approach for the Load-Flow Solution of AC–DC Distribution System With Distributed Generations", IEEE Transactions on Industrial Informatics, Vol. 15, No. 3, pp. 1508-1520, 2019.

[18] Prasanna, K. M. L., Somlal, J., Ranjithkumar, R.J. and Jain, A. "Load Flow studies for Distribution system with and without Distributed generation", Power Transformers, pp.34, 2015.

[19] Paatero, J.V. and Lund, P.D. "Effects of large-scale photovoltaic power integration on electricity distribution networks", Renewable Energy, Vol. 32, No. 2, pp. 216-234,2007.

[20] Mumtaz, M., Khan, H.S., Aamir, M., Ali, M. and Rehman, A. "Load Flow Analysis of CIGRE Benchmark Model Using ETAP", Proceedings of the International Conference on Renewable, Applied and New Energy Technologies ICRANET-2018, 19-22 November 2018, Air University, Islamabad, Pakistan

[21] Georgilakis, P. S. and Hatziargyriou, N.D. "Optimal distributed generation placement in power distribution networks: models, methods, and future research", IEEE Transactions on power systems, Vol. 28, No. 3, pp. 3420-3428, 2013.

[22] Shrestha, A., Kumar, S., Shah, B.B.,Raj, B. and Wagle, A. "Load Flow Analysis of Primary Distribution System using Power System Analysis Tool (PSAT): A Case of Upper Karnali Hydropower Project", Conference: 5th International Conference on Developments in Renewable Energy Technology, Kathmandu, Nepal

[23] Husain, T., Muqueem, K. and Ansari, M.M. "Load flow analysis of radial and mesh distribution system using ZIP model", In 2016 International Conference on Global Trends in Signal Processing, Information Computing and Communication (ICGTSPICC), pp. 419-427. IEEE, 2016.

[24] Buayai, K., Ongsakul, W., Nadarajah, M. and Pauirnchai, K. "GIS based distribution load flow for better planning and operation", In 2011 International Conference & Utility Exhibition on Power and Energy Systems: Issues and Prospects for Asia (ICUE), pp. 1-7. IEEE, 2011.

[25] Muruganantham, B., Gnanadass, R. and Padhy, N.P. "Performance analysis and comparison of load flow methods in a practical distribution system", In 2016 National Power Systems Conference (NPSC), pp. 1-6. IEEE, 2016.

[26] Idoniboyeobu, D. C. and Ibeni, C. "Analysis for Electical Load Flow Studies in Port Harcourt, Nigeria, Using Newton Raphson Fast Decoupled Techniques", Power Distribution Project.

[27] EFE, S. B. "Power Flow Analysis of a Distribution System Under Fault Conditions", International Journal, Vol. 1, No. 1,pp.22-27,2016.

[28] Kannan, S.M., Renuga, P., Kalyani, S., and Muthukumaran, E. "Optimal capacitor placement and sizing using Fuzzy-DE and FuzzyMAPSO methods", Applied Soft Computing, Vol.11, No. 8, pp. 4997–5005, 2011.

[29] Soni, N. B. and Tyagi, H. "Optimization of Electrical 3 phase power distribution loss to rural areas in Uttrakhand State", International Journal of Advances in Scientific Research and Engineering, Vol. 4,2018.

[30] Sultana, U., Khairuddin, A.B., Aman, M.M., Mokhtar, A.S. and Zareen, N. "A review of optimum DG placement based on minimization of power losses and voltage stability enhancement of distribution system", Renewable and Sustainable Energy Reviews, Vol. 63, pp. 363-378, 2016.

[31] Mendoza, G. E., Vacas, V.M. and Ferreira, N.R. "Optimal Capacitor Allocation and Sizing in Distribution Networks Using Particle Swarm Optimization Algorithm", In 2018 Workshop on Communication Networks and Power Systems (WCNPS), pp. 1-5. IEEE, 2018.

[32] Siddiqui, A.S., Khan, M.T. and Iqbal, F. “Determination of optimal location of TCSC and STATCOM for congestion management in deregulated power system", International journal of System Assurance and Engineering, Vol. 8, No.1, pp. 110–117,2017.

[33] Ponnavaikko, N., Rao, K.P. and Venkata, S.S. "Distribution system planning through a quadratic mixed integer programming approach", IEEE Transactions on Power Delivery, Vol. 2, No. 4, pp. 1157-1163, 1987.

[34] Olivella-Rosell, P., Bullich-Massagué, E., Aragüés-Peñalba, M., Sumper, A., Ottesen, S.Q., Vidal-Clos, J.A. and Villafáfila-Robles, R. "Optimization problem for meeting distribution system operator requests in local flexibility markets with distributed energy resources", Applied energy, Vol. 210, pp. 881-895,2018.

[35] Xie, M., Ji, X., Hu, X., Cheng, P., Du, Y. and Liu, M. "Autonomous optimized economic dispatch of active distribution system with multi-microgrids", Energy, Vol. 153, pp. 2479-489,2018.

[36] Jeong, J. S. and Ramírez-Gómez, A. "Optimizing the location of a biomass plant with a fuzzy-Decision-Making Trial and Evaluation Laboratory (F-DEMATEL) and multi-criteria spatial decision assessment for renewable energy management and long-term sustainability", Journal of cleaner production, Vol.182, pp. 509-520, 2018.

[37] Venkatesan, K. and Govindarajan, U. "Optimal power flow control of hybrid renewable energy system with energy storage: A WOANN strategy", Journal of Renewable and Sustainable Energy, Vol. 11, No. 1, p. 015501, 2019.

[38] Injeti, S. K., Thunuguntla, V.K. and Shareef, M. "Optimal allocation of capacitor banks in radial distribution networks for minimization of real power loss and maximization of network savings using bio-inspired optimization algorithms", International Journal of Electrical Power & Energy Systems, Vol. 69, pp. 441-455, 2015.

[39] Aman, M. M., Jasmon, G.B., Bakar, A.H.A., Mokhlis, H. and Karimi, M. "Optimum shunt capacitor placement in distribution system—A review and comparative study", Renewable and Sustainable Energy Reviews, Vol. 30, pp. 429-439, 2014.

[40] Kowsalya, M. "Optimal size and siting of multiple distributed generators in distribution system using bacterial foraging optimization", Swarm and Evolutionary computation, Vol.15, pp. 58-65, 2014.

[41] Ng, H. N., M. M. A. Salama, and A. Y. Chikhani. "Classification of capacitor allocation techniques", IEEE Transactions on power delivery, Vol. 15, No. 1, pp. 387-392, 2000.

[42] Reddy, M.D., and Reddy, V.C. "A two-stage methodology of optimal capacitor placement for the reconfigured network", Indian Journal of Engineering & Material Sciences, Vol. 17, pp. 105-112, 2010.

[43] El-Fergany, A. A. and Abdelaziz, A.Y. "Efficient heuristic-based approach for multi-objective capacitor allocation in radial distribution

networks", IET Generation, Transmission & Distribution, Vol. 8, No. 1, pp. 70-80, 2014.

[44] Das, D. "Reactive power compensation for radial distribution networks using genetic algorithm", International journal of electrical power & energy systems, Vol. 24, No. 7, pp. 573-581, 2002.

[45] Swarup, K. S. "Genetic algorithm for optimal capacitor allocation in radial distribution networks", In Proceedings of the 6th WSEAS international conference on evolutionary, Lisbon, Portugal, pp. 152-9. 2005.

[46] Levitin, G., Kalyuzhny, A., Shenkman, A. and Chertkov, M. "Optimal capacitor allocation in distribution systems using a genetic algorithm and a fast energy loss computation technique", IEEE Transactions on Power Delivery, Vol. 15, No. 2, pp. 623-628, 2000.

[47] Reddy, M.D. and Reddy, V.C. "Optimal capacitor placement using fuzzy and real coded genetic algorithm for maximum savings", Journal of Theoretical & Applied Information Technology, Vol. 4, No. 3, 2008.

[48] Reddy, V. V. K. and Sydulu, M. "Two Index and GA based optimal location and sizing of distribution system capacitors", In 2007 IEEE Power Engineering Society General Meeting, pp. 1-4. IEEE, 2007.

[49] Raju, M.R., Murthy, K.R. and Ravindra, K. "Direct search algorithm for capacitive compensation in radial distribution networks", International Journal of Electrical Power & Energy Systems, Vol.42, No. 1, pp. 24-30, 2012.

[50] Kaur, D. and Sharma, J. "Multiperiod shunt capacitor allocation in radial distribution networks", International Journal of Electrical Power & Energy Systems, Vol. 52, pp. 247-253, 2013.

[51] Devabalaji, K. R., Ravi, K. and Kothari, D.P. "Optimal location and sizing of capacitor placement in radial distribution network using bacterial foraging optimization algorithm", International Journal of Electrical Power & Energy Systems, Vol. 71, pp. 383-390, 2015.

[52] Antunes, C. H., Pires, D.F., Barrico, C., Gomes, A. and Martins, A.G. "A multi-objective evolutionary algorithm for reactive power compensation

in distribution networks", Applied Energy, Vol. 86, No. 7-8, pp. 977-984,2009.

[53] Mohammad, W.F., Tawalbeh, N. and Al-aubidy, K.M. "Fast Power Loss Computation and Shunt Capacitor Insertion Using Fuzzy Logic Technique ", American Journal of Applied Sciences, Vol. 4, No. 1, 2007.

[54] Prakash, K., and M. Sydulu. "Particle swarm optimization based capacitor placement on radial distribution networks", In 2007 IEEE Power Engineering Society General Meeting, pp. 1-5. IEEE, 2007.

[55] Nojavan, S., Jalali, M. and Zare, K. "Optimal allocation of capacitors in radial/mesh distribution systems using mixed integer nonlinear programming approach", Electric Power Systems Research, Vol. 107, pp.119-124, 2014.

[56] Laxmidhar, B. “NPTEL lecture on Intelligent control system", IIT Kanpur, 2008, lecture 13-15

[57] Dixit, S., Srivastava, L. and Agnihotri, G. "Power flow analysis using fuzzy logic", In 2006 IEEE Power India Conference, pp. 7-pp. IEEE, 2006.

[58] Meena, S. and Chitra, K. "An approach of firefly algorithm with modified brightness for PID and I-PD controllers of SISO systems", Journal of Ambient Intelligence and Humanized Computing, pp.1-9, 2018.

[59] Lee, C.S., Ayala, H.V.H. and dos Santos Coelho, L. "Capacitor placement of distribution systems using particle swarm optimization approaches", International Journal of Electrical Power & Energy Systems, Vol .64, pp. 839-851, 2015.

[60] Kanwar, N., Gupta, N., Niazi, K.R. and Swarnkar, A. "Simultaneous allocation of distributed resources using improved teaching learning based optimization", Energy Conversion and Management, Vol. 103, pp. 387-400, 2015.

[61] Shuaib, Y.M., Kalavathi, M.S. and Rajan, C.C.A. "Optimal capacitor placement in radial distribution network using gravitational search algorithm", International Journal of Electrical Power & Energy Systems, Vol. 64, pp. 384-397, 2015.

[62] de Assis, L.S., Vizcaı, J.F., Usberti, F.L., Lyra, C., Cavellucci, C. and Von Zuben, F.J. "Switch allocation problems in power distribution systems", IEEE Transactions on Power Systems, Vol. 30, No. 1, pp. 246-253, 2014.

[63] Muthukumar, K. and Jayalalitha, S. "Optimal placement and sizing of distributed generators and shunt capacitors for power loss minimization in radial distribution networks using hybrid heuristic search optimization technique", International Journal of Electrical Power & Energy Systems, Vol. 78, pp. 299-319, 2016.

[64] Zeinalzadeh, A., Mohammadi, Y. and Moradi, H.M. "Optimal multi objective placement and sizing of multiple DGs and shunt capacitor banks simultaneously considering load uncertainty via MOPSO approach", International Journal of Electrical Power & Energy Systems, Vol. 67, pp. 336-349, 2015.

[65] Esmaeilian, H.R. and Fadaeinedjad, R. "Energy loss minimization in distribution systems utilizing an enhanced reconfiguration method integrating distributed generation", IEEE Systems Journal, Vol. 9, No. 4, pp. 1430-1439, 2014.

[66] Olamaei, J., Moradi, M. and Kaboodi, T. "A new adaptive modified firefly algorithm to solve optimal capacitor placement problem", In 18th Electric Power Distribution Conference, pp. 1-6. IEEE, 2013.

[67] Tolabi, H.B., Ali, M.H. and Rizwan, M. "Simultaneous reconfiguration, optimal placement of DSTATCOM, and photovoltaic array in a distribution system based on fuzzy-ACO approach", IEEE Transactions on sustainable Energy, Vol. 6, No. 1, pp. 210-218, 2014.

[68] Esmaeilian, H.R. and Fadaeinedjad, R. "Distribution system efficiency improvement using network reconfiguration and capacitor allocation", International Journal of Electrical Power & Energy Systems, Vol. 64, pp. 457-468, 2015.

[69] Ramadan, H. S., Bendary, A.F. and Nagy, S. "Particle swarm optimization algorithm for capacitor allocation problem in distribution systems with wind turbine generators", International Journal of Electrical Power & Energy Systems, Vol. 84, pp. 143-152, 2017.

[70] Khwaja, A. S., Naeem, M., Anpalagan, A., Venetsanopoulos, A. and Venkatesh, B. "Improved short-term load forecasting using bagged neural networks", Electric Power Systems Research, Vol. 125, pp.109-115, 2015.

[71] Sudheer, G. and Suseelatha, A. "Short term load forecasting using wavelet transform combined with Holt–Winters and weighted nearest neighbor models", International Journal of Electrical Power & Energy Systems, Vol. 64, pp. 340-346, 2015.

[72] Chaturvedi, D. K., Sinha, A.P. and Malik, O.P. "Short term load forecast using fuzzy logic and wavelet transform integrated generalized neural network", International Journal of Electrical Power & Energy Systems, Vol. 67, pp. 230-237, 2015.

[73] Coelho, V.N., Coelho, I.M., Coelho, B.N., Reis, A.J., Enayatifar, R., Souza, M.J. and Guimarães, F.G. "A self-adaptive evolutionary fuzzy model for load forecasting problems on smart grid environment", Applied Energy, Vol. 169, pp. 567-584, 2016.

[74] Ghosh, S. and Das, D. "Method for load-flow solution of radial distribution networks", IEE Proceedings-Generation, Transmission and Distribution, Vol. 146, No. 6, pp. 641-648, 1999.

[75] Lantharthong T. and Rugthaicharoencheep, N. "Network reconfiguration for load balancing in distribution system with distributed generation and capacitor placement", World Acad Sci Eng Technol, Vol. 6, No. 4, pp. 396–401, 2012.

[76] Di Silvestre, M. L., La Cascia, D., Sanseverino, E.R. and Zizzo, G. "Improving the energy efficiency of an islanded distribution network using classical and innovative computation methods", Utilities Policy, Vol. 40, pp. 58-66, 2016.

[77] Manglani, T. and Shishodia, Y.S. "Reduction in Power Losses on Distribution Lines using Bionic Random Search Plant growth Simulation Algorithm", International Journal of Recent Research and Review, Vol. 3, No. 9, pp. 8-14, 2012.

[78] El-Khattam, W., Hegazy Y. G. and Salama, M. M. A. “An integrated distributed generation optimization model for distribution system

planning", IEEE Transactions on Power Systems, Vol. 20, No. 2, pp. 1158-1165, 2005.

[79] Vournas C. "Power System Voltage Stability", Encyclopedia of Systems and Control, pp. 1-7, 2014.

[80] Kessel, P. and Glavitsch, H. “Estimating the voltage stability of a power system", IEEE Transactions on Power Delivery, Vol. 1, No. 3, pp. 346-354, 1986.

[81] Zarate L. A. L., Castro C., Ramos, J. L. M. and Ramos, E. R. “Fast computation of voltage stability security margins using nonlinear programming techniques", IEEE Transactions on Power Systems, Vol. 21, No. 1, pp. 19-27, 2006.

[82] Chen, H., Chen, J., Shi, D. and Duan, X. “Power flow study and voltage stability analysis for distribution systems with distributed generation", In Proceedings of IEEE International Conference on Power Engineering Society General Meeting, pp. 1-8, 2006.

[83] Hamada, M. M., Wahab, M. A. and Hemdan, N. G. “Simple and efficient method for steady-state voltage stability assessment of radial distribution networks", Electric Power Systems Research, Vol. 80, No. 2, pp. 152-160, 2010.

[84] Hauqe, M. H. “A linear static voltage stability margin for radial distribution networks", In Proceedings of IEEE International Conference on Power Engineering Society General Meeting, pp. 1-6, 2006.

[85] Gallego, R., Monticelli, A.J. and Romero, R. “Optimal capacitor placement in radial distribution networks", IEEE Transactions on Power Systems, Vol. 16, No. 4, pp. 630-637, 2001.

[86] Singh, S.P. and Rao, A.R. "Optimal allocation of capacitors in distribution systems using particle swarm optimization", International Journal of Electrical Power & Energy Systems, Vol. 43, No. 1, pp. 1267-1275, 2012.

[87] Arefifar, S.A., Mohamed, Y.A.R.I and El-Fouly, T.H. "Supply-adequacy-based optimal construction of microgrids in smart distribution

systems", IEEE Transactions on Smart Grid, Vol. 3, No. 3, pp.1491-1502, 2012.

[88] El-Fergany, A. A. and Abdelaziz, A.Y. "Capacitor allocations in radial distribution networks using cuckoo search algorithm", IET Generation, Transmission & Distribution, Vol. 8, No. 2, pp. 223-232, 2014.

[89] Safigianni, A. S. and Salis, G.J. "Optimum VAR control of radial primary power distribution networks by shunt capacitor installation", International journal of electrical power & energy systems, Vol. 23, No. 5, pp. 389-401, 2001.

[90] Carlisle J. C. and El-Keib A. A. "A graph search algorithm for optimal placement of fixed and switched capacitors on radial distribution networks", IEEE Transactions on Power Delivery, Vol. 15, No. 1, pp. 423-428, 2000.

[91] Prakash K. and Sydulu M. "A Novel Approach for Optimal Location and Sizing of Capacitors on Radial distribution networks Using Loss Sensitivity Factors and α-Coefficients", In Proceedings of IEEE International Conference on Power Systems Conference and Exposition, pp. 1910-1913, 2006.

[92] Venkatesh B. and Ranjan R. "Fuzzy EP algorithm and dynamic data structure for optimal capacitor allocation in radial distribution networks", In IEE Proceedings on IET Generation, Transmission and Distribution, Vol. 153, No. 1, pp. 80-88, 2006.

[93] Baghaee, H. R., Jannati M., Vahidi, B., Hosseinian, S. H. and Rastegar, H. "Improvement of voltage stability and reduce power system losses by optimal GA-based allocation of multi-type FACTS devices", In Proceedings of IEEE International Conference on Optimization of Electrical and Electronic Equipment, pp. 209-214, 2008.

[94] Kim, T., Lee, Y., Lee, B., Song, H. and Kim, T. "Optimal Capacitor Placement Considering Voltage Stability Margin Based on Improved PSO Algorithm", In Proceedings of IEEE International Conference on Intelligent System Applications to Power Systems, pp.1-5, 2009.

[95] Kashem, M. A. and Moghavvemi, M. "Maximizing radial voltage stability and load balancing via loss minimization in distribution networks", In

Proceedings of IEEE International Conference on Energy Management and Power Delivery, Vol. 1, pp. 91-96, 1998.

[96] Shin J. R., Kim, B. S., Park, J.B. and Lee, K.Y. "A new optimal routing algorithm for loss minimization and voltage stability improvement in radial power systems", IEEE Transactions on Power Systems, Vol. 22, No. 2, pp. 648-657, 2007.

[97] Baran, M.E. and Wu, F.F. "Network reconfiguration in distribution systems for loss reduction and load balancing", IEEE Transactions on Power Delivery, Vol. 4, No. 2, pp.1401-1407, 1989.

APPENDIX-A

Table A1: System Data of 69-node Radial Distribution Network

Branch Number	Sending - end Node	Receiving - end Node	R(Ω)	X(Ω)	P(kW)	Q(kVAr)
1	1	2	0.0005	0.0012	0	0
2	2	3	0.0005	0.0012	0	0
3	3	4	0.0015	0.0036	0	0
4	4	5	0.0251	0.0294	0	0
5	5	6	0.366	0.1864	2.6	2.2
6	6	7	0.3811	0.1941	40.4	30
7	7	8	0.0922	0.047	75	54
8	8	9	0.0493	0.0251	30	22
9	9	10	0.819	0.2707	28	19
10	10	11	0.1872	0.0619	145	104
11	11	12	0.7114	0.2351	145	104
12	12	13	1.03	0.34	8	5
13	13	14	1.044	0.345	8	5.5
14	14	15	1.058	0.3496	0	0
15	15	16	0.1966	0.065	45.5	30
16	16	17	0.3744	0.1238	60	35
17	17	18	0.0047	0.0016	60	35
18	18	19	0.3276	0.1083	0	0
19	19	20	0.2106	0.069	1	0.6
20	20	21	0.3416	0.1129	114	81
21	21	22	0.014	0.0046	5	3.5
22	22	23	0.1591	0.0526	0	0
23	23	24	0.3463	0.1145	28	20
24	24	25	0.7488	0.2475	0	0
25	25	26	0.3089	0.1021	14	10
26	26	27	0.1732	0.0572	14	10
27	3	28	0.0044	0.0108	26	18.6
28	28	29	0.064	0.1565	26	18.6
29	29	30	0.3978	0.1315	0	0
30	30	31	0.0702	0.0232	0	0
31	31	32	0.351	0.116	0	0
32	32	33	0.839	0.2816	14	10
33	33	34	1.708	0.5646	9.5	14

34	34	35	1.474	0.4873	6	4
35	3	36	0.0044	0.0108	26	18.55
36	36	37	0.064	0.1565	26	18.55
37	37	38	0.1053	0.123	0	0
38	38	39	0.0304	0.0355	24	17
39	39	40	0.0018	0.0021	24	17
40	40	41	0.7283	0.8509	1.2	1
41	41	42	0.31	0.3623	0	0
42	42	43	0.041	0.0478	6	4.3
43	43	44	0.0092	0.0116	0	0
44	44	45	0.1089	0.1373	39.22	26.3
45	45	46	0.0009	0.0012	39.22	26.3
46	4	47	0.0034	0.0084	0	0
47	47	48	0.0851	0.2083	79	56.4
48	48	49	0.2898	0.7091	384.7	274.5
49	49	50	0.0822	0.2011	384.7	274.5
50	8	51	0.0928	0.0473	40.5	28.3
51	51	52	0.3319	0.1114	3.6	2.7
52	9	53	0.174	0.0886	4.35	3.5
53	53	54	0.203	0.1034	26.4	19
54	54	55	0.2842	0.1447	24	17.2
55	55	56	0.2813	0.1433	0	0
56	56	57	1.59	0.5337	0	0
57	57	58	0.7837	0.263	0	0
58	58	59	0.3042	0.1006	100	72
59	59	60	0.3861	0.1172	0	0
60	60	61	0.5075	0.2585	1244	888
61	61	62	0.0974	0.0496	32	23
62	62	63	0.145	0.0738	0	0
63	63	64	0.7105	0.3619	227	162
64	64	65	1.041	0.5302	59	42
65	11	66	0.2012	0.0611	18	13
66	66	67	0.0047	0.0014	18	13
67	12	68	0.7394	0.2444	28	20
68	68	69	0.0047	0.0016	28	20

APPENDIX-B

Table B1: System Data of 34-node Radial Distribution Network

Branch Number	Sending -end Node	Receiving -end Node	R(Ω)	X(Ω)	P(kW)	Q (kVAr)
1	1	2	0.117	0.048	230	190
2	2	3	0.107	0.044	0	0
3	3	4	0.165	0.046	230	190
4	3	13	0.157	0.27	230	190
5	4	5	0.15	0.042	0	0
6	5	6	0.15	0.042	0	0
7	6	7	0.314	0.54	230	190
8	6	17	0.179	0.05	230	190
9	7	8	0.21	0.036	0	0
10	7	28	0.105	0.018	230	190
11	8	9	0.314	0.54	137	84
12	9	10	0.21	0.036	72	45
13	10	11	0.131	0.023	72	45
14	10	31	0.157	0.027	72	45
15	11	12	0.105	0.018	13.5	7.5
16	13	14	0.21	0.036	230	190
17	14	15	0.105	0.018	230	190
18	15	16	0.052	0.009	230	190
19	17	18	0.165	0.046	230	190
20	18	19	0.208	0.047	230	190
21	19	20	0.189	0.043	230	190
22	20	21	0.189	0.043	230	190
23	21	22	0.262	0.045	230	190
24	22	23	0.262	0.045	230	190
25	23	24	0.314	0.54	230	190
26	24	25	0.21	0.036	137	85
27	25	26	0.131	0.023	75	48
28	26	27	0.105	0.018	75	48
29	28	29	0.105	0.018	75	48
30	29	30	0.157	0.027	57	34.5
31	31	32	0.21	0.036	57	34.5
32	32	33	0.157	0.027	57	34.5
33	33	34	0.105	0.018	57	34.5

Appendix- C

Table C1: System Data of 33-node Radial Distribution Network

Branch Number	Sending -end Node	Receiving -end Node	R(Ω)	X(Ω)	P(kW)	Q (kVAr)
1	1	2	0.092	0.047	100	60
2	2	3	0.493	0.251	90	40
3	3	4	0.366	0.186	120	80
4	4	5	0.381	0.194	60	30
5	4	6	0.819	0.707	60	20
6	6	7	0.187	0.618	200	100
7	7	8	0.711	0.235	200	100
8	8	9	1.030	0.740	60	20
9	9	10	1.044	0.740	60	20
10	10	11	0.196	0.065	45	30
11	11	12	0.374	0.123	60	35
12	12	13	1.468	1.155	60	35
13	13	14	0.541	0.712	120	80
14	14	15	0.591	0.526	60	10
15	15	16	0.746	0.545	60	20
16	16	17	1.289	1.721	60	20
17	17	18	0.732	0.574	90	40
18	2	19	0.164	0.156	90	40
19	19	20	1.504	1.355	90	40
20	20	21	0.409	0.478	90	40
21	21	22	0.708	0.937	90	40
22	3	23	0.451	0.308	90	50
23	23	24	0.898	0.709	420	200
24	24	25	0.896	0.709	420	200
25	6	26	0.203	0.103	60	25
26	26	27	0.284	0.144	60	25
27	27	28	1.059	0.933	60	20
28	28	29	0.804	0.700	120	70
29	29	30	0.507	0.258	200	600
30	30	31	0.974	0.963	150	70
31	31	32	0.310	0.361	210	100
32	32	33	0.341	0.530	60	40

Publications

1. Sarika Sharma and Smarajit Ghosh, Effective Design and Development of Hybrid ABC-CSO Based Capacitor Placement with Load Forecasting Based on Artificial Neural Network, Assembly Automation, Vol. 39, Issue 5, pp. 917-930, 2019. **(SCIE Indexed, Impact Factor: 2.21)**
2. Sarika Sharma and Smarajit Ghosh, FIS and hybrid ABC-PSO based optimal capacitor placement and sizing for radial distribution networks, Journal of Ambient Intelligence and Humanized Computing, Vol. 11, pp. 901-916, 2020. **(SCIE Indexed, Impact Factor: 4.594)**

BIOGRAPHY

Sarika Sharma: Born in Ambala, Haryana, India on 06th September, 1982. She did B.Tech. (Electrical Engineering) from Kurukshetra University Kurukshetra, M. Tech. (Instrumentation and control Engineering) from Maharshi Dayanand University, Rohtak and MBA (Human Resource) from Guru Jambheshwar University Hisar, Haryana in 2004, 2006 and 2008 respectively. She is pursuing Ph.D. as part-time research scholar in Department of Electrical and Instrumentation Engineering of Thapar Institute of Engineering and Technology (Deemed to be University), Patiala, Punjab, India under the sole supervision of Dr. Smarajit Ghosh.

Her areas of interest are load-flow, network reconfiguration, deregulated power system, optimal DG and capacitor placement etc. for electrical power distribution networks.

Contact email: sarikaharyana@gmail.com

Smarajit Ghosh: Born in Ghatal, West Bengal, India on 16 August, 1967. He did his B.Sc. (Physics Hons.), B. Tech. (Electrical Engineering),M. Tech. (Electrical Machines and Power Systems) from Calcutta University in 1991, 1994 and 1996 respectively. Finally, he did his Ph.D. from Indian Institute of Technology, Kharagpur, India in 2000. His research areas include load flow study, network reconfigurations, optimum capacitorallocation, application of soft computing in Electrical Power Distribution Systems, data-security. He has already served REC (Durgapur), BITS Pilani and Sikkim Manipal University, as a lecturer, an Assistant Professor and a Professor respectively. He has authored a number of books published by Prentice Hall of India Private Limited and Pearson Education as a single author.

Smarajit Ghosh is presently serving as a Professor at Thapar Institute of Engineering and Technology (Deemed to be University), Patiala in Department of Electrical and Instrumentation Engineering from 2007.

Contact email: smarajitg@hotmail.com