REACTIVE POWER LOSS MINIMIZATION IN RADIAL DISTRIBUTION NETWORK USING BFOA

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DECLARATION

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

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It is certified that the above statement made by the student is correct and true to the best of my knowledge and belief.

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"Achievement is finding out what you would be doing, what you have to do. The higher the summit, higher will be the climb." It has been rightly said that we are build on the shoulders of others but the satisfaction that accompanies the successful completion of any task would be incomplete without the mention of the people who made it possible.

Gratitude is accorded to all the authorities of Thapar University, Patiala for providing the necessary facilities to complete my M.E thesis work.

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

(RITU SUTHAR)

DEDICATED TO MY PARENTS

ABSTRACT

Active and reactive power losses have been a major challenge in the field of power system since beginning. Many techniques have evolved since then for reducing these losses and hence improving voltage profile. Power compensation has become very important so as to improve power system stability and hence preventing the operation of system closer to the voltage stability boundaries. Reactive power compensation plays a vital role in improving the voltage profile and planning of power system. DG allocation and capacitor placement are the most common and powerful techniques used to improve voltage profile and reduce losses. DG is used for active power compensation whereas capacitor is used for reactive power compensation. The capacitor placement problem involves determining the location and also the optimal size of the capacitor so as to minimize the losses. In this thesis firstly load flow is performed to determine the actual losses and voltages at different nodes without compensation. Next the optimal location and size of the capacitor to be installed is found. Location is determined by calculating the voltage stability index and loss sensitivity factor at each node. For size determination the technique used is bacterial foraging algorithm. After installing capacitor for reactive power compensation at the candidate node again the load flow is performed to justify the objective. The results thus obtained were compared with other techniques and were tested on 33-node radial distribution network.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

P_{LOSS}	Total real power loss
Q_{LOSS}	Total reactive power loss
$I(jj)$	Current through branch-jj
$X(jj)$	Reactance of branch-jj
$R(jj)$	Resistance of branch-jj
$V_{i_{min}}$	Minimum voltage limit for node ‘i’
$V_{i_{max}}$	Maximum voltage limit for node ‘i’
V_i	Voltage at node ‘i’
N	Number of buses
$I(jj)_{max}$	Maximum current carrying capacity of branch-jj
NB	Total number of branches
P_{iG}	Total active power generation at node ‘i’
Q_{iG}	Total reactive power generation at node ‘i’
P_{iD}	Total active power demand at node ‘i’
Q_{iD}	Total reactive power demand at node ‘i’
SE(jj)	Sending-end node for branch-jj
RE(jj)	Receiving-end node for branch-jj
Z(jj)	Impedance of branch-jj
PL(i)	Active power load at node ‘i’
QL(i)	Reactive power load at node ‘i’
IL(i)	Load current at node ‘i’
L_m	Voltage stability index of node ‘m’
$x^i(m,n,o)$	Position of i th bacterium in m th chemotactic step, n th reproductive step, o th elimination-dispersal step.

p	Dimension in search space
S	Bacteria population
N_i	Number of iterations
N_s	Swim length of a bacteria
N_c	Maximum chemostatic steps
N_{re}	Maximum reproduction steps
N_{ed}	Maximum elimination-dispersal event
P_{ed}	Probability of elimination-dispersal event
C(i)	Step size of bacteria
x_k	Size of capacitor at k th node

CHAPTER -1

INTRODUCTION

1.1 ELECTRICAL POWER SYSTEM

Electrical power is usually transmitted at high voltage from generating units to primary substations. The voltage is then stepped down at the receiving-end substation to a lower value (say 11kV or 33kV or 66kV). The power from this substation is then transferred to secondary substation. A secondary substation has two or more step down transformers simultaneously with voltage regulating equipments, switchgear and buses. Voltage is then stepped down to 11kVat this substation. The network that connects these secondary substations and consumers is referred to distribution system. This distribution system can be categorized into two parts namely primary and secondary system [1].

A secondary substation may further have its primary and secondary distribution systems as the area under any secondary substation may be large. The primary distribution system has main feeders and laterals. The main feeders run from low voltage buses and are main source of supply for sub-feeders or laterals and direct connected distribution transformers. The lateral extends through the load area with connection to distribution transformers. The distribution transformers may be located in specifically constructed enclosures or might be pole mounted. Here the voltage is further stepped down to 400V and after that the power is received by the secondary distribution systems. A secondary distribution system consists of distributors that are laid along road sides. The connections to regulars are tapped off from these distributors. The main feeders, distributors and laterals consist of either overhead lines or cables or sometimes both. For distribution generally 3 phase, 4 wire circuits are used, where the neutral wire is mandatory so that power can be supplied single phase loads. Usually major part of consumers (residential or commercial) is fed with single phase power supply.

The consumers receive electric power from the distribution system. A distribution system broadly consists of a receiving substation, sub- transmission lines, distribution substation generally located nearer to the load centre, secondary circuits connected to LV side of the

distribution transformer and service mains. Service mains are the connections of consumers.
The main difference between a transmission system and distribution system is in the network structure. Transmission system has a loop structure whereas the latter generally, a radial structure [1].

A distribution systems has several service lines, distribution transformers, one or two receiving substations and associated primary or secondary circuitry. Distribution systems are much complicated and have problems like drop in voltage magnitude during peak load time and sudden or gradual rise in voltage during off peak load. Transformer overload is also one of the major problems.

1.2 DISTRIBUTION SYSTEM

The part of power system that deals with distribution of electric power for local use is called distribution system. In other words the electrical system that transfers electrical power from the substation, which is fed by transmission system to the consumers and provides a link between the consumers and power generators is referred as distribution system. The three major components of distribution system are feeders, distributers and service mains.

A feeder is typically a conductor that connects the substation to the sub area where power is to be transmitted. It remains same throughout as no tappings are generally taken from a feeder. The current carrying capacity of a feeder is to be considered while designing of the feeder.

Second major component of the distribution system i.e. distributors are the conductors from which tappings can be taken so that power can be supplied to consumers. The voltage variations at the consumer ends may vary only up to ±10% of the rated value. Therefore, the voltage drop along the length of the line is considered as a designing parameter for distributors. Since tappings are taken along the length of distributor at various places, current through a distributor keeps on varying.

The small cable that connects the distributor and the consumer terminal is known as service mains. The circuitry after these service mains doesn’t come under distribution system anymore and only the owner or the consumer is liable for further circuitry or equipments.

For a good and reliable distribution system, there are many challenges such as modernization and automation. A good distribution system must maintain its power quality i.e. good power factor, less voltage dips, balanced three phase supply. There must be minimum interruptions in the power supply and the voltage must flicker within the permissible limits. Providing service connections to the consumers in urban or rural areas and industrial customers in the remote areas is also a major challenge to the distribution system.

1.3 CLASSIFICATION OF DISTRIBUTION SYSTEM

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

(i) Nature of current:
  (a) DC distribution system
  (b) AC distribution system

Since AC system is simpler and is also more economical than DC system therefore it is universally adopted for the distribution of electric power. AC system also facilitates step-up and step-down of voltage level easily which makes power flow easy.

(ii) Type of construction**:**
  (a) overhead system
  (b) Underground system.

Generally overhead system is employed for distribution as erecting an overhead system is easy and 5 to 10 times cheaper than equivalent underground system. But at the places where overhead system in not practically possible, underground system is used.

(iii) Type of connection:
  (a) Radial system
  (b) Ring main system
  (c) Interconnected system

In radial system several feeders branch out from single substation and fed to various distribution centers at one end only. There is no intermediate connection between the feeders and there is single main feeder. Radial systems are very simple and are least expensive to build. Operation and expansion of radial systems is also very convenient and simple. Major disadvantage of radial networks is that any fault in either in line, cable or in primary supply or transformer leads in outage of all the loads that are being served by the feeder. These are used for short distances only as the consumers at the end point suffer large voltage fluctuations if the distance is large.

In ring main or loop system the system encircles an area and may be serving one or more load centers or distribution transformers while being supplied by one substation. The conductor of the system then returns to the same substation. It is more expensive to build as compared to a radial system, but is more reliable.

In Interconnected system the feeder ring is energized by the generating stations or substations which may be two or more in number. Interconnected systems increase the service reliability and efficiency of the system. During peak load hours a load of any generating station can be fed by some other generating station thereby reducing reserve power capacity. Interconnected systems improve system reliability.

Radial systems are the most common systems used for power flow in power system due to their simple construction and low cost.

1.4 LOSSES IN POWER SYSTEM

In an electrical system losses can occur due to flow of current through the branch. The resistance value is higher in distribution systems compared to transmission systems. Hence the losses are higher in distribution system. There are real and reactive power losses due to the flow of currents and the computation of these losses are required for.Hence the role of load-flow is important. The load-flow study of a system ensures the computation of voltage of other nodes as well as the measurement of these losses.

1.5 POWER LOSS MINIMIZATION

Active power losses are actually the resistive losses or the line losses. These active power losses may be minimized by employing numerous techniques such as carrying out online real time optimal flow calculation considering control and state variables [2], by using phase shifting transformers [3] or Intellectual Particle Swarm Optimization [4]. An expert system integrating optimization method and Artificial Intelligence techniques can also be used for reducing active power losses [5]. Reactive power compensation can be done by installing shunt capacitors. Restructuring of power system is yet an additional approach for minimizing losses by doing network reconfiguration. Combination of shunt capacitor and reactor also minimizes the losses. DGs or Flexible AC transmission system can also be used for reducing active power losses.

Power System is becoming more and more complex and critical. Most of the power companies bear much pressure due to deregulation. As a result, in order to achieve maximum profit and at the same time having minimum losses capacitor installation technique and reconfiguration of network have proved to be economically beneficial as compared to other techniques. Capacitor installation simply means shunt compensation of reactive power.

1.5.1 REACTIVE POWER COMPENSATION

Loss minimization has a great significance in power system as losses contribute in wastage of considerable amount of generated power. Reducing losses improves efficiency of the system, which is now-a-days very important as power utilities now forced to have greater efficiency. Reducing losses also reduces line loads. It is shown in the studies that distribution system losses make up to 70% of the total losses in any system as most outages occur in distribution system. So it has become essential for power utilities to reduce the losses at distribution part. Different methods are adopted for the reduction of losses in distribution system like conductor grading, reinforcement of conductors, feeder reconfiguration, high voltage distribution system, doubly fed induction generator, reactive power compensation, etc.

Reactive power compensation is for the most part commonly used technique for reduction of losses in distribution system. This can be done either by using shunt capacitors or series capacitors. Installing shunt capacitors is more beneficial than the later one as this reduce kVA loading on generator, improves voltage regulation and stability, reduces losses and improves the power factor of the system.

Reactive power compensation reduces the distribution system losses by providing additional reactive power at the nodes or load ends. By providing reactive power on the load ends or nearer to the nodes requiring reactive power also decreases the loading of the lines. Shunt reactive power compensation is provided by installing capacitors banks at the end of load terminal or transmission lines.

Application of capacitor banks at electric buses produces a rise in their voltages. The capacitor reduces inductive current, and thus the voltage at the bus rises on which capacitor is installed and beyond the capacitor location rises in a radial system. Capacitor placement improves voltage profile and also reactive power requirements at generator and thus improves the power factor. This also increases the steady state stability limits of the system.

Considering the constantly growing load demand, this in turn increases the burden on the distribution system and thus leads to reduced voltage. In a typical distribution network as we move away from the substation, voltage at the nodes reduces mainly due to lack of sufficient amount of reactive power. Under certain circumstances such as critical loading in industrial areas or during peak demand hours this reduction in voltage may lead to voltage collapse. These conditions signify the instability of the distribution system. Hence improving stability is a major challenge in power system. Reactive power compensation is required to avoid voltage collapse and improving the voltage profile.

In a distribution system, the losses are much more significant as compared to the losses in case of transmission system. Reducing these losses in a distribution network is mandatory for the power utilities to improve the overall efficiency of power delivery. Various methods can be used to reduce the losses like installing DGs or shunt capacitors, network reconfiguration, etc.

Shunt capacitors reduce the current and MVA in lines by supplying the reactive power to the circuit. Thus installing shunt capacitors in distribution networks reduces energy losses and peak demand losses. This also improves the voltage profile, power factor and reliability of the system.

Installing of shunt capacitor involves determining the optimal location as well as size of the capacitor to be placed so as to reduce maximum losses.

1.6 LITERATURE REVIEW

Akagi [6] presented various active power line conditioners (series and shunt). Instead of active power filters, he used the term active power line conditioners so as to cover wider sense. In that paper trends in active power line conditioners were presented using PWM inverters, paying attention to practical applications. Results obtained were not to directly compensate harmonics, but to improve the filtering characteristics for shunt passive filter used alone, which can further be expanded from voltage regulation to improvement of stability as the shunt active power line conditioners capacity became larger.

Abul'Wafa [7] presented the results for fuzzy real coded genetic algorithm (FRCGA) that was much more satisfactory than the analytical method. The location of the capacitor was found out by fuzzy expert system (FES) and sizing was done using genetic algorithm. The study was done on standard 33-node radial distribution system. He showed that the solution produced with FRCGA had good performance of convergence.

Baran and Wu [8] proposed a new methodology for capacitor placement in radial distribution network considering type, location and size of capacitor along with load variations and voltage constraints. The methodology incorporated by him was to decompose the original problem in two parts, master problem and slave problem. The former part of the problem determined the location of the capacitor whereas later provided the size and type of capacitor to be installed.

Mohan and Arvindhababu [9] focused on the voltage instability problem due to the rapid increase in the load demand day by day, which brings the operating states much close to stability limits. The algorithm proposed for sizing of capacitors and their location focused on enhancing voltage stability along with minimizing losses and improving voltage profile. Only one node at a time was selected irrespective of system size and size of the capacitor was computed using iterative process involving simple computations. Superiority of the proposed algorithm was justified by the test results on 33-node and 69-node radial distribution systems.

Abul'Wafa [10] proposed network topology method for the load flow analysis of radial distribution network. The receiving-end nodes must be arranged in ascending order during the tabulation of line data as input information. The given approach allowed building of two different matrices: BIBC and BCBV matrix to find load flow solution. The method proposed was compared with other methods and the convergence ability was evaluated for different loading conditions and different tolerance values. The effectiveness was tested on eight systems.

Neagle and Samson [11] presented the justification of the trend of installation of capacitors near loads on primary distribution feeders and not on the substation. The proposed method reduced the losses in distribution system along with reduction in overall cost. Ease of availability of pole mounted equipment also facilitated the trend to install capacitor closer to loads on primary feeders. Maximum loss reduction was obtained at the node where the capacitor kVA rating was twice of the load kVAr.

Ahmad and Hosam [12] presented test results of CP problem for interconnected distribution system using genetic algorithms considering the presence of non-linear loads. These results were compared to that of a radial distribution system. Though radial system offered better annual benefits after CP, still in distorted networks better benefits and operating conditions were provided in interconnected systems.

Baran and Wu [13] formulated radial distribution system as nonlinear programming problem. Author focuses on minimizing the losses for given load profile, and at the same time also considered capacitor cost. DistFlow approach was introduced for radial distribution system with novel power flow equations. The method was found to be numerically robust and computationally efficient even for distribution systems having large R/X ratio. The results obtained indicated the good convergence characteristics of the given approach.

Teng [14] provided a direct approach for an unbalanced three-phase load-flow solution for a distribution system. The approach used for obtaining load-flow solution was formulation of bus injection to branch current matrix and branch current to bus voltage matrix. Rather than using traditional time consuming approaches like LU decomposition, admittance matrix formation, forward/backward substitution of Jacobian matrix simple matrix multiplication was used. The method proposed proved to be time efficient and robust and at the same time appropriate for large scale distribution system.

Legha *et al.* [15] proposed Artificial Bee Colony (ABC) algorithm for capacitor placement as it did not require external parameters such as mutation rate or cross over rate, which were must in case of differential evolution and genetic algorithm. In the proposed method the line losses were reduced marginally as capacitor installation could only reduce line losses. Computer simulations were carried out for demonstrating the validity of specified approach and algorithm and were shown as result.

Ahmed *et al.* [16] emphasised on identifying the loss sensitivity factor to determine the location of the capacitor and for sizing used discrete particle swarm optimization. Proposed algorithm was verified on 10-node, 15-node and 34-node radial distribution system. The proposed algorithm directly dealt with discrete nature of design variables.

El-Fergany and Abdelaziz [17] introduced the scheme to assign static capacitors in the radial distribution network using Artificial Bee Colony (ABC) algorithm. The proposed algorithm initially identified optimal size and location and the final location was obtained later on. The results obtained were found out for various topologies. The effort of tuning the control parameters was reduced.

Kannan *et al.* [18] presented Differential Evolution (DE) technique and multi agent Particle Swarm Optimization technique to identify the capacitor’s size. The location was obtained by finding weak buses of system using sensitivity index for which power loss and node voltage indices work as input parameters. The result was illustrated by performing simulation on 34-node RDS and an existing 15-node RDS.

Devabalaji *et al.* [19] introduced long term scheduling for allocation of capacitor bank for minimizing losses. Integrated approach was used to find the location for CP, which incorporated computation of both VSI and LSF. The size of the capacitor banks was then determined by Bacterial Foraging Optimization Algorithm (BFOA). Proposed algorithm was tested on 34-node and 85-node radial distribution networks considering the possible load changes. Simulation results were presented to illustrate the suitability of proposed algorithm.

Prakash and Sydulu.[20] proposed an approach to determine the optimal location of capacitor and its size for improvement of voltage profile and reduction in active power loss on radial distribution systems. Hence the target was achieved by Loss Sensitivity Factor (LSF) in former and Differential Evolution in later.

Sirjani *et al.* [21] presented a survey for determination of capacitor placement optimally and its size in context of Radial Distribution Networks by using Heuristic Optimization Techniques.

Kumar and Renuga [22] presented an application of (BF) algorithm in optimization of optimal location and designing of Thyristor Controlled Series Capacitor (TCSC) for improving voltage profile and minimizing losses in a power system in which control variable used is TCSC. Enhancement in stability of voltage was achieved through L -index . Comparison was made with Non-dominated Sorting Particle Swarm Optimization and GAs. It was concluded that the performance of system is better by connecting TCSC using proposed method.

Mohamed and Kowsalya [23] presented a technique for minimization of power loss by installation of distributed generation combined with placement of capacitor in distribution system .Optimal size of capacitor and DG was found by using BFOA. The voltage profile was improved and power loss was reduced by simultaneous placement of DG and Capacitor.

Rani *et al.* [24] proposed a algorithm named as Self Adaptive Harmony Search for optimal placement of capacitor for minimizing the power loss. Method for solving radial distribution system used was Forward/Backward sweep power flow. Using the proposed method, capacitors with optimum size were placed at less number of locations and were cost effective.

Ghosh and Das [25] proposed a simple and efficient method for the load-flow of radial distribution networks. The technique used involved evaluation of simple algebraic expressions only. The proposed method was demonstrated through examples, which proved to be very efficient.

Ghosh [26] proposed yet another method for solving load-flow problem. Using the proposed method, the data preparation was reduced and could handle arbitrary node numbering scheme easily.

Chakravorty and Das [27] proposed the method of voltage stability index to identify the node most sensitive to voltage collapse. Appropriate location was determined by computing the parameter at all nodes. Effectiveness of the method was proved by testing it on 69-node RDS and was found satisfactory.

Das *et.al.* [28] presented the study of BFOA and analyzed dynamics of simulated chemotaxis step with help of mathematical model. The study was based on the Foraging strategy of E.coli bacterium, which could be used as simple algorithm. Hybridization of BFOA with other optimization techniques was discussed and significant applications of BFOA were provided.

1.7 RESEARCH GAP

From above Article 1.6, there is still possible to obtain optimum location and size of capacitors to be placed in Radial distribution networks using Bacterial Foraging Optimization Algorithm and a suitable voltage stability index obtained by less number of assumptions.

1.8 OBJECTIVE OF THE WORK

The objective of the thesis work is minimization of reactive power losses and also improving the voltage profile of system by identifying the appropriate node and optimal size of the capacitor using Bacterial Foraging Optimization Algorithm and improved voltage stability index.

1.9 ORGANIZATION OF THE THESIS

Chapter-1 presents introduction and overview of distribution generation, literature review and objective of thesis work and organization of thesis.

Chapter-2 shows an overview of load-flow of distribution system.

Chapter-3 presents methodology for load-flow calculations and procedure to find optimal size and location for capacitor. It also illustrates the problem formulation.

Chapter-4 shows the results for a 33-node radial distribution system and concludes the thesis work.

Chapter-5 presents Conclusions and Future Scope of Further Research Work.

References

Appendix-A represents the system data for a 33-node radial distribution network.

CHAPTER 2

DISTRIBUTION SYSTEM LOAD-FLOW

2.1 INTRODUCTION

In power system active and reactive power flow has a very important role. The power flows from generating station to receiving station or load via different network buses, nodes and branches. The load-flow of a power system network provides the steady state solution of the network so that currents, voltages, losses can be computed. Load-flow is essential to examine the issues allied to planning, design, operation and control. Some applications like DG allocation or optimal capacitor placement, distribution automation system, etc. also require repeated load-flow solution. Various methods are used for load-flow studies, for example Gauss-Seidel method, Newton-Raphson method, Fast Decoupled method, etc.

Some natural characteristics of an electric distribution system are:

(i) Unbalanced operation and distributed loads
(ii) Radial or weakly meshed structure
(iii) Large number of buses, nodes and branches
(iv) Wide range of reactance and resistance values
(v) Multiphase operation.

Objective of load-flow studies is to determine power flows through interconnecting power channels, power injection at all buses, nodal voltages and phase angles. It also helps in determining best location and optimal capacity of proposed generating station, substations and new lines.

The buses are classified in three types: load bus, generator bus and slack (or swing) bus. This classification has been done on the basis of four variables. These are real power (P), reactive power (Q), voltage magnitude (V) and phase angle (δ). For each bus two out of four variables are known. At load bus active and reactive power are specified. For a generator bus voltage magnitude and real power are specified and for a slack bus the voltage magnitude and phase angle are fixed as shown in Table 2.1

Table 2.1 Buses in distribution network

Bus Type	Specified Variables	Unspecified Variables
Slack Bus	V, δ	P,Q
Generator Bus	V,P	Q, δ
Load Bus	P,Q	V, δ

The efficiency of optimization problem in some or the other way depends on the load-flow algorithm as in any case load-flow solution needs to be run many times. Therefore, the load-flow solution should be robust and have time efficient characteristics. In this thesis work the load-flow proposed by Ghosh and Das [25] is used.

CHAPTER 3

PROBLEM FORMULATION

3.1 INTRODUCTION

The chapter covers the methodology for optimal capacitor placement involving problem formulation, load-flow analysis, determination of optimal location and size of capacitor.

3.2 PROBLEM FORMULATION AND CONSTRAINTS

3.2.1 OBJECTIVE FUNCTION

The objective of the thesis is to minimize the reactive power losses by using reactive power compensation, i.e. installation of capacitor. Thus, the objective can be expressed as:

$$Minimize\ \ Q_{Loss} = \sum_{i=1}^{NB} |I(jj)|^2 X(jj) \tag{3.1}$$

where, Q_{LOSS} = Total reactive power loss in system.

NB = Total number of branches.

I(jj) = Current through branch-jj.

X(jj) = Reactance of branch-jj.

3.2.2 CONSTRAINTS

The objective function stated in Eq.(3.1) has the following constraints:

a.) Bus voltage limits: The voltage at the operating nodes in any system must be in safer limits so that the problem of voltage collapse and overvoltage may be avoided. Thus

$$V_{i_{min}} \le V_i \le V_{i_{max}} \qquad \forall i = 1,2,\dots,N \tag{3.2}$$

where, $V_{i_{min}}$ = Minimum voltage limit for node ‘i’

$V_{i_{max}}$ = Maximum voltage limit for node ‘i’

V_i = Voltage at node 'i'

N = total number of buses or nodes.

b.) Current carrying capacity: The current flowing in every branch must be within the permissible limits.

$$|I(jj)| \leq I(jj)_{max} \qquad \forall\, i = 1,2,\dots,NB \tag{3.3}$$

where, I(jj) = Current through branch-jj.

$I(jj)_{max}$ = Maximum current carrying capacity of branch-jj

c.) Power flow equations: The power demand and supply must be balanced for any distribution system for its smooth operation. Thus, active power generated should be equivalent to the sum of active power demand and the active power losses in the system. Similarly, reactive power generated must be equivalent to sum of reactive power loss and reactive power demand. This can be expressed mathematically as:

$$\sum P_{iG} = P_{LOSS} + \sum P_{iD} \tag{3.4}$$

$$\sum Q_{iG} = Q_{LOSS} + \sum Q_{iD} \tag{3.5}$$

where, $\sum P_{iG}$ = Total active power generated

$\sum Q_{iG}$ = Total reactive power generated

P_{LOSS} = Total active power losses

Q_{LOSS} = Total reactive power losses

$\sum P_{iD}$ = Total active power demand or load

$\sum Q_{iD}$ = Total reactive power demand or load.

3.3 LOAD-FLOW OF RADIAL DISTRIBUTION SYSTEM

In proposed method the branch current is computed using load-flow method [25]

3.3.1 METHODOLOGY

Assuming the system to be radial distribution network and considering the single line diagram shown in Fig. 3.1.

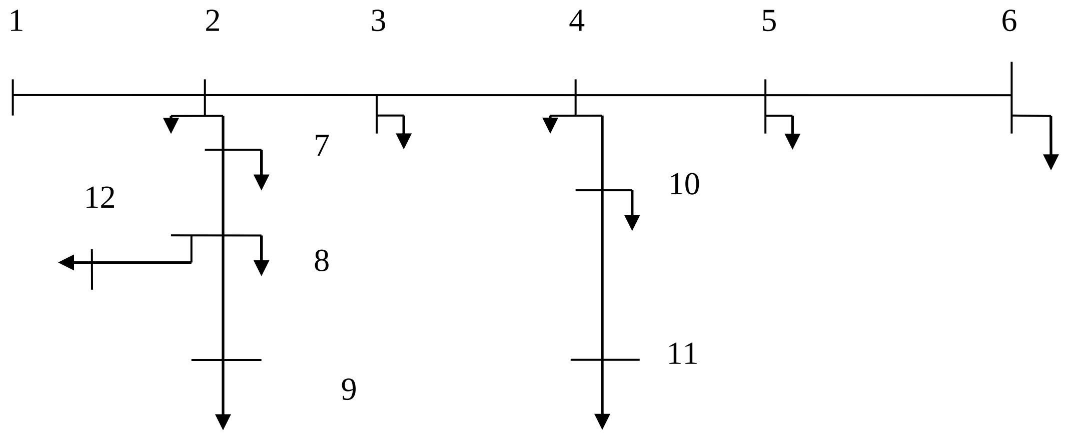


Figure 3.1 Single line diagram for radial distribution network

The branch number, sending-end and receiving-end node of Fig. 3.1 has been presented in Table 3.1

Table 3.1 Branch number, sending-end and receiving-end node of Fig. 3.1

Branch Number (jj)	Sending End m1=SE(jj)	Receiving End m2=RE(jj)
1	1	2
2	2	3
3	3	4
4	4	5
5	5	6
6	2	7
7	7	8
8	8	9
9	4	10
10	10	11
11	8	12

The receiving-end voltage for branch-1 for Fig.3.1 can be calculated by,

$$V(2) = V(1) - I(1)Z(1) \tag{3.6}$$

Similarly for branch-2

$$V(3) = V(2) - I(2)Z(2) \tag{3.7}$$

and so on.

The substation voltage V(1) is known, if current of branch-1 can be computed,the receiving end voltage i.e. V(2) can be easily calculated. Once we get value of V(2) and we have current of branch-2, V(3) can be calculated. Therefore, if all the branch currents are known, the node voltages can be easily determined.

In general we may write:

$$V(m2) = V(m1) - I(jj)Z(jj) \qquad \forall jj = 1,2,\dots,N-1 \tag{3.8}$$

where,

m1=Sending end node of branch-jj.

m2=Receiving-end node of branch-jj.

jj=branch number.

Z(jj)=Impedance of branch-jj

N=total number of nodes.

For calculating the voltages, the branch currents should be computed first, which can be calculated only if we have load currents at each node as branch current is sum of the load currents and the branch currents beyond that particular branch. The load data for all the buses except bus-1 is provided as bus-1 is slack bus and the rest are load buses. The active and reactive load of each node are known, the load current can be calculated if we know the node-voltages. Initially the voltages at all the nodes are assumed as unity. The load current at any node 'i' is expressed by

$$IL(i) = \frac{PL(i) - jQL(i)}{V^{*}(i)} \qquad \forall i = 2,3,\dots,N \qquad (3.9)$$

where,

IL(i)=load current at node 'i'

PL(i)= Active power load at node 'i'

QL(i)= Reactive power load at node 'i'.

Further, the branch current of any branch can be computed as sum of load current beyond that branch and branch currents just next to the given branch. For terminal buses the branch current is equal the load current itself as there are no branches beyond that. Terminal buses can be easily found out by analyzing the sending-end buses, the bus which doesn't exist in array m1 of Table 3.2 will be terminal bus.

Calculation for branch current

Step-1: Let $I(jj) = IL(jj+1)$ (3.10)

Step-2: Let k=1,2,…,N-1

Step-3: If jj≠k and m2(jj)=m1 (jj+k)

$$I(jj) = I(jj) + II(jj+k) \qquad (3.11)$$

Step-4: If k<N-1, let k=k+1 and go to 3.

Step-5: End.

Once load current and branch currents are computed, the above equations will updated the voltages of all nodes and these are calculated using Eq.(3.8)

ΔV is calculated using Eq.(3.14)

$$\Delta V = V1(i) - V(i) \qquad \forall i = 2,3,\dots,N \qquad (3.12)$$

where V1 = updated voltages and V = voltages of previous iteration.

The ΔV_{max} from ΔV is found out.

Now, let V=V1

The process is repeated till the convergence is achieved with the convergence criterion ΔV <Є where Є=0.0001 .

After convergence, the active and reactive power losses can be determined by:

$$P_{Loss}(jj) = |I(jj)|)^2 * R(jj) \tag{3.13}$$

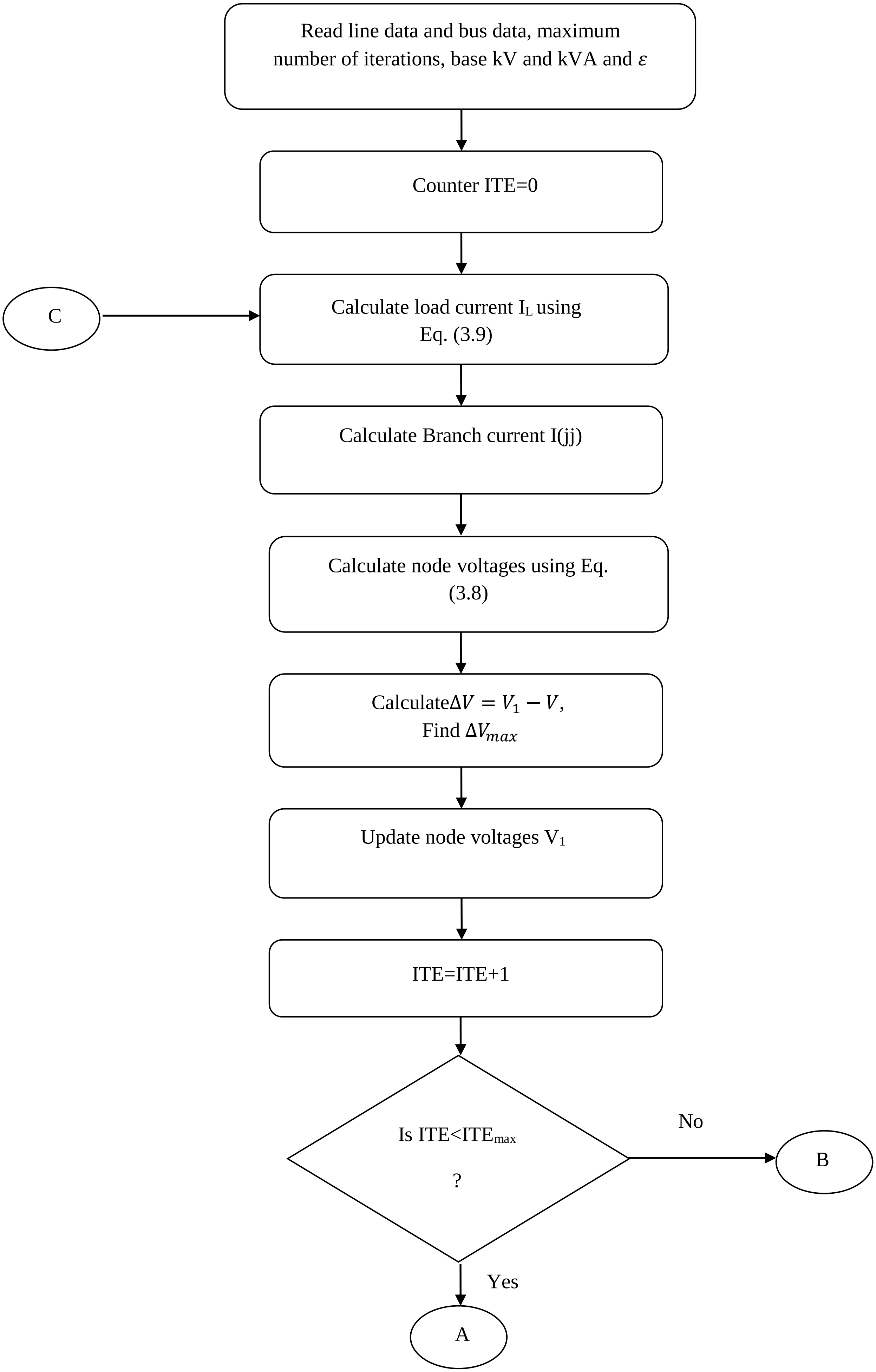
$$Q_{Loss}(jj) = |I(jj)|)^2 * X(jj) \tag{3.14}$$

where,

R(jj)= resistance of branch jj

X(jj)= reactance of branch jj

Figure 3.2 shows the flowchart of the load-flow used in the proposed method. The constant power modeling has been used throughout the thesis work.


Read line data and bus data, maximum number of iterations, base kV and kVA and ε
Counter ITE=0
C
Calculate load current I_L using Eq. (3.9)
Calculate Branch current I(jj)
Calculate node voltages using Eq. (3.8)
Calculate$\Delta V = V_1 - V$,
Find ΔV_{max}
Update node voltages V_1
ITE=ITE+1
Is ITE<ITE_{max}
?
No
B
Yes
A

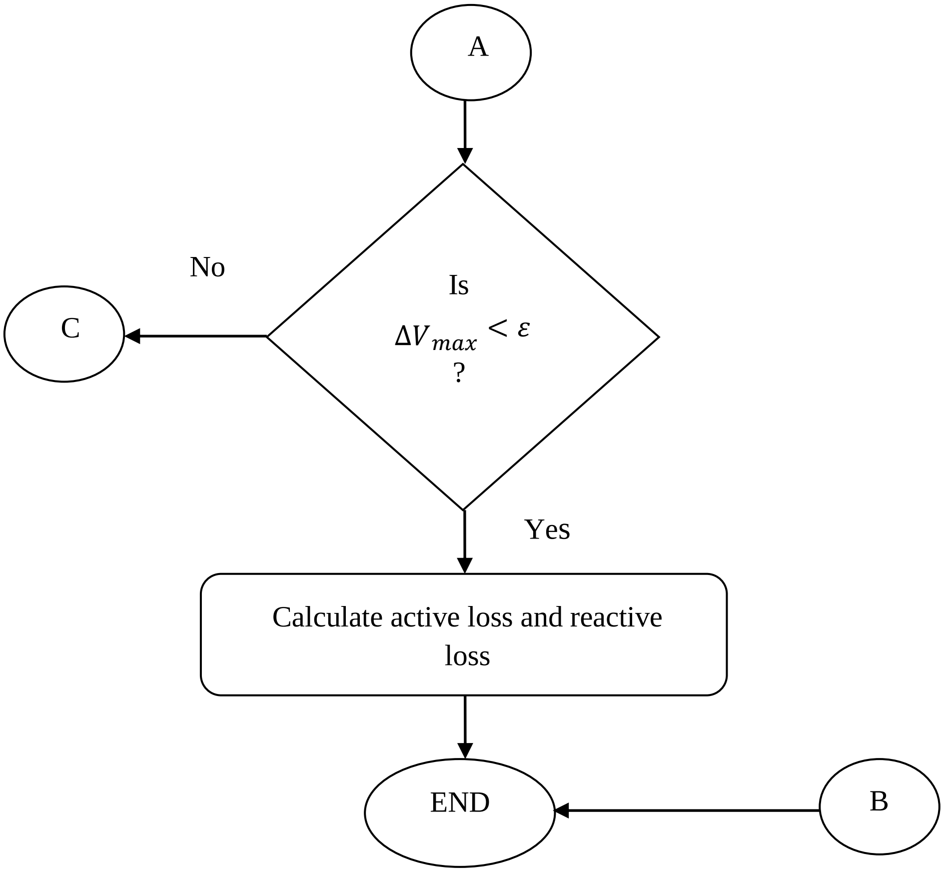


Fig. 3.2 Flowchart for load-flow analysis

3.4 NODE SELECTION

Node selection for capacitor installation can be done using various techniques. The node selection should be done in such a manner, which yields best results for power loss minimization and cost minimization. It should also improve the voltage profile of the system and at the same time reliability of overall system. Since the next step of power loss minimization i.e. choosing the capacitor size depends upon the node selected for compensation, hence it is very important to choose the appropriate node. In this thesis VSI and LSF are chosen to identify the optimal node for capacitor placement.

3.4.1 VOLTAGE STABILITY INDEX

Voltage Stability Index suggests the node, which will give maximum voltage stability and improve voltage profile after capacitor placement [9].

In this approach first of all VSI (voltage stability index) is computed at all the nodes and these VSI values are then arranged in ascending order. The node having lowest value of VSI is more likely to have voltage collapse with respect to other nodes. Order of the nodes with respect to ascending order of VSI represents the order of candidate nodes for compensation. The value of VSI varies between 0 and 1. (Unity at no load and zero at voltage collapse point).

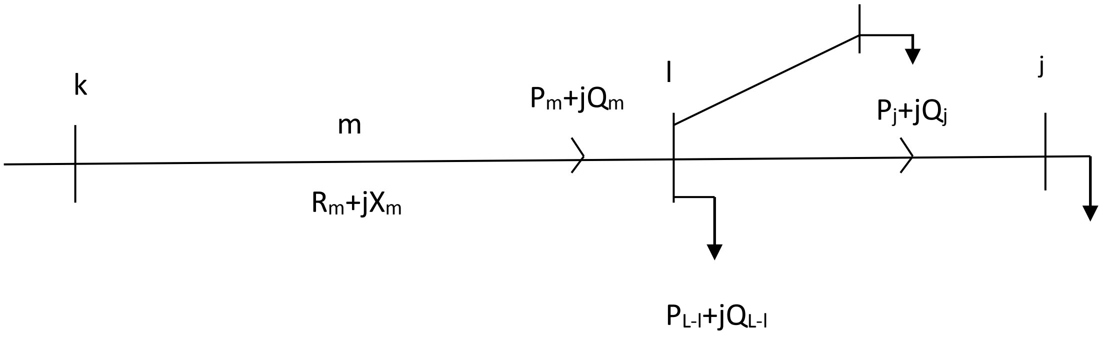


Figure 3.3 Single line diagram of two bus distribution network

Considering two bus network shown in Fig.3.3, if power flows from bus k to bus l, the VSI can be calculated [27] using Eq. (3.15) given below

$$L_l = V_k^4 - 4(P_l X_m - Q_l R_m)^2 - 4(P_l R_m - Q_l X_m)V_k^2 \tag{3.15}$$

where,

V_l and V_k are the voltage magnitude of bus 'l' and 'k' respectively.

L_l is the VSI of node 'l'.

X_m and R_m are the reactance and resistance respectively for line m.

P_l and Q_l are the active and reactive load at bus l respectively.

After computing VSI of each node, the voltage stability of the system can be improved by injecting reactive power at appropriate nodes.

Further calculation of capacitor size has been done using analytical approach. The required change in Q_l will be the measure of amount of capacitor to be placed at node 'l' and can be obtained by linearizing Eq.(3.15) by treating Q_l as the control variable and neglecting the higher order terms. Change in VSI can be computed using:

$$\frac{\Delta L_l}{\Delta Q_l} = \frac{dL_l}{dQ_l} \tag{3.16}$$

where,

$$\Delta L_l = L^t - L_l \tag{3.17}$$

$$\frac{dL_l}{dQ_l} = 8[P_m R_m X_m - Q_m R_m^2 + 0.5 X_m V_k^2] \tag{3.18}$$

where L^t is the threshold VSI of the system.

VSI will be computed using Eq.(3.15) for all the nodes. These nodes are then ranked in ascending order. The node with lowest value of VSI is selected as the candidate node for compensation. Solving Eq.(3.16), the additional reactive power compensation, ΔQ_l , to be provided at node 'l' can be computed.

The maximum compensation at each node is limited to the initial reactive power delivered by respective node Q_l° prior to compensation. This avoids over dimensioning of capacitor banks as

$Q_{cl} \leq Q_l^{\circ}$.

Voltage deviation index (VDI) also needs to be defined in order to quantify the extent of violation of limits imposed on bus voltages in radial system as,

$$VDI = \sqrt{\sum_{i=1}^{nn} \frac{(V_i - V_{limit})^2}{nn}} \quad (3.19)$$

where V_{limit} will be the upper limit of voltage if there is a upper limit violation or lower limit if there is a lower limit violation.

In this thesis only node selection is done using VSI.

3.4.2 LOSS SENSITIVITY FACTOR

Loss sensitivity factor is yet another parameter, which will determine the candidate node for reactive power compensation. It determines the bus having the highest loss reduction.

The estimation of the candidate buses generally helps in cutback of the search space for the optimization of problem. Since only few buses are selected as candidate buses for compensation, cost for capacitor installation can also be reduced [20].

Considering a distribution line linked between buses ‘m’ and ‘n’ connected to a load as in Fig.3.4

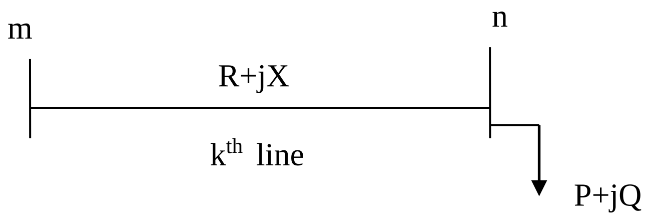


Figure 3.4 Distribution line with a load and impedance

The total active power loss in kth line will be [I_k^2]*R[k], and this loss can be expressed as,

$$P_{lineloss}[n] = \frac{(P^2[n] + Q^2[n])R[k]}{(V[n])^2} \quad (3.20)$$

Similarly for reactive power loss we can write,

$$Q_{lineloss}[n] = \frac{(P^2[n] + Q^2[n])R[k]}{(V[n])^2} \quad (3.21)$$

where,

P[n] is total active power supplied beyond node ‘n’.

Q[n] is total reactive power supplied beyond node ‘n’.

R[k] is the resistance of the k th line.

X[k] is the reactance for k th line.

Loss sensitivity factor can be calculated by partial differentiation of $P_{lineloss}$ with respect to Q,

$$\frac{\partial P_{lineloss}}{\partial Q} = \frac{(2 * Q[n] * R[k]}{(V[n])^2} \tag{3.22}$$

For selecting the optimal node for compensation the loss sensitivity factor $(\partial P_{lineloss}/\partial Q)$ is computed from load-flow on base case. These values are then arranged in descending order for all the lines in the given system. This sequence determines the order of candidate nodes for power compensation. Since this sequence is entirely determined by $(\partial P_{lineloss}/\partial Q)$, it is very useful and powerful method for capacitor placement.

In this thesis work three nodes are chosen for compensation, two on the basis of LSF and one based on VSI.

3.5 SIZING OF CAPACITOR

Size of the capacitor bank to be installed at the chosen node has a great significance as optimal size leads to reduction of cost as well as losses in the system. Various methods are used to determine the size of capacitor to be installed. Some common methods that are Particle swarm Optimization, Tabu search, Fuzzy logic control, Differential Evolution, artificial neural network, Genetic Algorithms, Artificial Bee Colony, Heuristic Optimization technique, etc.

Here the technique used for determining the optimal size of capacitor is Bacterial Foraging Optimization Algorithm (BFOA) [19]. BFOA is a new technique under the category of nature-inspired optimization algorithms. The key idea of this algorithm is group foraging strategy of swarm of E.coli bacteria in a multi optimal function optimization. The bacteria search for food such that it can maximize the energy obtained per unit time. The individual bacterium communicates with other bacteria by sending signals. This algorithm is not much effected by the size or the non linearity of the system. Some more advantages of this algorithm are less computational burden and time, global convergence and also it more number of objective functions can be handled as compared to other evolutionary algorithms.

During foraging the real motion is achieved by flagella or a set of tensile flagella. This flagella helps E.coli bacterium to swim or tumble. When the bacterium rotates the flagella in clockwise direction the bacterium tumbles and moves to next place whereas if flagella is made to move in anticlockwise direction, it helps bacterium to swim as shown in Fig. 3.5 [19].

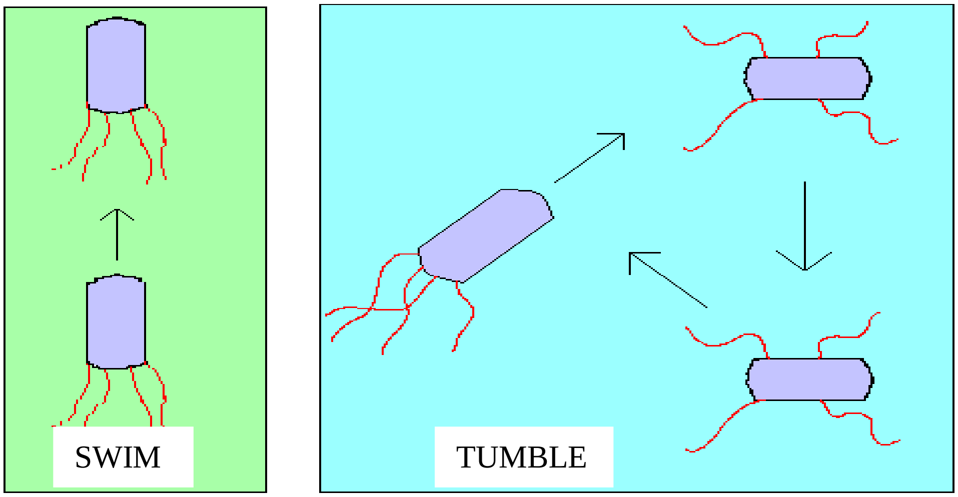


Figure 3.5 Swim and tumble of bacterium [19]

BFOA has four prime steps:

a) Chemotaxis
b) Swarming
c) Reproduction
d) Elimination and dispersal

Chemotaxis is the process in which the bacterium moves taking small steps in problem search space. This movement is either through tumbling or swimming via flagella. Biologically an E.*coli* bacterium has two different movements. It may swim for a certain period of time in same direction or can tumble and alternate in between these two for entire lifetime. Assuming that $x^i(m, n, o)$ represents ith bacterium in mth chemotactic step, nth reproductive step and oth elimination dispersal step. And also assuming that C(i) represents the step size taken by tumble in random direction. Then the movement of bacterium in computational chemotaxis will be given by,

$$x^i(m+1, n, o) = x^i(m, n, o) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}} \tag{3.23}$$

where Δ represents a vector in any random direction the elements of which lie in [-1,1].

Swarming refers to the behavior of several motile species of bacteria in which intricate and spatio temporal patterns are created in semisolid nutrient medium. Group of E.*coli* bacterium arrange themselves in travelling rings. When the cells are simulated by high level of succinate, they release an attractant named aspertate. This aspertate helps them to get amassed and thus moving as concentric patterns of swarms.

Reproduction is the step in which the least healthy bacteria die and the healthier bacteria asexually split into two bacteria. These are then placed at same location of their parents thus keeping swarm size constant.

In elimination and dispersal any gradual or sudden change may occur in the local environment where the bacterium population lives. In this either all the bacteria in a region may be killed or any group is dispersed into new location. The bacteria are liquidated at arbitrary with a small probability called elimination-dispersal probability.

Basically BFOA is based on the behavior of virtual E.coli bacterium and mimicking its chemotactic movement in search space.

3.5.1 CALCULATION FOR SIZING USING BFOA

For sizing of the capacitor using BFOA let us consider the following steps:

1. Initialization of variables

p= Dimension of search space (3).

S = Bacteria population (100).

N_s = Swim length of a bacteria (5).

N_c = Maximum chemotactic steps (4).

N_{re} = Maximum reproduction steps (4).

N_{ed} = Maximum elimination-dispersal steps (2).

N_i = Maximum iterations (10).

P_{ed} = Probability of elimination-dispersal event (0.5).

C(i) = step size of bacteria in random direction (.05*ones(s,1)).

After specifying the above parameters initial value of θ^i is selected, which is done in the areas where the optimum value is expected to exist.

$$x^i = \left(x_1^i, x_2^i, x_3^i, \dots x_k^i\right) \qquad \forall i = 1,2,\dots,S \;\&\; k = 1,2,\dots,p \tag{3.24}$$

where x_k is the size of capacitor at node k.

2. Initialization of the loops for iteration (q=1,2,…,N_i), elimination dispersal (o=1,2,…,N_{ed}), reproduction (n=1,2,…N_{re}) and chemotaxis step (m=1,2,...,N_c).

a.) Initialize loop for population size (i=1,2,…,s).

b.) Calculate the value of objective function J(i,m,n,o) for given ‘S’ population of bacteria . The objective function is calculated as:

$$J(i,m,n,o) = J(i,m,n,o) + J_{cc}\big(x, P(m,n,o)\big) \qquad \forall i = 1,2,\dots,S \tag{3.25}$$

Here $P(m,n,o) = \{x^i(m,n,o) | i = 1,2,\dots,S\}$

i.e. position of ith bacterium in mth chemotactic, nth reproduction and oth elimination-dispersal step and

$$J_{cc}(x,P(m,n,o)) = \sum_{i=1}^{s} J_{cc}\left(x,x^i(m,n,o)\right)$$

$$= \sum_{i=1}^{s}\left[-d_{attract}exp\left(-w_{attract}\sum_{k=1}^{p}\left(x_k - x_k^i\right)^2\right)\right]$$

$$+ \sum_{i=1}^{s}\left[h_{repelent}exp\left(-w_{repelent}\sum_{k=1}^{p}\left(x_k - x_k^i\right)^2\right)\right] \qquad (3.26)$$

where, $d_{attract}$ = depth of attractant released by cell (0.1)

$w_{attract}$ = width of attractant signal (0.2)

$h_{repelent}$ = height of repellent effect (0.1)

$w_{repelent}$ = width of repellent (1.0)

c.) Now, let J_{last}=J(i,m,n,o) = Jh

d.) Tumble: a random vector Δ(i) in the domain [-1,1] is generated, with each element $\Delta_k(i)$, for k=1,2,...,p.

e.) Move: the next position for the bacteria is calculated using Eq.(3.23) This results in movement of bacterium in the direction of tumble with a step size C(i).

f.) Calculate x(i,m+1,n,o).

g.) Swim: assume j=0 and while $j<N_s$, let j=+1 (where j is counter for swim length).

h.) If J(i,m+1,n,o)<J_{last} , let J_{last}=J(i,m+1,n,o) and move x^i(m+1,n,o) and compute new J(i,m+1,n,o) using this x.

i.) Else, generate random vector Δ(i) and calculate new values for x^i(m+1,n,o) and thus J(i,m+1,n,o).

j.) If i<s, go to (b), else end the loop.

k.) Let Jh=[Jh J]

3. If m<N_c , let m=m+1, else end chemostatic loop.
4. Reproduction: for the given reproduction and elimination-dispersal loop, let the health of bacterium i be given by:

   $$Jhealth(i) = sum(Jh(i)) \tag{3.27}$$

   After calculating health of each bacterium discard half of the population of bacteria and replace them by the exact copy of remaining half, i.e. the $S/2$ bacteria possessing higher value of Jhealth are discarded and replaced by the bacteria with lower Jhealth value.

   Now if n<N_{re}, let n=n+1. Else end the reproduction loop.
5. Calculate $Jmin = \min(J)$
6. Elimination-dispersal loop: for i=1,2,…,S eliminate and disperse each bacterium with probability P_{ed} by generating a random value.
7. If o<N_{ed} then let o=o+1, else end the elimination loop.
8. If q<N_i, let q=q+1, else end the iteration loop.

The final value of Jmin thus obtained corresponds to the bacterium that yields the optimal size of capacitors to be placed for compensation.

The losses after compensation can be computed by providing the computed amount of kVAr compensation at the respective nodes and running the load-flow.

In this chapter voltage stability index, loss sensitivity factors and bacterial foraging for capacitor placement have been discussed. The VSI and LSF are used to find out the candidate buses for compensation and BFOA is used to get the optimal sizes of shunt capacitors which are to be installed at candidate buses.

CHAPTER 4

EXAMPLES AND RESULTS

In this chapter the results after the implementation of methodology presented in chapter-3 are presented. The presented algorithm is implemented on 33-node radial bus system. Single line diagram for 33-node system is shown in Fig 4.1.

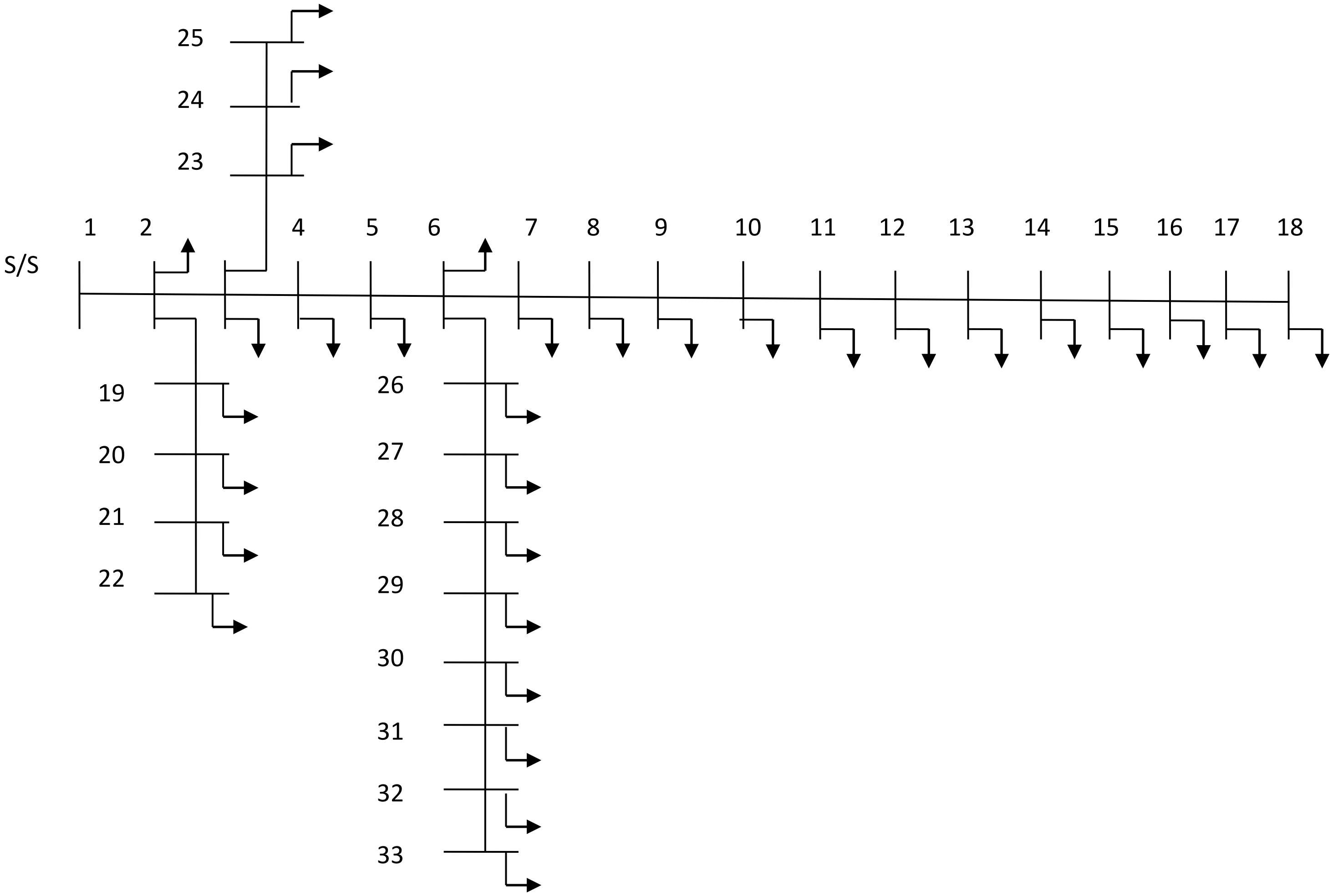


Figure 4.1 33-node radial distribution network [26]

The line and bus data are obtained from [25, 26], and the results for load-flow analysis are shown in Table 4.1 obtained by coding the given algorithm in MatLab. Fig.3.1 has following characteristics

Total number of nodes or buses = 33

Total number of branches or lines = 32

Base voltage = 12.66kV

Base MVA = 100

Bus 1 is considered as slack bus.

Rest 32 buses are PQ bus.

Total real power load and reactive power load of 33-node radial distribution network shown in Fig. 4.1 are 3.715MW and 2.3MVAr respectively.

The node voltages for all nodes obtained by load-flow [25] is shown in Table 4.1.

Table 4.1: Node voltages for base case of 33-node radial distribution network

Node	Volatage magnitude (p.u.)
1	1.000
2	0.9970
3	0.9830
4	0.9755
5	0.9681
6	0.9498
7	0.9463
8	0.9415
9	0.9352

10	0.9294
11	0.9286
12	0.9271
13	0.9210
14	0.9187
15	0.9173
16	0.9160
17	0.9139
18	**0.9133**
19	0.9965
20	0.9929
21	0.9922
22	0.9916
23	0.9794
24	0.9727
25	0.9694
26	0.9479
27	0.9453
28	0.9339
29	0.9256
30	0.9218
31	0.9176
32	0.9167
33	0.9160

Total active power losses = 202.1821kW

Total reactive power losses = 135.0091kVAr

Minimum system voltage = 0.9133p.u. (at node 18).

Loss sensitivity factor and voltage stability index methods were used for selection of optimal node as discussed in Chapter-3. The nodes 30 and 25 were obtained by LSF and the node 18 was obtained by VSI.

After identifying the node, optimal capacitor size for each node was chosen using BFOA. Table-4.2 shows the size of each capacitor obtained for compensation at respective nodes.

Table 4.2: Optimal Size of capacitor to be installed in 33-node radial distribution network

Node.	Size of Capacitor (kVAr)
30	474.9
25	987.5
18	353.9
Total compensation provided (kVAr)	1816.3

After identifying the capacitor size and location, load-flow[25] was performed once again to obtain the node voltages and losses of the system..

Table 4.3 shows the load-flow results after capacitor placement at node 30, 25 and 18.

Table 4.3: Load flow results of 33-node radial distribution network after compensation

Node	Volatage magnitude (p.u).
1	1.000
2	0.9977
3	0.9870
4	0.9815
5	0.9761
6	0.9648
7	0.9630
8	0.9589
9	0.9547
10	0.9510
11	0.9503
12	0.9492
13	0.9462
14	0.9458
15	**0.9457**
16	0.94582
17	0.9481
18	0.9489

19	0.9971
20	0.9936
21	0.9929
22	0.9922
23	0.9844
24	0.9800
25	0.9789
26	0.9636
27	0.9621
28	0.9572
29	0.9540
30	0.9522
31	0.9482
32	0.9473
33	0.9471

Total active power losses = 132.5797kW

Total reactive power losses = 89.271kVAr

Minimum system voltage = 0.9457p.u. (at node 15).

Table 4.4 shows the performance of Bacterial Foraging Optimization Algorithm and base case for 33-node radial distribution system.

Table 4.4: Comparison of performance of BFOA and base case for 33-node radial distribution network

PARAMETER	WITHOUT COMPENSATION	WITH COMPENSATION		
		Using single capacitor unit	Using two capacitor units	Using three capacitor units
NODE	-	25	25,30	25,30,18
CACPACITOR VALUE (kVAr)	-	474.9	474.9, 987.5 (1462.4)	474.9, 987.5, 353.9 (1816.3)
P_{LOSS} (kW)	202.1821	192.9963	140.3712	132.5797
Q_{LOSS} (kVAr)	135.0091	129.9358	94.2638	89.271
V_{MIN} (p.u.)	0.9133	0.9144	0.9251	0.9458
VSI_{MIN} (p.u)	0.6969	0.7002	0.7344	0.8025

Figure 4.2 shows the plot of voltage magnitude(p.u.) Vs node number before and after compensation.

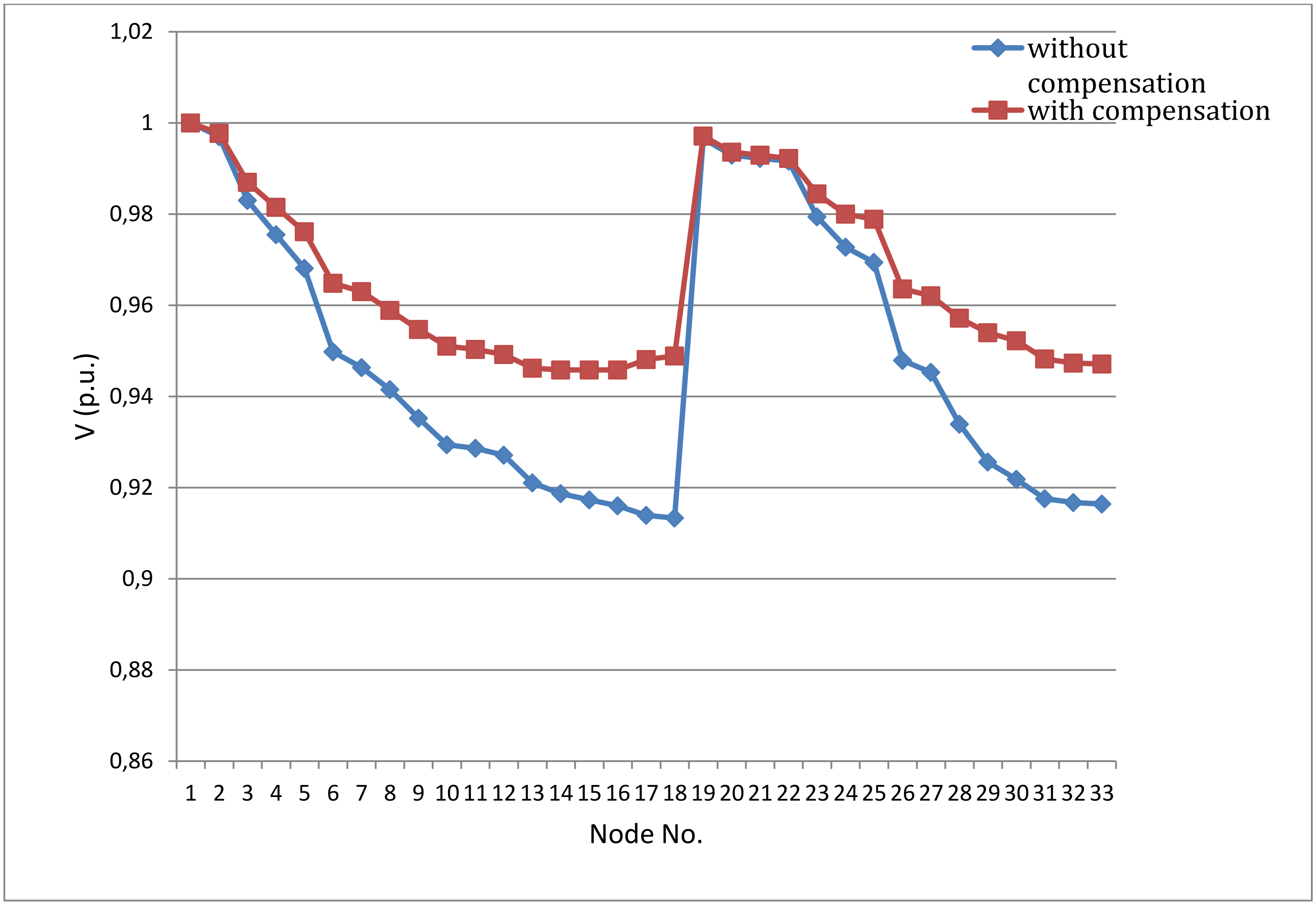


Figure 4.2 Voltage profile of system before and after compensation

In Fig.4.2 the blue line indicates the voltage profile before compensation and the red line indicates voltage profile after compensation. From the graph it can be concluded that the voltage profile for the system has increased significantly and the minimum p.u. voltage has increased from 0.9133 to 0.9458.

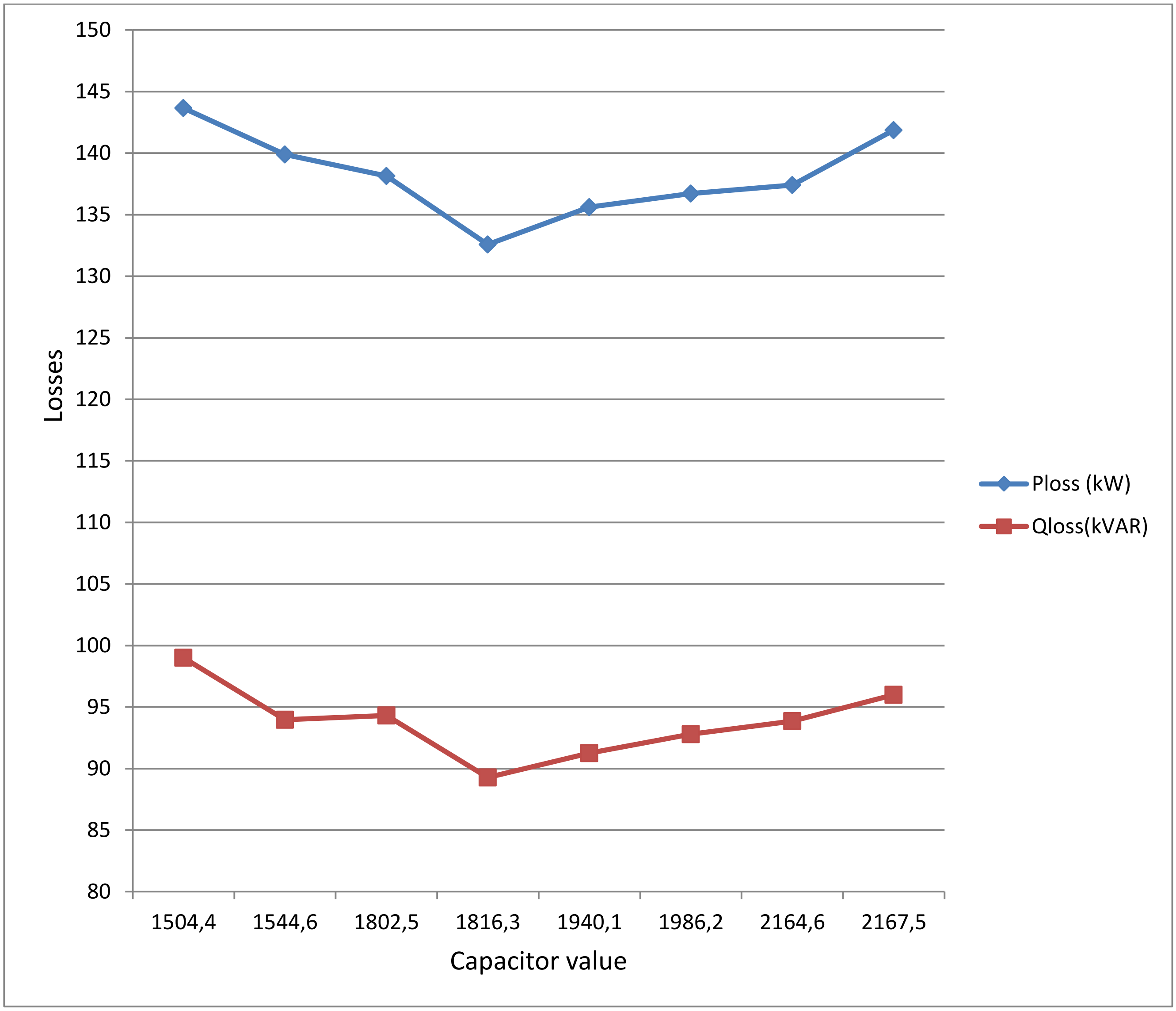


Figure 4.3: Active and reactive power losses at different capacitor value

The plot in Fig 4.3 shows variation of losses (on vertical axis) in the system at different values of capacitor units (on horizontal axis) and justifies that best results are obtained when the value of capacitor is 1816.3kVAr (353.9kVAr, 474.9kVAr and 987.5kVAr at nodes 18, 25 and 30 respectively).

The voltage stability index for the system also increased after reactive power compensation. The minimum value of VSI before compensation was 0.6969p.u.(at node 18) which increased to 0.8025p.u.(at node 15). This increase in VSI signifies less threat for voltage collapse with respect to base case.

Figure 4.4 shows the plot for Voltage stability index Vs node number before and after compensation.

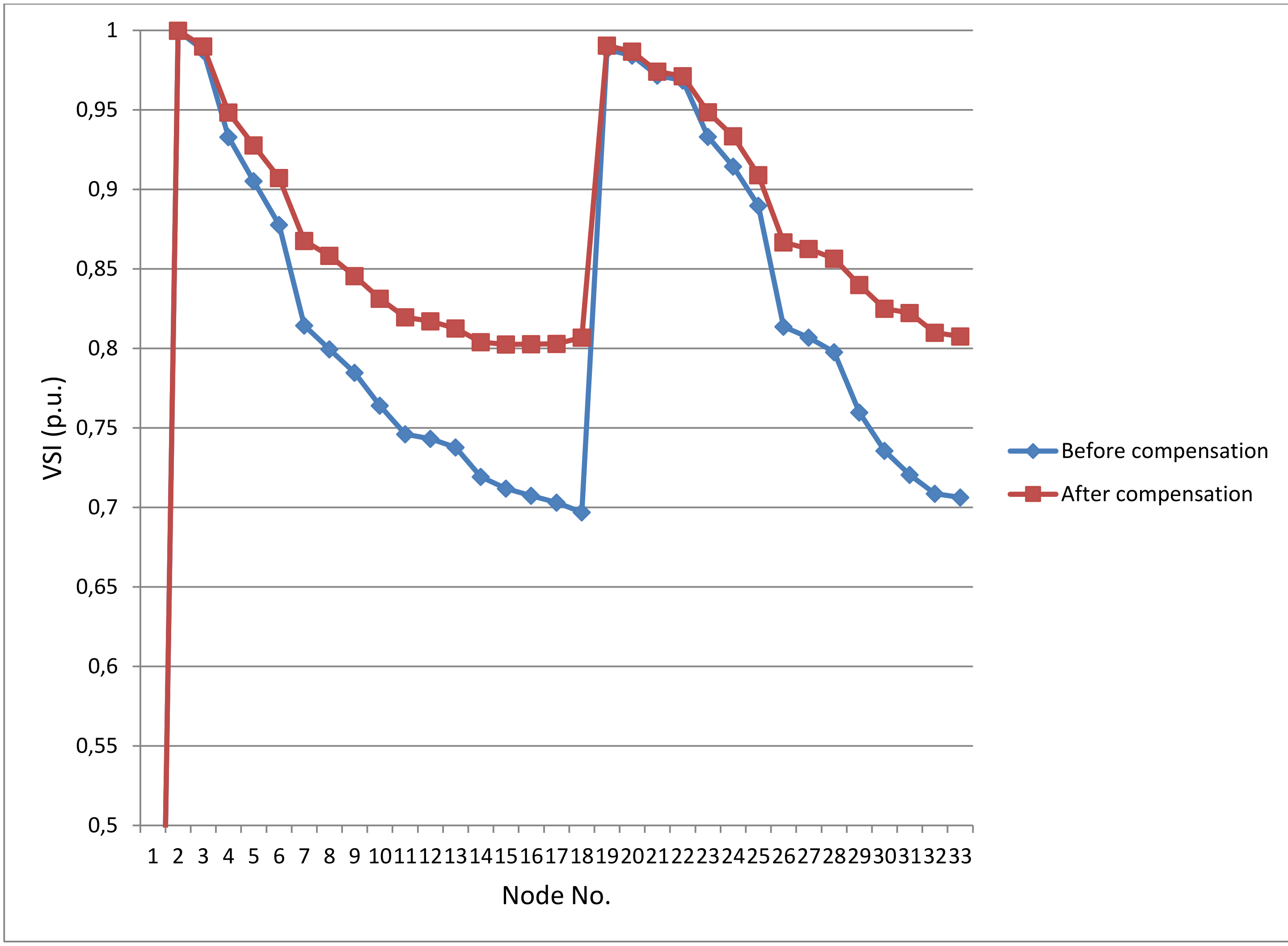


Figure 4.4: Voltage stability index before and after compensation

The proposed method is compared with the method [23, 24] in terms of losses and minimum voltage after compensation as shown in Table 4.5. The reactive power for these is recomputed using load-flow [25] for comparison, as it was not mentioned in the paper.

Table 4.5 Comparision of proposed method with other methods

Methods	Real Power Loss (kW)	Reactive Power Loss (kVAr)	Minimum Voltage (p.u.)
BFOA with LSF [23]	144.04	90.90	V_{15}=0.9361
SAHSA [24]	135.12	90.16	V_{18}=0.9344
Proposed method	132.57	89.271	V_{15}=0.9457

The method proposed by Abul'Wafa [7] is recomputed using the load-flow [26] used in this thesis work. The capacitors installed at nodes 28, 6, 29, 8, 30 and 9 with kVAr values 25, 475, 300, 175, 400 and 350 respectively. Total kVAr is 1725. The real power loss and reactive power loss of 33-node radial distribution after compensation with the load-flow [25] are 135.81kW and 90.81kVAr respectively. The proposed method is compared with the method [7] are shown in Table 4.6

Table 4.6 Comparison of proposed method with recomputed previous method [7]

Method	Real Power Loss (kW)	Reactive Power Loss (kVAr)	Minimum Voltage (p.u.)
FRCGA [7]	135.81	90.81	V_{18}=0.9367
Proposed method	132.57	89.271	V_{15}=0.9457

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE

5.1 CONCLUSION

The thesis work was carried out to minimize the reactive power losses in a 33-bus radial distribution system. The objective was achieved by allocating capacitor banks at different nodes. Solution was found in two steps, first was determination of location and then finding optimal size. Location was determined by VSI and LSF and the size was determined by Bacterial Foraging Algorithm. The results thus obtained were better as the losses were reduced and the voltage profile also improved.

5.2 FUTURE SCOPE

The completion of one research work opens the scope for research in many other related areas.

1. The capacitor allocation could also be extended from balanced distribution system to unbalanced distribution system
2. The allocation of DG, DSTATCOM can be considered, which will be supportive during transients too.

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APPENDIX-A

Table A-1: Line data for 33 bus radial distribution system

Branch Number	Sending-end Bus	Receiving-end Bus	Branch Resistance(Ω)	Branch Reactance (Ω)
1	1	2	0.0922	0.0477
2	2	3	0.4930	0.2511
3	3	4	0.3660	0.1864
4	4	5	0.3811	0.1941
5	5	6	0.8190	0.7070
6	6	7	0.1872	0.6188
7	7	8	1.7114	1.2351
8	8	9	1.0300	0.7400
9	9	10	1.0040	0.7400
10	10	11	0.1966	0.0650
11	11	12	0.3744	0.1238
12	12	13	1.4680	1.1550
13	13	14	0.5416	0.7129
14	14	15	0.5910	0.5260
15	15	16	0.7463	0.5450
16	16	17	1.2890	1.7210
17	17	18	0.7320	0.5740
18	2	19	0.1640	0.1565
19	19	20	1.5042	1.3554
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3083
23	23	24	0.8980	0.7091
24	24	25	0.8960	0.7011
25	6	26	0.2030	0.1034

26	26	27	0.2842	0.1447
27	27	28	1.0590	0.9337
28	28	29	0.8042	0.7006
29	29	30	0.5075	0.2585
30	30	31	0.9744	0.9630
31	31	32	0.3105	0.3619
32	32	33	0.3410	0.5302

Table A-2: Bus data for 33 bus radial distribution system

Bus Number	P(kW)	Q(kVAr)
1	0.0	0.0
2	100.0	60.0
3	90.0	40.0
4	120.0	80.0
5	60.0	30.0
6	60.0	20.0
7	200.0	100.0
8	200.0	100.0
9	60.0	20.0
10	60.0	20.0
11	45.0	30.0
12	60.0	35.0
13	60.0	35.0
14	120.0	80.0

15	60.0	10.0
16	60.0	20.0
17	60.0	20.0
18	90.0	40.0
19	90.0	40.0
20	90.0	40.0
21	90.0	40.0
22	90.0	40.0
23	90.0	50.0
24	420.0	200.0
25	420.0	200.0
26	60.0	25.0
27	60.0	25.0
28	60.0	20.0
29	120.0	70.0
30	200.0	600.0
31	150.0	70.0
32	210.0	100.0
33	60.0	40.0