OPTIMAL PLACEMENT AND SIZING OF CAPACITOR IN RADIAL DISTRIBUTION NETWORK USING FUZZY AND BFOA

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

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in
Power Systems

Submitted by

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DECLARATION

I hereby certify that the work which is presented in dissertation entitled, **"Optimal Placement and Sizing of Capacitor in Radial Distribution Network using Fuzzy and BFOA"**, in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Power Systems, submitted to Electrical & Instrumentation Engineering Department of Thapar University, Patiala is as authentic record of my own work carried under the supervision of Dr. Smarajit Ghosh. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor 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 to the best of my knowledge and belief.

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CERTIFICATE

Certified that the dissertation entitled, "**Optimal Placement and Sizing of Capacitor in Radial Distribution Network using Fuzzy and BFOA**", which is being submitted by Chandan Kishore in fulfillment of the requirements for the award of the **Master of Engineering in Power Systems**, to Thapar University, Patiala, is a bona-fide record of the candidate's own work carried out by him under my supervision and guidance. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other university or institute for award of any degree.

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ABSTRACT

This dissertation represents an approach for the ideal placing and sizing of capacitors in radial distribution networks (RDNs) using the application of fuzzy and Bacterial Foraging Optimization Algorithm (BFOA). In the early day's reduction of losses in power distribution networks had been a greater challenge. Compensating the power of the system has become the major tool to improve the stability of the system. The reactive power compensation of the power distribution system is significantly improved by capacitor placement which is one of the most impressive techniques that are used to reduce losses. The capacitor allocation for distribution system problem involves determining the ideal place and also the perfect size of the capacitor. In this work, load flow is performed at first to compute the losses and voltages at different nodes without compensation. In the proposed technique the combined approach of LSF (Loss sensitivity factor) and VSI (Voltage stability index) are used to determine the optimal placement of capacitor banks. The optimal size of the capacitor banks has been determined by Bacterial Foraging Optimization Algorithm (BFOA). To justify the objective of the proposed method after installing the capacitor, the load flow is performed again to get the system losses and node voltages. The suggested system is tried out on standard IEEE 33-node, 69-node and 141-node radial distribution systems and compared with other existing methods.

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Chandan Kishore

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LIST OF ABBREVIATIONS

RDN	Radial Distribution Network
VSI	Voltage Stability Index
LSF	Loss Sensitivity Factor
GA	Genetic Algorithm
PSO	Particle Swarm Optimization
LSI	Loss Sensitivity Index
BFOA	Bacterial Foraging Optimization Algorithm
ABC	Artificial Bee colony
DSA	Direct Search Algorithm
GSA	Gravitational Search Algorithm
RCGA	Real Coded Genetic Algorithm
PLI	Power Loss Index
MOPSO	Multi Objective Particle Swarm Optimization
FPA	Flower Pollination Algorithm
IP	Interior Point
SA	Simulated Annealing
TLBO	Teaching Learning based Optimization

NOMENCLATURE

w_v	Weighting factor for the voltage membership function,
$v_{\min}$	Minimum value of permitted voltage,
$v_{\max}$	Maximum value of permitted voltage.
w_p	Weighting factor for membership function of active power loss;
$L(p)$	Real power loss between *l* and *l*+1 bus;
T_p	Total real power loss
w_Q	Weighting factor for reactive power loss membership function;
$L(q)$	Reactive power loss between *l* and *l*+1 bus;
T_q	Total reactive power loss.
P_m	Effective active power at the node m;
Q_m	Effective reactive power at the node m;
R_{lm}	Resistance between the node *l* and m;
X_{lm}	Reactance between the node *l* and m;
V_l	Voltage at node *l*;
V_m	Voltage at node m.
P	Number of optimization variables
N_s	Number of iteration
S	Number of bacteria used for searching the total area
N_c	Number of chemotactic steps
N_{ed}	Maximum number of elimination dispersal events
N_{re}	Maximum number of reproduction steps
P_{ed}	Probability of elimination dispersal process
n	Number of nodes
$C(i)$	Step change of size in the random direction

CHAPTER-1

INTRODUCTION

In early days the demand of electricity was less. Due to rapid modernization, the electrical energy demand has been increased. There is a need of the bulk production of electricity. The generation should be economical and efficient. So electricity is generated in power station by using nuclear, thermal, hydro, solar, wind, geothermal energy, but these power stations are generally located far away from load centres. So there is a need of supply networks, called power supply network, to transmit power to the consumers from the power station. Power supply network mainly has the following three components:

1) Power station
2) Transmission network
3) Distribution network

1.1 TRANSMISSION NETWORK

Transmission network is used to transmit power from generating end substation to the receiving end substation. It transmits bulk power for a long distance at EHV and HV levels without supplying power to consumers. It transmits power at high voltage to reduce current and hence losses. The voltage is stepped up by using step up transformer after generation and then it is step down at the receiving end by using step down transformer. Tie lines are used to connect different grids to form a regional grid and national grid is formed by connecting different regional grids. These grids do not depend on each other and operate independently. But in case of sudden loss or in case of increase of energy demand, the power can be transmitted to each other. It may be divided into two following types:

a) Primary transmission network
b) Secondary transmission network

1.2 DISTRIBUTION NETWORK

The distribution network is a component of power networks, transmitting power to all consumers in a given area, which is connected to a bulk power source. It may be divided into two parts.

1. Primary distribution network: Voltage at receiving end substation is received at voltage ranges from 33 kV to 220 kV from transmission network. It is then step down to 11 or 6.6 or 3.3 kV. Power is transmitted to a different substation for distribution at these voltages. It is also known as a high voltage distribution network.
2. Secondary distribution network: In secondary network the voltage is stepped down at the substation to 400 V and then this low voltage is supplied to the consumers. It is also known as a low voltage distribution network.

Distribution network has three components

1. Feeder: Feeder is a conductor, which carries power from the generating station or substation to secondary substation. The current loading remains same throughout its length. Its size depends on its current carrying capability.
2. Distributors: Distributor is a conductor, which has numerous tapping so that current is tapped off and it can supply to the consumer. The current loading is different throughout the length. Voltage drop along distributor or limit on voltage variation is the design parameter for it. The permissible voltage variation must be ± 5% at consumer terminals.
3. Service mains: Consumer's terminals are connected to the distributor by using a small cable, which is service mains.

1.3 CLASSIFICATION OF DISTRIBUTION NETWORK

Distribution network can be categorized according to

1. Behaviour of current: On the basis of the nature of the current distribution network is categorized in two parts

a) A.C. distribution network

b) D.C. distribution network

The A.C. distribution network is generally preferred for distribution of power because of its less complexity and economical behaviour as compare to the D.C. distribution network.

2. Types of construction: - Distribution network can be classified into two parts depending on construction

a) Overhead network

b) Underground network

We generally prefer the overhead network because it is cheaper as compared to the underground system. Underground system is employed when it is practically not possible to use overhead system.

3) Type of connection:

Distribution network can be categorized in three parts

a) Radial distribution network (RDN):

In this type of network distributor is fixed to the one end of the supply system. It has only one power source for all its consumers. In radial network power from distribution substation is taken by primary feeder and delivered to load area by using sub-feeders and lateral branch circuits. It is the cheapest and simple so it is extensively used for distribution.

b) Ring distribution network:

In a ring distribution network, distributor and feeder cover the total area of supply and finally return to the generating station. In this type of distribution system, the feeder forms a complete ring, closed by itself. The greatest advantage of the ring type distribution system is its reliability. If there is any fault occurs on any part of the feeder, the supply of consumer will continue as before and faulty section will be isolated. It is more expensive in comparison to radial distribution system.

c) Interconnected system:

In the interconnected network generating stations or substations are used to energize the feeder ring, where the number of substations may be two or more than two. It is most reliable and efficient distribution system, but it is very costly. At the time of the maximum load hour, the demand of power in any area that is fed from one generating station can be fed from another generating station.

The radial type of distribution network is mostly used for distribution of power because of their low cost and simple construction.

1.4 LOSSES, AND LOSS MINIMIZATION IN POWER SYSTEM NETWORK

The flow of heavy current causes major losses in an electrical system. In distribution system the R/X ratio is very high; therefore the power loss in the distribution system is very high. In a power system network the role of real and reactive power losses is highly effective so that it becomes a matter of huge interest to compute and analyse these losses. The load flow analysis can be used to find these losses and voltages at all the nodes. After computation of losses, it becomes very necessary to minimize its magnitude to avoid the wastage of power. By reducing the losses the efficiency of the system improves. The power loss in the distribution system is 70% of the total losses occur in electric power systems. So for power utilities it is very important to minimize these losses at distribution side. There are different methods used for minimization of these losses such as feeder reconfiguration, conductor grading, use of distributed generation unit, high voltage distribution system, and reactive power compensation. Major losses occur due to reactive power losses and should be controlled by reactive power compensation.

1.5 REACTIVE POWER COMPENSATION

Reactive power compensation is used to curtail the loss in distribution system using shunt capacitor or series capacitor. Shunt capacitor, installation of the distribution system is preferred because it has more advantages than series capacitor. Proper installation of shunt capacitor improves the power factor, reduces power loss, increases the available capacity of feeders and also improves the voltage profile. Shunt capacitor provides additional reactive power at the nodes to reduce the losses. By installing capacitor at the nodes requiring reactive power, we provide required reactive power and the loading of lines is decreased. Capacitor installation also reduces the chance of voltage collapse. Voltage collapse occurs when there is voltage instability (due to some large or small disturbances) and the voltage falls sharply causing voltage collapse. If the proper reactive source is provided, there will be no sharp fall of voltage and hence no voltage collapse. This reactive power is provided by installing shunt capacitor at the appropriate location. By using capacitor banks the voltage at bus rises and thus improves voltage stability. It also improves reactive power requirement and thus improves power factor. It is very important to determine the optimal position and optimal size of the capacitor to be installed in the RDN. If the capacitor is not installed at the proper location, the advantages of installing capacitor will be nullified and proper system operation will be disturbed. So it is very necessary to obtain the optimal position and size of the capacitor to be placed.

1.6 LITERATURE REVIEW

Baghzouz and Ertem [1] proposed a new technique for obtaining the best size for capacitor to be installed in RDNS. The main aim was to curtail the losses keeping harmonics in safe limit and less voltage variation. The heuristic numerical technique was utilized for the capacitor problem solution.

Baghzouz [2] proposed the solution of capacitor problems in RDNs considering the nonlinear loads. A current injected load was used, which was voltage dependent to obtain the voltage variation. The main aim was to keep the harmonics in limits and to minimize the losses.

Chang and Leung [3] proposed new technique "Genetic Algorithm" (GA) to obtain the best position of the capacitor in the RDN for betterment of voltage level and for minimization of the losses while considering harmonics problems. The main objectives were to curtail the total cost, increase savings and kept harmonics distortion in limits. Harmonics was also computed in GA solutions to improve the capacitor allocation.

Huang [4] proposed an Immune Algorithm for obtaining the best position and size of capacitor for installing in RDNs. In the suggested technique antigens were used to represent objective functions. The suggested technique was validated on a test network.

Yu *et al.* [5] suggested "Particle Swarm Optimization" (PSO) for identifying the best position of capacitor installation. It considered the effect of harmonics and different load levels in the formulation of the objective function. The suggested method was validated on 9-node system.

Hsiao *et al.* [6] suggested GA and Fuzzy Logic to obtain the best position of capacitor. The objective function was based on voltage variations, increased the capacity of feeders and total saving. The objectives were converted into fuzzy sets by fuzzy technique. The optimum value of the capacitor is determined by the GA. The technique was validated on Tai system.

Ghose and Goswami [7] suggested a combination of "Simulated Annealing" (SA) and Heuristic method for the suitable position and sizing of capacitors. The unbalanced load, harmonics and nonlinear behaviour of the load was considered in forming objective function. The suggested approach was validated on 10-node system.

Subrahmanyam [8] suggested a new method to determine the best position for capacitor placement in unbalanced RDNs. The presented method used GA to obtain the optimal value of the capacitor bank. The objective function had been formulated based on energy cost, capacitor purchase cost and installation cost. The fitness function should be maximized for net saving.

Prakash and Sydulu [9] proposed a unique technique to obtain the best position and value of capacitors by using “Loss Sensitivity Factors” (LSF) and PSO respectively in the RDN. The main benefit of this approach is that it decided the position and value of capacitors in systematic way such that losses were minimized and voltage profile was better.

Jabr [10] proposed the two stage approach for capacitor, installation in RDNs. In first stage all buses were selected for positioning of capacitor and objective function was formed on this basis. Interior-point (IP) technique was used to find the solution. In second stage capacitor sizes were considered as a discrete variable and solution was obtained by linear programming solver. The results obtained with this technique were compared with the results obtained from other technique.

Gautam and Mithulananthan [11] suggested two methods for best position of distributed generation in the deregulated electricity scenario. In this paper two objectives, profit maximization and social welfare maximization were formulated for optimal position of distributed generation. The Locational marginal price was used for optimal location. In the presented method number of distributed generation cost characteristics were assumed to show the variety of distributed generation available in the market. Optimal position and sizing were found for each distributed generation cost characteristics. The presented method was tested on 14-bus RDNs.

Khodr *et al.* [12] presented a new technique for obtaining the best position and size for switched type and static type capacitor in RDNs. The objective function was formed with the aim to curtail the system cost and losses and maximize the net savings. The objective function was linearized and then solved by mixed integer linear technique. The result obtained from this technique was compared with the results obtained from other technique and was found to be better. The suggested method was validated on 15-node and 33-node RDNs.

Das [13] suggested the combination of Fuzzy Logic and GA to form the objective function to determine the best position and value of switched and fixed capacitors to curtail the losses and for betterment of voltage level. Voltage variations and cost savings were fuzzified and then integrated by using weighting factors, to obtain the objective function. GA was utilized to obtain the suitable value of the capacitor to be installed.

Huang *et al*. [14] presented a two stage technique for obtaining the best value and position of the capacitor. The fuzzy technique gave Pareto solutions instead of one solution. This technique removed the requirement of defined weighting factor in fuzzy logic. The technique was validated on the actual system.

Kannan *et al.* [15] proposed fuzzy approximate reasoning to locate the capacitor. Sizing of capacitor is determined by PSO technique. Real power loss indices and voltage magnitude were used as an intake for fuzzy logic. The fuzzy interface system was then used for location of the capacitor. The "Loss Sensitivity Index" (LSI) was used as a criterion for the location of capacitor by using fuzzy interface system. The main aim was the betterment of stability of the system.

Das *et al.* [16] utilized "Bacterial Foraging Optimization Algorithm" (BFOA) as an optimization method. The suggested algorithm was based on hunting behaviour of Escherichia coli. The BFOA was very efficacious in the solution of real world problems, which arises in several applications. The hunting strategy of Escherichia coli bacteria was emulated and utilized as an optimization algorithm. The hybridization of other optimization techniques with BFOA was also discussed.

Abdelaziz *et al.* [17] presented two techniques for curtailing the system losses and betterment of voltage stability in distribution feeders. Fuzzy expert system was utilized to determine the optimal position of capacitor to reduce losses and increase net savings. The second method was concerned with the voltage regulator problem. The second method was utilized to obtain the tapping ratio and position of a voltage regulator to curtail the total system losses.

Taher *et al.* [18] used GA for obtaining the best position and size of fixed capacitor with nonlinear loads and distributed generations to curtail the losses and betterment of voltage level. This approach also considered harmonics problem. The main advantage of this technique was that it obtained global solution very fast avoiding local solution and initial condition. The suggested technique was validated on 18-node and 33-node RDNs.

Tabatabaei and Vahidi [19] proposed a new methodology for the ideal position and measuring of shunt capacitors in outspread circulation feeders. This framework depended upon a cushy basic leadership, which utilized another transformative method for the capacitor position issue. The capacitor situation optimization issue consisted of diminishing the cost of top force, minimizing essentialness misfortune and improving the voltage profile. By utilizing the soft thinking, the establishment centre for picking capacitor was fortified by the feathery set speculation in an oversaw methodology. BFOA was used as a piece of managing the objective multivariable optimization issue and the degree of the capacitor. The outcomes displayed that the proposed method gave a more sensible strategy by lessening power misfortunes, essentialness misfortune, and total required capacitive cost and demonstrated a reasonable change in node voltages.

Xu *et al.* [20] presented a new "Artificial Bee Colony" (ABC) algorithm to modify the performance of ABC. The presented method modified the search pattern of onlookers and employed bees. By storing some good solutions a solution pool is formed for current swam. To generate new candidate solutions, it searched the neighbourhood of the solution that was randomly chosen from solution pool.

Raju *et al.* [21] proposed "Direct Search Algorithm" (DSA) to determine the optimal value of both switched and fixed capacitors in RDNs for minimizing the total loss of the system. They tested their on different networks and checked the results obtained by their method with the other techniques.

El-Fergany and Abdelbaiz [22] presented a "Cuckoo Search" (CS) technique to find the best position of the static shunt capacitor in the RDN. The objective function formulated on the basis of improving the voltage profile of the system and to curtail the system working cost. The presented method was tested on 69 node and 118 node RDNs. To check the achievability, the bus systems were used with different loading levels.

Elsheikh *et al.* [23] suggested LSF to determine the best position of the capacitors. A discrete PSO was utilized to decide the sizes of the capacitors to curtail the losses and reduce voltage variations. The results obtained by this technique were compared with the results obtained by other technique.

Devi and Geethanjali [24] suggested the issue of determination of the optimal size and optimal position of Distribution Static Compensator and Distributed Generation. The proposed method used PSO. The main aim was to enhance the voltage level and curtail the total losses.

Sultana and Roy [25] proposed a new technique namely teaching learning based optimization to minimize cost of the capacitor and losses in RDNs by the optimal arrangement of capacitors. The proposed methods were depended on two essential ideas of instruction, teaching stage and learning stage. In the first stage, learners enhanced their capacity through the teaching arrangement of the teacher. Learners expanded their knowledge by cooperation among themselves in the learning stage. To check the achievability, the proposed technique was tested on 22 node, 69 node, 85 node and 141 node RDNs.

Shuaib *et al.* [26] presented "Gravitational Search Algorithm (GSA)" for optimal capacitor placement in RDNs. The main aim was the curtailment of the losses and enhancement of voltage level. They tested their method on 33 node, 69 node, 85 node and 141 node RDNs and showed the comparison of the proposed method with IP and SA.

Abul'Wafa [27] proposed two algorithms for optimal placement of capacitor to improve the voltage stability. For optimal placement of the capacitor fuzzy expert system was used. Fuzzy expert system used power loss reduction index for the location of the capacitor. "Real Coded Genetic Algorithm" (RCGA) was used for sizing of capacitor to improve the voltage profile while considering voltage limits. The proposed method was validated on 33-node RDN and results were compared with other techniques.

Nojavan *et al.* [28] suggested a mixed integer nonlinear technique for optimal position and optimal value of capacitors in mesh or radial systems to curtail the capacitor costs and total system loss. The suggested method was tested on a CIVANLAR mesh distribution system and 10-node, 34-node, 85-node RDNs. The suggested techniques were compared with other techniques.

Devabalaji *et al.* [29] proposed another long term scheduling method for a spiral dispersion framework for the ideal setting and estimating of capacitor spare cash with the aim of curtailing force losses of the circulation framework and also supported reasonableness and difference goals. The new joined methodology of LSF and VSI were utilized to obtain the ideal reach for the establishment of capacitors. BFOA was suggested to locate the ideal value of the capacitors.

Lee *et al.* [30] proposed a new technique for optimal position of the capacitor for minimizing the losses. The proposed method was PSO, which used Gaussian and Cauchy probability distribution for its operator to provide faster convergences in local searches. Chaotic sequence was used to search the size and position of capacitors to be installed. The presented approaches were shown by two examples.

Chiou and Chang [31] proposed a new technique for effective placement of the capacitor situation in distribution configuration by using hybrid CODEQ called HCODEQ technique. The ideas of quantum mechanics, resistance based learning and chaotic search were utilized as a part of the CODEQ technique to eliminate the drawback of parameter choice in the "Differential Evolution" (DE).

Zeinalzadeh *et al.* [32] presented a new technique, namely "Multi Objective Particle Swarm Optimization" (MOPSO) to obtain the optimal position and value of shunt capacitor banks and distributed generations simultaneously. The presented method had considered the load uncertainty. The three main objectives of multi target advancement included improved voltage stability, minimizing active power losses for buses and adjusting the current in framework segments. This strategy utilized Pareto ideal answers for solving the problem while considered objective function and constraints. Fuzzy logic was also used in addition to obtain the best solution while considered all three objective functions.

Abdelaziz *et al.* [33] proposed a new technique called "Flower Pollination Algorithm" (FPA) for capacitor sizing and location. "Power Loss Index" (PLI) was used to obtain the location of capacitor. Capacitor size was determined by using FPA. Objective function was devised to curtail the losses. The presented approach was tested on various distribution systems and results were compared with other techniques.

Das *et al.* [34] presented an efficient technique for RDN. The presented method needed to solve only simple algebraic expression, no trigonometric function was involved. The presented method required very least amount of computer memory. They tested their method on several rural distribution networks of India.

Ghosh and Das [35] proposed a new, efficient and simple technique for solution of RDN. The suggested method used the simple algebraic expression of receiving end voltages. The technique was efficacious and had fast convergence characteristics. The technique was validated with the assistance of three lessons.

Chakravorty and Das [36] proposed a new Voltage stability index (VSI) of RDNs to determine stability indices for all nodes and the node having least value of VSI is the most sensitive to voltage collapse.

1.7 RESEARCH GAP

There is a scope to determine optimum position and optimal value of capacitor with the help of VSI, LSF and BFOA that will further reduce loss and give better voltage profile.

1.8 OBJECTIVES OF THE THESIS WORK

The purpose of the thesis is to obtain the optimum position and optimal size of the capacitor for improvement of voltage profile and minimization of the net power losses of the system. For achieving the objectives, the following actions have been taken.

- The load flow method has been used for computation of the total losses and obtains the voltage at each node. This is done by fuzzy method.
- The VSI and LSF have been used to identify the best position of the capacitor in the RDN.
- The BFOA is used to determine the optimal value (size) of capacitor in the RDN.

1.9 ORGANIZATION OF THE THESIS

Chapter 1 shows introduction and overview of the electric power supply network, research gap, objective and organization of the thesis.

Chapter 2 shows literature review of past work related to optimal position and the optimal size of the capacitor in the RDN.

Chapter 3 shows proposed methodology for optimal position and optimal size of capacitor in the RDN.

Chapter 4 shows results and analysis of the results obtained from a suggested method and comparison of these results with the result obtained from other method.

Chapter 5 shows the conclusion and future scope.

References show the previously published paper surveyed by the author related to the optimum position and value of the capacitor in the RDN.

Appendix- A shows the test data for 33- bus RDN.

Appendix- B shows the test data for 69- bus RDN.

Appendix -C shows the test data for 141- bus RDN.

CHAPTER-2

PROPOSED METHODOLOGY

To maintain the stability of the power system and curtail the losses in RDNs, it is essential to integrate shunt capacitor [29]. The proper position and the ideal size of the capacitor is very important, otherwise, it reduces the benefits of capacitor usage. The main aim of this thesis work is to form a better technique for the ideal sizing and position of the capacitor in RDNs. In this work fuzzy power flow analysis is used to maximize the accuracy of the method and to minimize the computational effort. Then BFOA with multi objective is used for the best position and value (size) of shunt capacitor in distribution networks.

2.1 FUZZY BASED LOAD FLOW

Here load flow using fuzzy modelling improves accuracy. A sample distribution network model is shown in Fig. 2.1

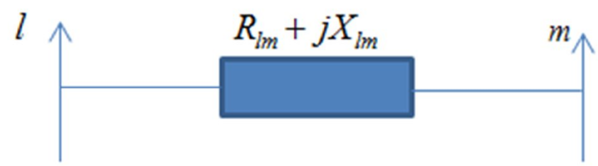

Fig.2.1 Illustrational distribution network

The VSI and LSF are dependent on power losses and voltage at the particular node. The degree of range of symmetry fuzzy is between 0 and 1. The voltage membership function is described in Eq. (2.1).

$$\mu_v(l) = \begin{cases} 0 & V_l \le v_{\min} \\ \exp\left\{ -w_v \left[\dfrac{V_l - 1}{v_{\max} - v_{\min}} \right]^2 \right\} & v_{\min} < V_l < v_{\max} \\ 1 & V_l \ge v_{\max} \end{cases} \tag{2.1}$$

Where w_v is weighting factor for the voltage membership function, $v_{\min}$ is the minimum value of permitted voltage, $v_{\max}$ is the maximum value of permitted voltage.

The formula below depicts the membership function for active power loss as given in Eq. (2.2)

$$\mu_p(l) = \begin{cases} 0 & T_p \le T_{p,\min} \\ \exp\left\{\dfrac{-w_p \times L(p)}{T_p}\right\} & T_{p,\min} < T_p < T_{p,\max} \\ 1 & T_p \ge T_{p,\max} \end{cases} \tag{2.2}$$

Where w_p is the weighting factor for membership function of active power loss; $L(p)$ is the real power loss between l and $l + 1$ buses; T_p is the total real power loss

The membership function of reactive power loss is given in Eq. (2.3).

$$\mu_Q(l) = \begin{cases} 0 & T_q \le T_{q,\min} \\ \exp\left\{\dfrac{-w_Q \times L(q)}{T_q}\right\} & T_{q,\min} < T_q < T_{q,\max} \\ 1 & T_q \ge T_{q,\max} \end{cases} \tag{2.3}$$

Where w_Q is the weighting factor for reactive power loss membership function; $L(q)$ is the reactive power loss between l and $l + 1$ bus; T_q is the total reactive power loss.

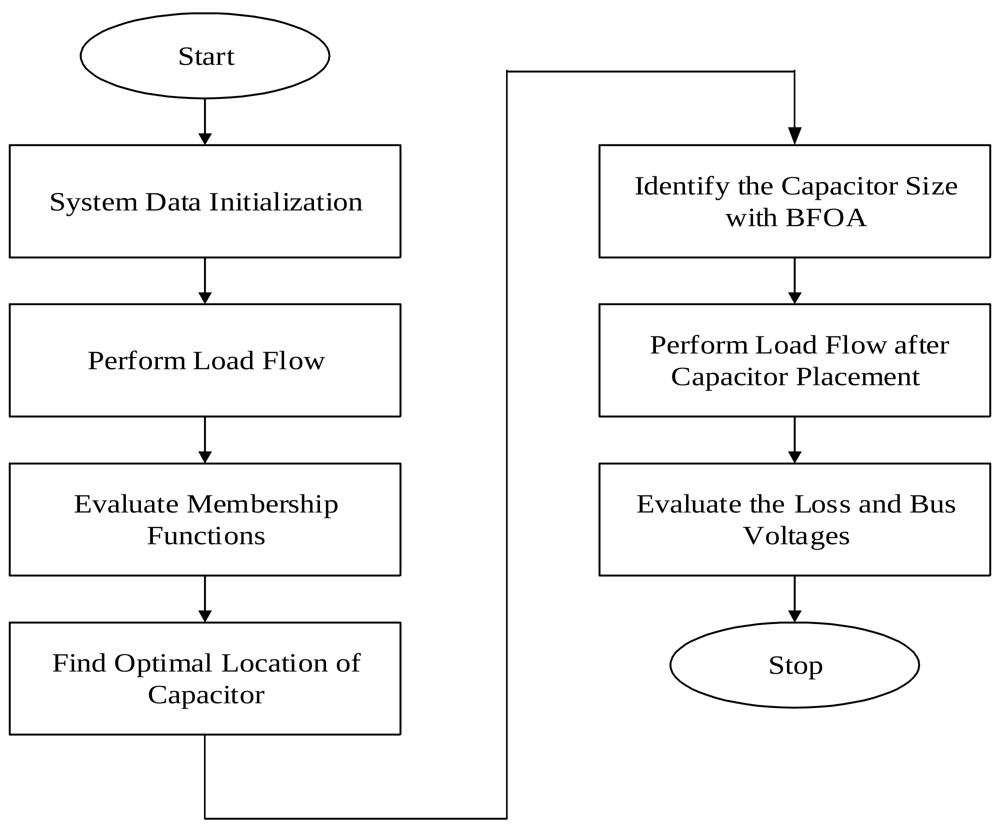

Fig. 2.2 Flow chart for proposed method

Figure 2.2 explains the flow chart for the proposed method. The above formulas are the membership functions of the power loss and voltage values. The membership functions are calculated from the initial load flow and using this membership functions the fuzzy condition is formed. The fuzzy condition is given in the Section 2.2. By using this condition the LSF and VSI values are evaluated for each node. Based on the values the optimal location for capacitor placement is identified.

2.2 OPTIMAL PLACEMENT AND SIZING OF THE CAPACITOR

Fuzzy method is used for load flow. The voltage and loss of the system are measured from the membership functions. By using the measured value, the below condition is checked and then VSI and LSF values are measured in order to place the capacitor. The capacitor is placed on the nodes, which have the lowest value of VSI and maximum value of LSF.

At all nodes,

The fuzzy condition

$$
\begin{aligned}
& if\ \mu_P(l)\ \&\ \mu_Q(l)\ is\ greater \\
& \{ \\
& \quad if\ \mu_v(l)\ is\ smaller \\
& \quad\quad \{ \\
& \quad\quad\quad then\ find\ LSF\ \&\ VSI \\
& \quad\quad \} \\
& \}
\end{aligned}
$$

a) LSF: The loss sensitivity factor is used to recognize the proper location for the capacitor. The node of the radial distribution system, which has more chance to lay capacitor, has the maximum value of LSF [9]. Equation (2.4) shows the representation of LSF [9].

$$LSF = \frac{2Q_m R_{l,m}}{|V_m|^2} \tag{2.4}$$

We arrange the LSF values of all nodes in descending order.

b) VSI: To check power system security level, many parameters are used; one of that parameter is VSI. The node, which is producing more voltage collapse, is identified by using VSI. The VSI at every node is computed using Eq. (2.5) [36].

$$VSI = |V_l|^4 - 4[P_m \cdot X_{lm} - Q_m . R_{lm}]^2 - 4[P_m . R_{lm} + Q_m \cdot X_{lm}]|V_l|^2 \quad (2.5)$$

Where; 'P_m' is the effective active power at the node 'm'; 'Q_m' is the effective reactive power at the node m; 'R_{lm}' is the resistance between the node '*l*' and 'm'; 'X_{lm}' is the reactance between the node '*l*' and 'm'; 'V_l' is the voltage at node '*l*'; 'V_m' is the voltage at node 'm'.

2.3 BACTERIAL FORAGING OPTIMIZATION ALGORITHM (BFOA)

BFOA has been used as an optimization technique in distribution systems. It is efficacious and swarm intelligence method created by Kevin Passino. The thought to drive Bacterial Foraging Optimization Algorithm relies on the way that normal determination leads to terminating binges with poor foraging approach and it is favoured those, which have a productive foraging approach. The weak foraging approach is transformed into extraordinary ones or eliminated, after numerous eras. The normal developmental procedure strategy relies on the their wellness criteria and are requested into,

a. Ability to search food
b. Self-Charging (Mobile behaviour)

The foraging mechanism of E. coli bacteria are governed by four processes; which are as follows:-

1) Chemotaxis process,

2) Swarming process

3) Reproduction process, and

4) Elimination and dispersal process.

Parameters used in the BFOA algorithm are P, S, N_s, N_c, N_{re}, N_{ed}, P_{ed}, n,C(i), θ^i.

Chemotaxis Process: Chemotaxis can be achieved by swimming and tumbling movements of each bacterium. Swimming the name denotes the movement of bacterium is done in a predefined way. Tumbling means the movement in a random way.

$$Tumble = Step\ length\ of\ that\ bacteria \\ * Unit\ length\ of\ random\ direction$$

Swarming Process: The march of bacteria in the direction of the enriched nutrition source in a concentric way with high bacterial quantity is referred as the process of swarming.

$$F_{cc}(\theta, P(j,k,l)) = \sum_{i=1}^{S} F_{cc}(\theta, \theta^{i}(j,k,l)) \tag{2.6}$$

$$F_{cc} = \sum_{i=1}^{S}\left[-d_{attract\tan t}\exp\left(-w_{attract\tan t}\sum_{m=1}^{p}(\theta_m - \theta_m^i)^2\right)\right] + \sum_{i=1}^{S}\left[h_{repellant}\exp\left(-w_{repellant}\sum_{m=1}^{p}(\theta_m - \theta_m{}^{i})^2\right)\right] \tag{2.7}$$

Reproduction Process: When the unhealthy bacteria will die the healthiest one split into two bacteria this makes the bacteria population as a constant value. The new bacteria placed in the position where the least healthy bacteria were present.

Elimination and dispersal Process: Bacterium population may change into new value because of unexpected changes. For example, a significant rise in environment factor like temperature kills bacteria present in a particular place. All the bacteria in a particular place are killed or replaced into a new location. Pseudo code for BFOA algorithm is shown below.

BFOA

1) Initialize parameters
2) Optimal placement of capacitor

   if $\mu_P(l)$ & $\mu_Q(l)$ is greater and **if** $\mu_v(l)$ is smaller **then,** calculate VSI, LSF.

   Evaluate fitness function 1 for each node
3) Update Elimination and dispersal, reproduction, chemotaxis steps
4) Perform chemotaxis to find best fitness

   Calculate Fitness function for every bacterium

   Substitute the value in F_{last}

   Generate random vector

   Evaluate movement of bacterium

   Update fitness function

   If $i \neq S$ **then** go to the next bacterium
5) Perform reproduction up to $k \geq N_{re}$.

6) Perform Elimination – dispersal and Evaluate fitness 2.

   Perform elimination and dispersal up to $l \geq N_{ed}$

7) Calculate fitness for capacitor size
8) End

Step 1: Parameter Initialization

The speed of convergence of the algorithm contrasts for various mixes of the parameters accordingly to accomplish the fastest convergence of the algorithm ought to keep running for various times for various estimations of above defined parameters. The variables used in this algorithm are; 'P' is the number of optimization variables (3); 'N_s' is the number of iteration (31); 'S' is the number of bacteria used for searching the total area (50); 'N_c' is the number of chemotactic steps (4); 'N_{ed}' is the maximum number of elimination dispersal events (2); 'N_{re}' is the maximum number of reproduction steps (4); 'P_{ed}' is the probability of elimination dispersal process (0.25); 'n' is the number of nodes; '$C(i)$' is the step change of size in the random direction ($0.05 \times ones(S,1)$); and 'θ^i' is the location, minimum and maximum limits of the capacitor bank ($\theta^i = (\theta^i{}_1, \theta^i{}_2, \theta^i{}_3)$ where $i = 1,2,\ldots,S.$); height of repellent: $h_{repellent}$ (0.1); width of attractant: $w_{attractant}$ (0.2); width of repellent: $w_{repellent}$ (1.0); depth of attractant released by cell: $d_{attractant}$ (0.1).

Step 2: Optimal placement

For the optimal placement of capacitor the proposed method to check conditions with the membership functions $\mu_P(l)$ & $\mu_Q(l)$ & $\mu_v(l)$, the values of VSI and LSF are determined to decide the best place for capacitor placement. The process is repeated up to all nodes. The optimum location is computed by using below formula,

$$Optimum\ Location: Fitness1(F1) = \min\left\{\frac{VSI}{LSF}\right\} \tag{2.8}$$

Step 3: Update the BFOA, Elimination –Dispersal, reproduction and chemotaxis processes. After every N_{re} times the elimination dispersal is done likewise every N_{cd} times a reproduction is taken into account.

Step 4: Chemotaxis process

The chemotaxis is run for all bacteria. The fitness function is,

$$F(i, j, k, l) = F(i, j, k, l) + F_{cc}\left(\theta^{i}(j, k, l), P(j, k, l)\right) \tag{2.9}$$

In chemotaxis by using the objective function the fitness function is computed. The objective function is based on repellent and attractant signal. Fitness function value is equated in the F_{last} value. For the next fitness it is necessary to compute the movement. For that a random vector is generated. The movement is computed by,

$$\theta^{i}(j+1, k, l) = \theta^{i}(j, k, l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^{T}(i)\Delta(i)}} \tag{2.10}$$

For every bacterium the fitness function is computed and updated in F_{last}. When the number of iterations is exceeded the number of bacteria, the chemotaxis process is ended.

Step 5: Reproduction process

The low F value bacterium will be selected. Wipe out and disperse every bacterium with likelihood, which keeps the quantity of microbes in the population consistent value. For conclusive bacteria population ascertain the value of F. The ideal size of the capacitor bank is given by the bacterium, which gives the best F value.

$$F^{i}{}_{health} = \sum_{i=1}^{N_c+1} F(i, j, k, l) \tag{2.11}$$

If the value of the highest number of reproductions is less than *k* value, perform incremental of reproduction.

Step 6: Elimination and dispersal process

Choose the best bacterium, which has least F value. Wipe out and disperse every bacterium with likelihood, which keeps the quantity of microbes in the population consistent value. For conclusive bacteria population ascertain the value of F. The bacterium, which determines the best F value, determines the ideal value (size) of the capacitor bank.

$$Fitness\ 2(F2) = \min\left\{F^{i}{}_{health}\right\} \tag{2.12}$$

By combining the two fitness values, we can get the optimal place for the capacitor with suitable size.

$$Fitness = \min\left[\left(\frac{VSI}{LSF}\right) + F2\right] \tag{2.13}$$

CHAPTER-3

RESULTS

The load model used for the analysis of the RDN in this presented work is of constant power type. MATLAB is used as a working platform for the distribution system analysis and load modelling using 33, 69, and 141 node RDNs. In our proposed method the cost value is taken as the load value. MATLAB software has been made to guide the load flow, for computing the losses and to obtain capacitor bank's best position and value. The correctness of the proposed methodology are checked with existing papers. The voltage and power values of base case are computed from the load flow analysis. The load modelling is done by using (14).

$$P_{l,new} + jQ_{l,new} = \alpha\left(P_l + jQ_l\right) \tag{3.1}$$

Where; 'α' is the cost of the capacitor.

3.1 33 - NODE RADIAL DISTRIBUTION NETWORK

In this method, 33 node RDN [35] shown in Fig. 3.1 is analysed having total load of 3.7 MW and 2.3 MVAr respectively. The base values are 12.66 kV and 100 MVA. The results (optimal location and size, minimum voltage and node number, minimum value of VSI and node number, and real power loss) for three different types of load, i.e., light (50%), normal (100%) and peak (160%) before and after compensation utilizing the proposed method has been presented in Table 3.1.

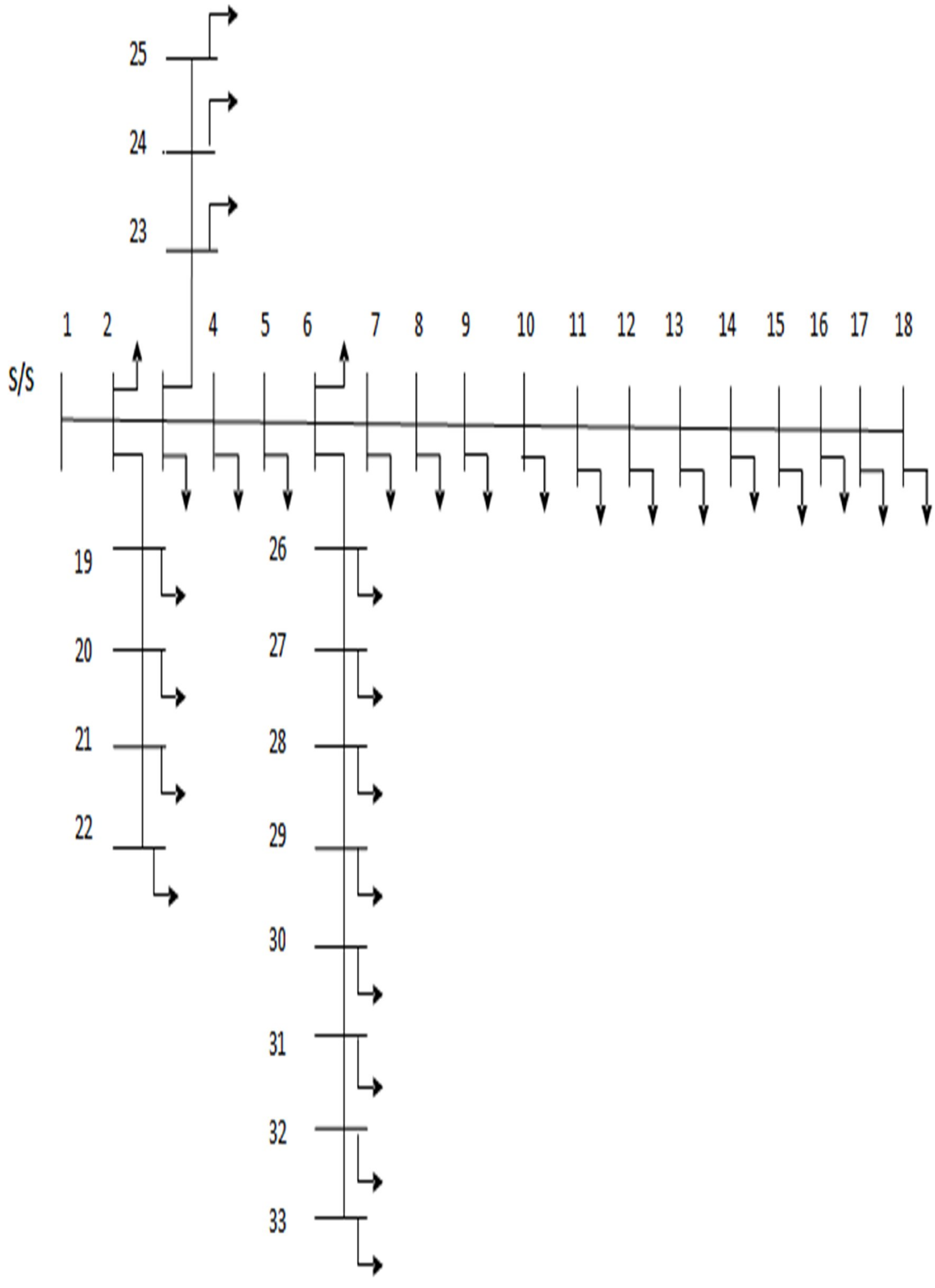

Fig. 3.1 33 node RDN

Table 3.1 Comparison of results of the proposed method with Teaching Learning Based Optimization (At loads 50%, 100%, 160%) for 33 node

Parameters	**Base Case**	**Proposed Method**
	Light Load (50%)	
Optimal location & size	-	18 & 695 30 & 176 25 & 350
V_{min} (p.u.) & node number	0.9545 & 18	0.9725 & 32
VSI_{min}(p.u.) &node number	0.6959 & 18	0.7264 & 32
Power loss (kW)	57.33	42.21
	Nominal Load (100%)	
Optimal location & size	-	18 & 695 30 & 800 25 & 500
Vmin (p.u.) & node number	0.9133 & 18	0.9698 & 32
VSI_{min}(p.u.) & node number	0.7849 & 18	0.8759 & 32
Power loss (kW)	202.25	132.56
	Peak Load (160%)	
Optimal location & size number	-	18 & 695 30 & 800 25 & 1066
Vmin (p.u.) & node number	0.8543 & 18	0.8865 & 32
VSI_{min}(p.u.) & node number	0.8876&18	0.9712 & 32
Power loss (kW)	523.85	412.25

Figure 3.2 presents the plot of magnitude of voltage vs number of nodes before and after compensation for three different types of load, i.e., light (50%), normal (100%) and peak (160%).

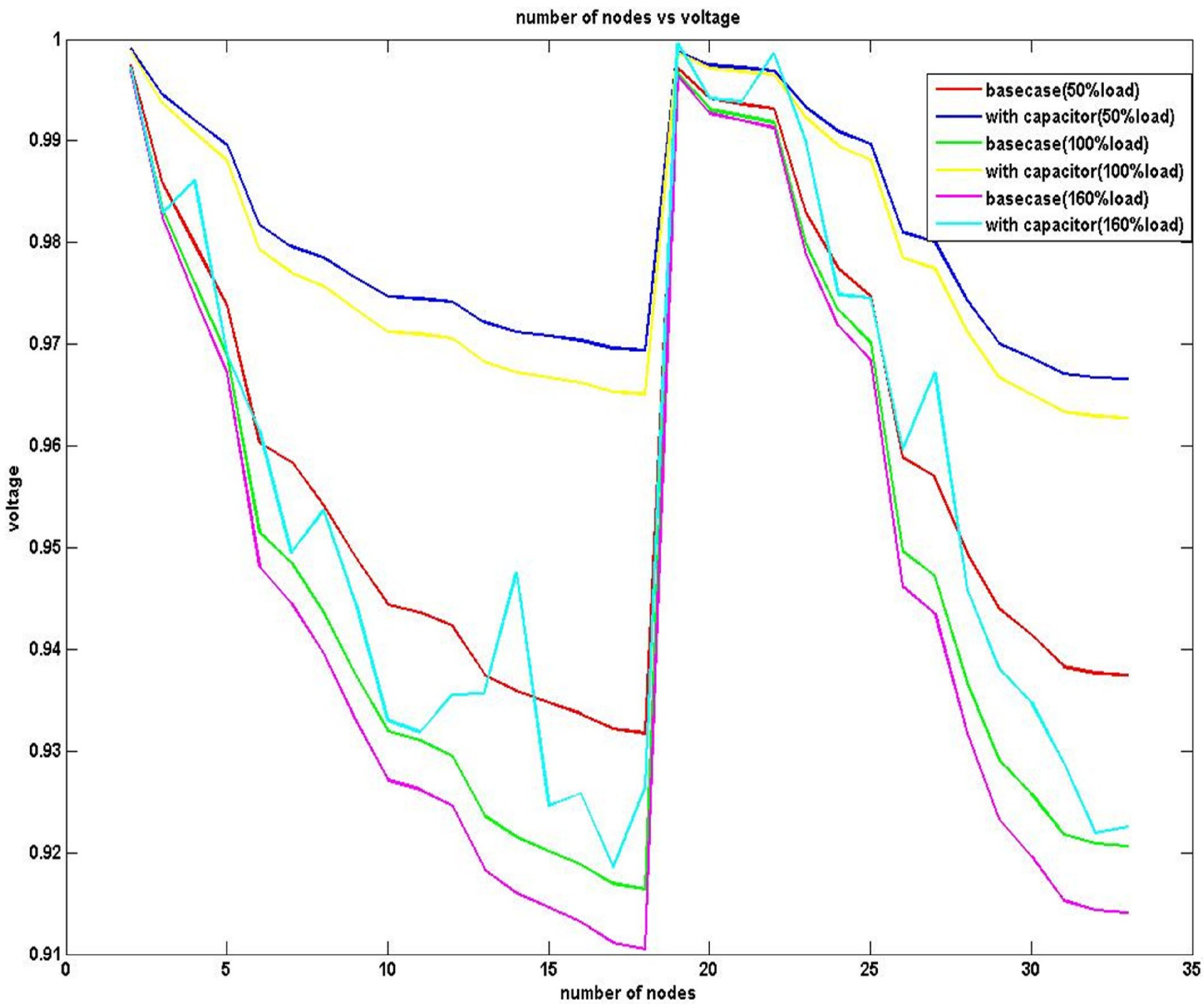

Fig. 3.2 Comparision of voltage magnitude vs number of nodes with and without capacitor (for 33node)

Figure 3.3 shows the plot of VSI vs number of nodes for three different types of load, i.e., light (50%), normal (100%) and peak (160%) before and after compensation.

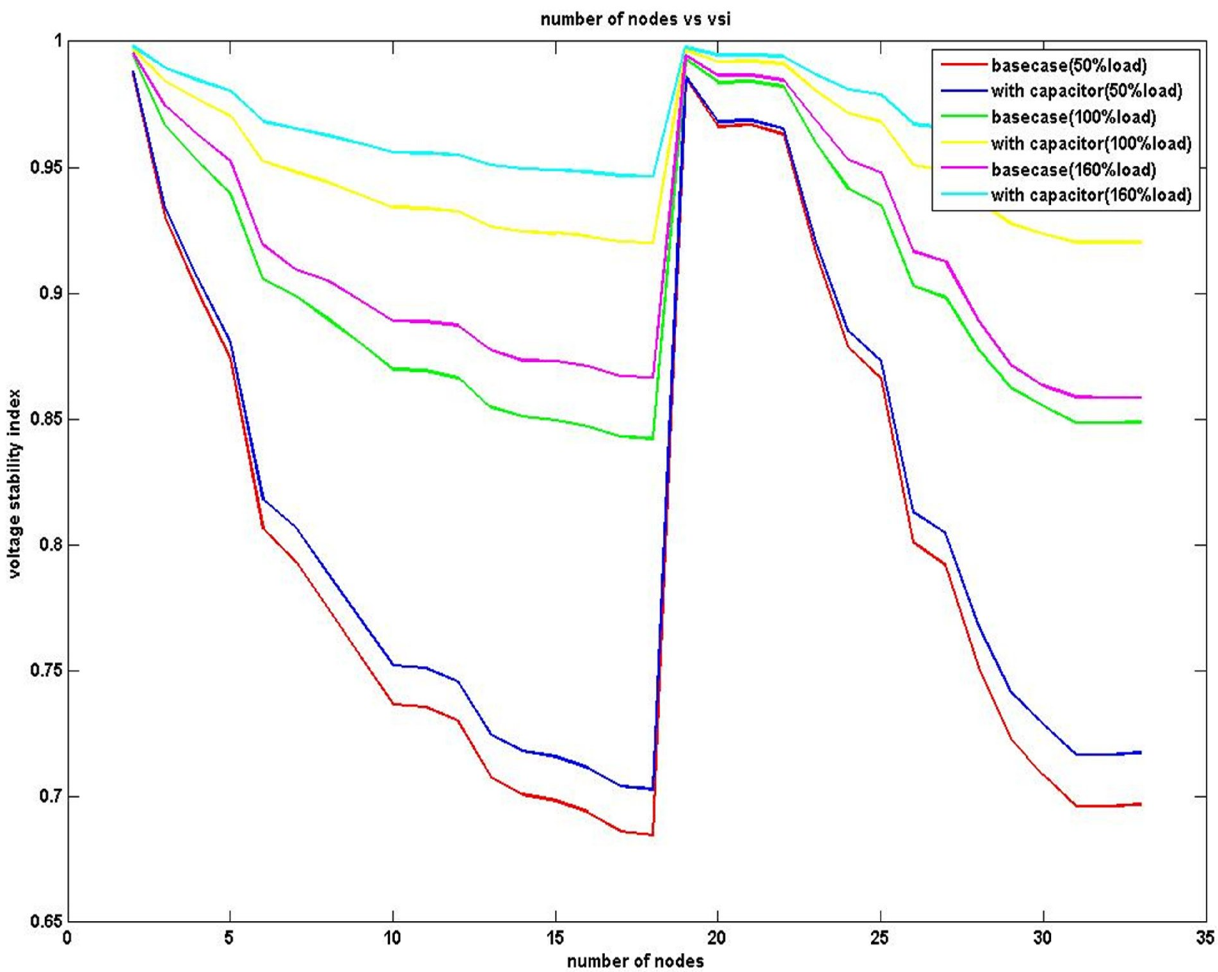

Fig. 3.3 VSI vs node number before and after compensation (for 33node)

The results determined by the proposed method after compensation has also been compared with GSA, SA and IP [26] as shown in Table 3.2 for normal load (100%).

Table 3.2 Comparison of outcomes obtained by the proposed method with GSA, SA and IP [26] for normal load

Load Type	**Cases**	**Power Loss (kW)**	**Min. Voltage (p.u)**	**Capacitor Location**	**Capacitor Size (kVAr)**
Normal load (100%)	**Proposed Method**	132.56	0.9698 (32)	18, 25, 30	695, 500, 800
	GSA [24]	134.5	0.9672	26,13,15	350,450, 800
	SA[24]	151.75	0.9591	10,30,14	450,350, 900
	IP[24]	171.78	0.9501	9,29,30	450,800, 900

3.2 69- NODE RADIAL DISTRIBUTION NETWORK

In this method, 69 node RDN shown in Fig. 3.4 is analysed having total load of 3.8 MW and 2.69 MVAr respectively. The base values are 12.66 kV and 100 MVA. The system data of this system are available in [35, 36]. The respective losses are 51.59 kW, 224.96 kW and 652.34 kW nodes for three different types of load, i.e., light (50%), normal (100%) and peak (160%) before compensation and the minimum voltages are 0.9566 (65), 0.9099 (65) and 0.8444 (65) respectively for these three loads.

The results (optimal location and size, minimum voltage and node number, and real power loss nodes for three different types of load, i.e., light (50%), normal (100%) and peak (160%) after compensation determined by the proposed method has been shown in Table 3.3 along with the results obtained by TLBO [25] and DSA[21].

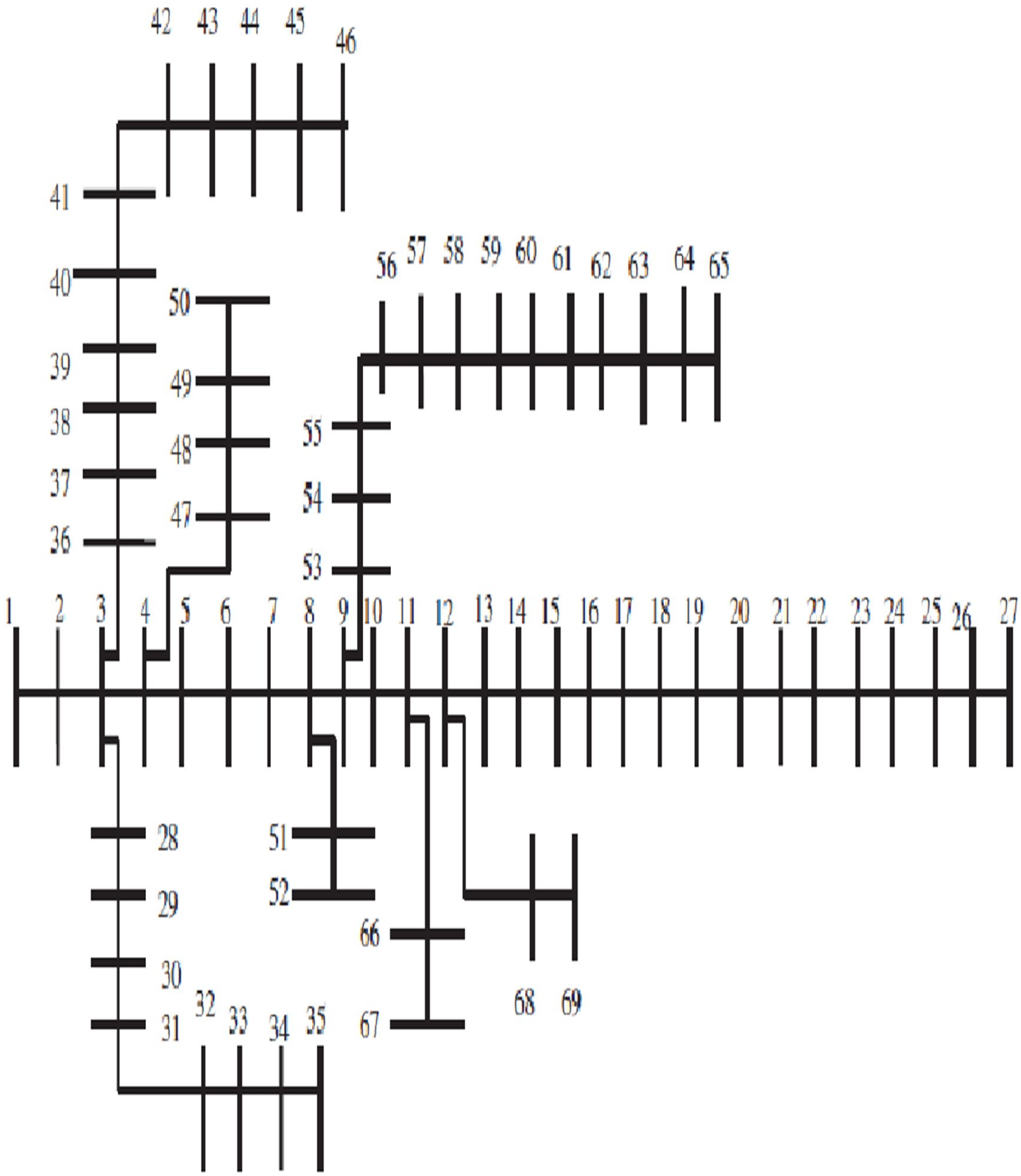

Fig. 3.4 69 node RDN

Table 3.3 Comparison of results of proposed method with TLBO [25] and DSA [21] (at loads 50%, 100%, 160%) for 69 node

Parameters	TLBO [25]	Proposed Method	DSA [21]
Light Load (50%)			
Optimal location & size (kVAr)	22 & 150 61 & 450 62 & 450	65&283 60&283 10&489	15 & 300 60 & 300 61 & 450
Vmin (p.u.) & node number	0.9662 & 65	0.9684&65	0.9683 & 65
VSI_{min}(p.u.) & node number	-	0.7189&65	-
Power loss (kW)	34.43	33.74	35.52
Nominal Load (100%)			
Optimal location & size (kVAr)	22 & 300 61 & 1050 62 & 300	65 & 416 60 & 416 10 & 828	15 & 450 60 & 450 61 & 900
Vmin (p.u.) & node number	0.9321 & 65	0.9401 & 65	0.9318 & 65
VSI_{min}(p.u.) & node number	-	0.7943 & 65	-
Power loss (kW)	146.80	144.99	147.00
Peak Load (160%)			
Optimal location & size (kVAr)	22 & 300 61 & 1050 62 & 750	65 & 1210 60 & 561 10 & 480	15 & 900 60 & 900 61 & 1800
Vmin (p.u.) & node number	0.8795 & 65	0.8812 & 65	0.8936 & 65
VSI_{min}(p.u.) & node number	-	0.9745 & 65	-
Power loss (kW)	417.28	416.01	427.3

Figure 3.5 presents the plot of voltage magnitude vs number of nodes before and after compensation for three different types of load, i.e., light (50%), normal (100%) and peak (160%).

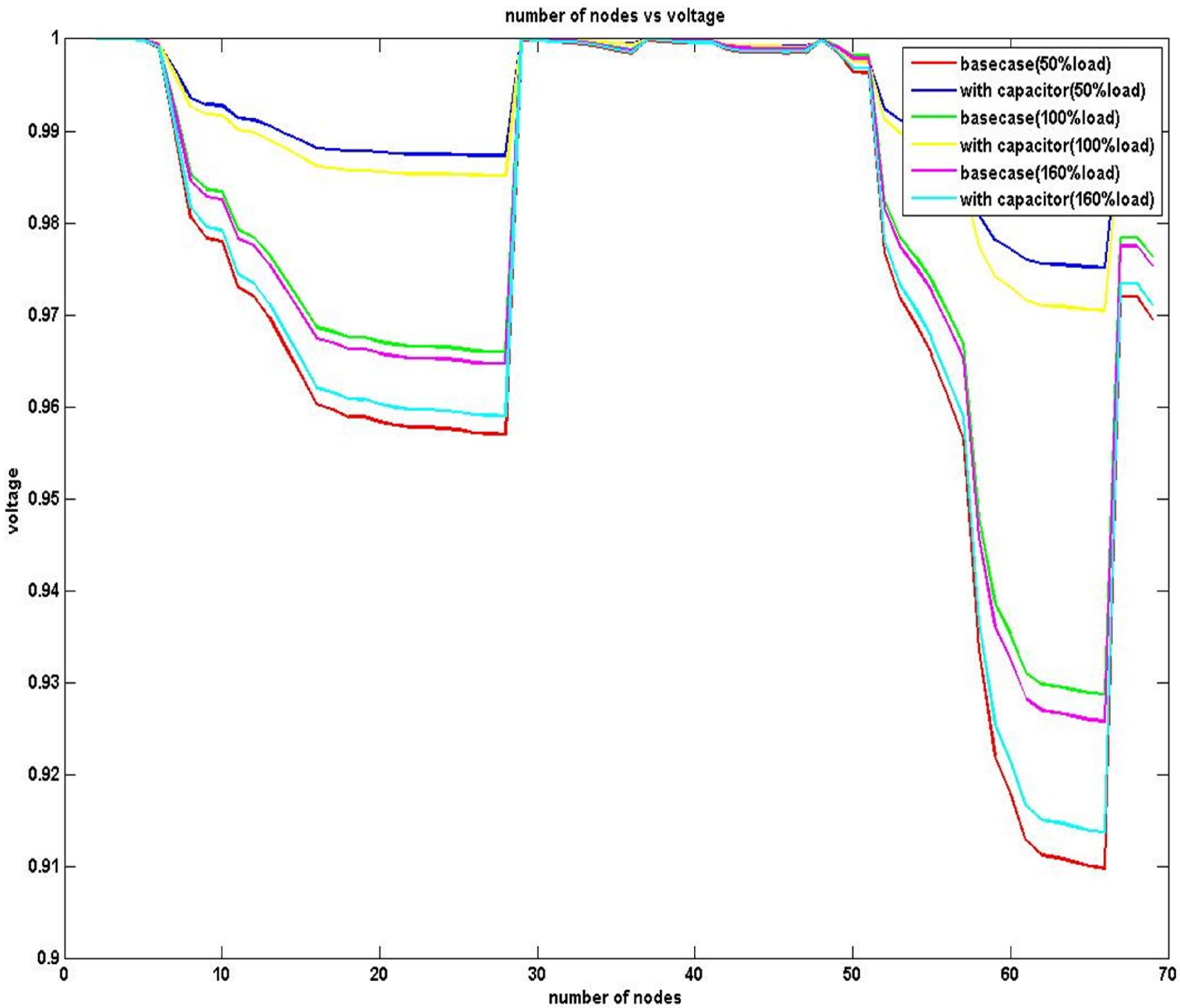

Fig.3.5 Comparision of voltage magnitude vs number of nodes with and without capacitor (for 69 node)

Figure 3.6 presents the plot of VSI vs number of nodes before and after compensation for three different types of load, i.e., light (50%), normal (100%) and peak (160%).

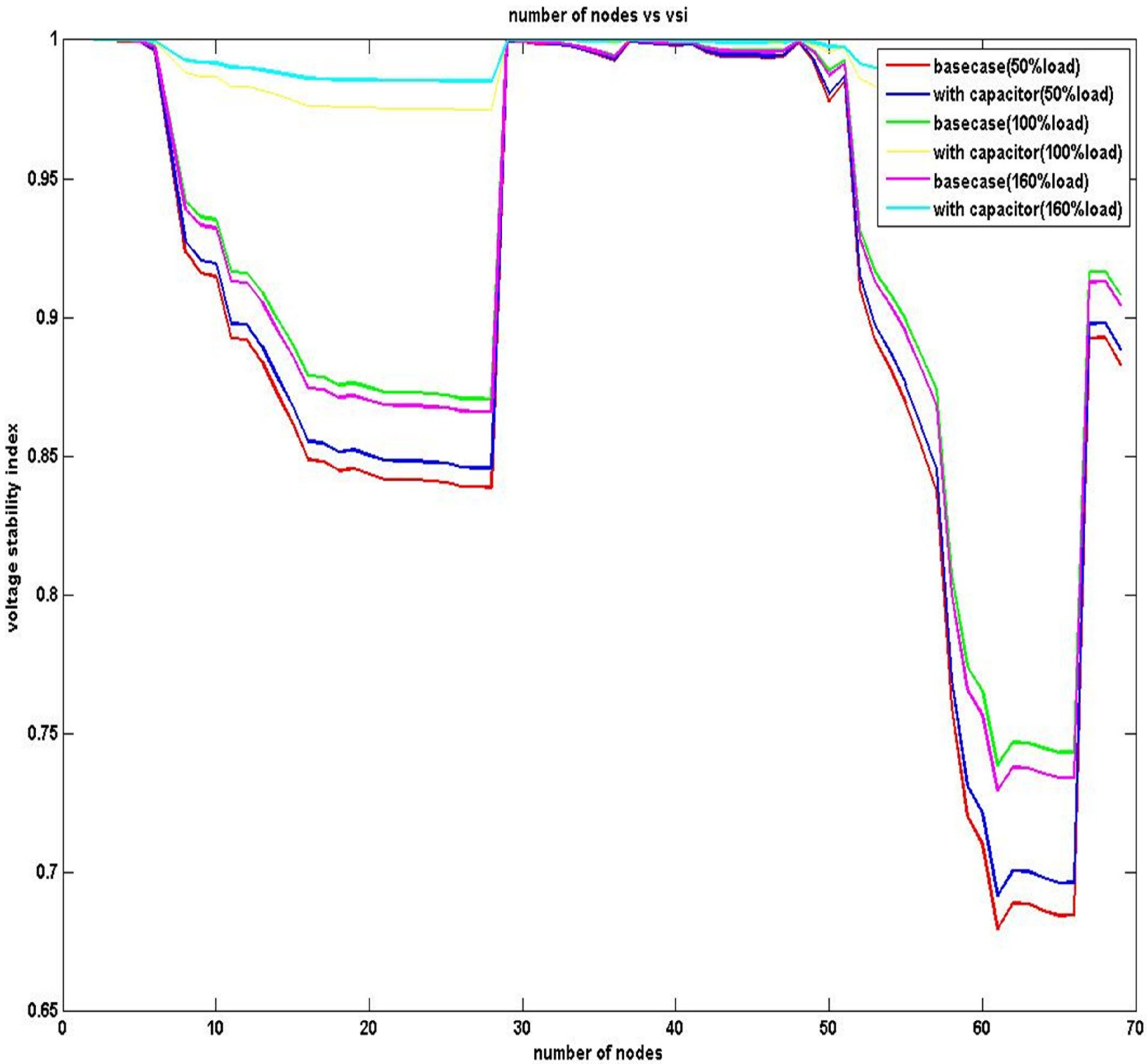

Fig.3.6 VSI vs node number before and after compensation (for 69 node)

3.3 141 Node RDN

The third example is 141 node RDN shown in Fig. 3.7 is considered having total loads of 1171.5125 kW and 725.7846 kVAr, respectively. The base values are 12.47 kV and 100 MVA. The system data of this system is available in [26].

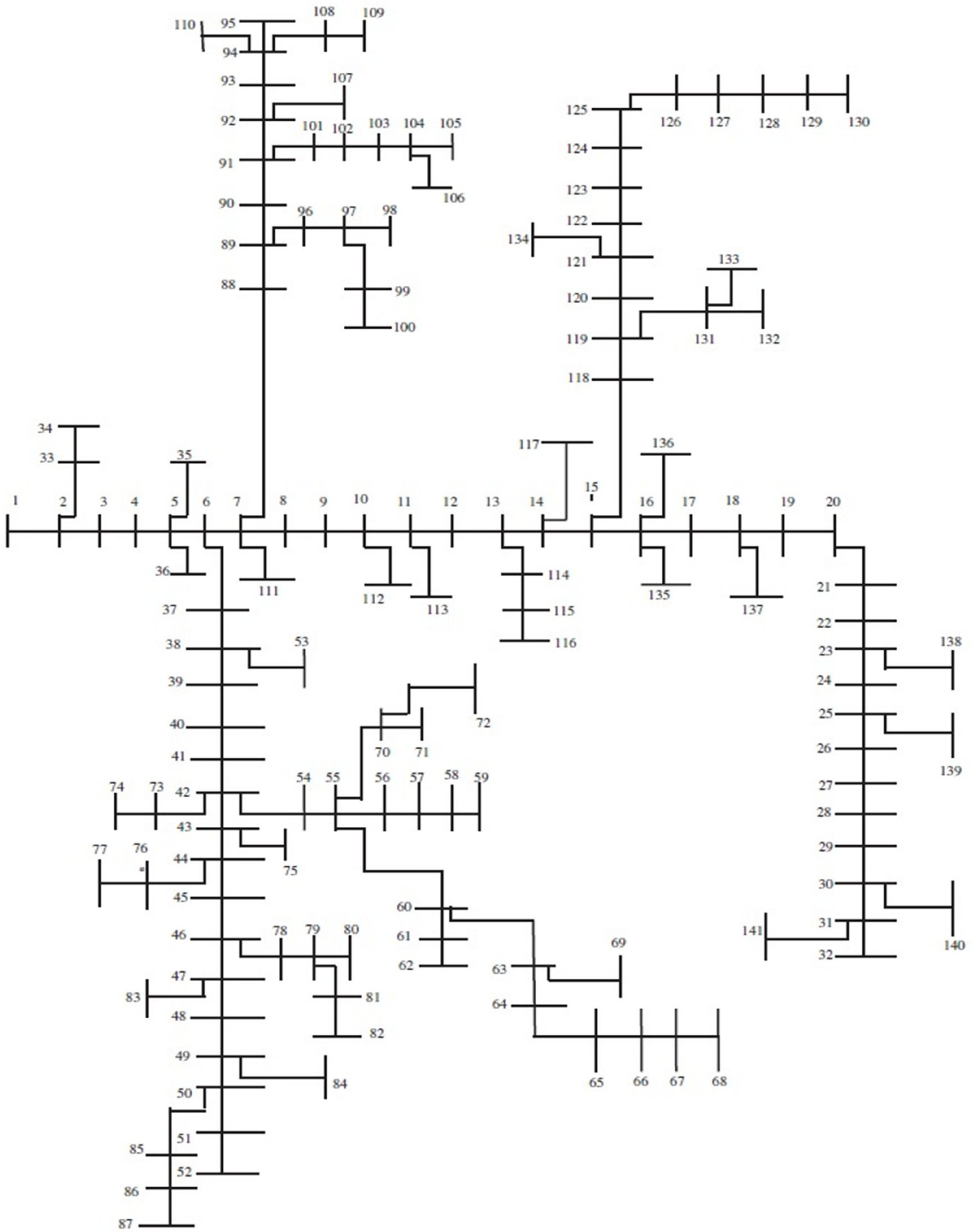

Fig. 3.7 141 node RDN

The result determined by the proposed method has been compared with the methods TLBO [25] for three types of load (light, normal and peak) and GSA [26] for normal load as shown in Table 3.4 after compensation. The proposed method gives the better result compared to [25, 26].

Table 3.4 Comparison of results of proposed method with Teaching Learning Based Optimization (At loads 50%, 100%, 160%) for 141 node

Parameters	TLBO [25]	Proposed Method	GSA (100% load only) [26]
Light Load (50%)			
Optimal location & size (kVAr)	49 &150 50 & 0 75 & 0 78 & 0 81 & 150 87 &150	52 & 321 32 & 434 80 &450 42 & 150 43 & 570 116 & 150	
Vmin (p.u.) & node number	0.9680 &52	0.9698 & 52	
VSI_{min} & node number	-	0.8596 & 52	
Power loss (kW)	13.2511	12.32	
Nominal Load (100%)			
Optimal location & size (kVAr)	15 & 900 21 & 600 55 & 900 63 & 900 78 & 900 85 & 750	52 & 870 32 & 878 80 & 450 42 & 878 43 & 750 116 & 900	23 & 150 50 & 350 55 & 350 64 & 150 80 & 150 99 & 150
Vmin (p.u.) & node number	0.9484 & 52	0.9500 & 52	
VSI_{min} & node number	-	0.9276 & 52	
Power loss (kW)	44.7311	43.02	45.74
Peak Load (160%)			
Optimal location & size (kVAr)	31 & 900 45 & 900 62 & 900 63 & 900 79 & 900 87 & 900	52 & 870 32 &750 80 & 450 42 & 350 43 & 570 116 & 350	
Vmin (p.u.) & node number	0.9073 & 52	0.9224 &52	
VSI_{min} & node number	-	0.9452 & 52	
Power loss (kW)	129.1649	127.57	

CHAPTER-4

CONCLUSION AND FUTURE SCOPE

4.1 CONCLUSION

The main objective of this thesis is the curtailment of net losses and betterment of voltage profile and voltage stability of any RDN. In the RDN reduction of power loss and enhancement of the voltage profile as well as voltage stability can be performed by optimal capacitor placement that has been presented in this thesis. The combined approach of fuzzy and BFOA is utilized for the capacitor, installation with proper size, for the betterment of voltage stability and for reducing net losses. The previous published LSF and VSI have been used in this thesis work. BFOA has also been used to get the appropriate location with the help of LSF and VSI and appropriate size of the capacitor ha also been determined. The recommended approaches are validated on 33-node, 69-node, and 141-node RDN. The outcomes of the suggested method is compared with the result of other methods. The suggested method provides better results for the minimization of loss and enhancement of voltage. Hence, by using the suggested method the losses in the radial distribution system are reduced with enhancement of voltage profile and stability is increased.

4.2 FUTURE SCOPE

Further modifications can be possible in following ways:-

1. It is still possible to determine the position and value of capacitor by using different techniques.
2. The problem of optimal position and sizing of capacitor can also be extended for 3-phase balanced and 3-phase unbalanced distribution systems.
3. For total system loss minimization and improvement of voltage profile distributed generation units and Facts devices such as DSTATCOM can also be used.

LIST OF PUBLICATIONS

(i) Chandan Kishore and Smarajit Ghosh, "Literature Survey on Optimal Capacitor Placement and Size in Radial Distribution Networks", Communicated on International Journal of Scientific Research and Education.

(ii) Chandan Kishore and Smarajit Ghosh, SYMMETRIC FUZZY AND BFOA FOR OPTIMAL POSITION AND RATING OF CAPACITORS IN RDNs, Submitted in Neural Computing and Applications, NCAA-D-16-00862R1.

REFERENCES

[1] Baghzouz Y, Ertem S: Shunt capacitor sizing for radial distribution feeders with distorted substation voltages. IEE Trans Power Delivery, doi: 10.1109/61.53067, 5:650-656, 1990

[2] Baghzouz Y: Effects of nonlinear loads on optimal capacitor placement in radial feeders. IEEE Trans Power Delivery, doi: 10.1109/61.103744, 6:245-251, 1991

[3] Chung TS, Leung HC: A genetic algorithm approach in optimal capacitor selection with harmonic distortion considerations. Electrical Power and Energy Systems, doi: 10.1016/S0142-0615(99)00025-3, 21:561-569.1999

[4] Huang SJ: An immune-based optimization method to capacitor placement in a radial distribution system, IEEE Trans. Power Delivery, doi:10.1109/61.853014,15:744-749, 2000

[5] Yu XM, Xiong XY, Wu YW: A PSO-based approach to optimal capacitor placement with harmonic distortion consideration. Electric Power System Research, doi:10.1016/j.epsr.2004.01.002, 71:27-33, 2004.

[6] Hsiao YT, Chen Ch, Chien CC: Optimal capacitor placement in distribution systems using a combination fuzzy-GA method. Electrical Power and Energy Systems, doi:10.1016/j.ijepes.2004.01.002, 26:501-508, 2004.

[7] Ghose T, Goswami SK: Effects of unbalances and harmonics on optimal capacitor placement in distribution system. Electric Power System Research, doi: 10.1016/S0378-7796(03)00149-4, 68:167-173, 2004.

[8] Subrahmanyam JBV: Optimal capacitor placement in unbalanced radial distribution networks. Journal of Theoretical and Applied Information Technology, 6:106-115, 2005.

[9] Prakash K, Sydulu M: Particle swarm optimization based capacitor placement on radial distribution systems. IEEE Power Engineering Society General Meeting, doi:10.1109/PES.2007.386149,1-5.2007

[10] Jabr RA: Optimal placement of capacitors in a radial network using conic and mixed integer linear programming. Electric Power System Research, doi:10.1016/j.epsr.2007.07.002, 78:941-948, 2008

[11] Gautam D, Mithulananthan N: Optimal DG placement in deregulated electricity market. Electric Power System Research, doi:10.1016/j.epsr.2006.11.014,77:1627-1636, 2007

[12] Khodr HM, Olsina FG, Oliveira-De Jesus PMD, Yusta JM: Maximum savings approach for location and sizing of capacitors in distribution systems. Electric Power System Research, doi:10.1016/j.epsr.2007.10.002, 78:1192-1203, 2008

[13] Das D: Optimal placement of capacitors in radial distribution system using a Fuzzy-GA method. Electrical Power and Energy Systems, doi:10.1016/j.ijepes.2007.08.004, 30:361-367, 2008

[14] Huang TL, Hsiao YT, Chang CH, Jiang JA: Optimal placement of capacitors in distribution systems using an immune multi-objective algorithm. Electrical Power and Energy Systems, doi:10.1016/j.ijepes.2007.06.012, 30:184-192, 2008

[15] Kannan SM, Monica ARG, Slochanal SMR: Fuzzy Logic Based Optimal Capacitor Placement on Radial Distribution Feeders. Power System Technology and IEEE Power India Conference, doi: 10.1109/ICPST.2008.4745163,1-6, 2008

[16] Das S, Biswas A, Dasgupta S, Abraham A (2009) Bacterial Foraging Optimization Algorithm: Theoretical Foundations, Analysis, and Applications. Foundations Compu Intelli, doi: 10.1007/978-3-642-01085-9_2, 3:23-55, 2009

[17] Abdelaziz AY, Mekhamer SF, Nada MH: A fuzzy expert system for loss reduction and voltage control in radial distribution systems. Electric Power Systems Research, doi:10.1016/j.epsr.2009.12.020, 80:893-897, 2010

[18] Taher SA, Hasani M, Karimian A: A novel method for optimal capacitor placement and sizing in distribution systems with nonlinear loads and DG using GA. Commun Nonlinear Sci Numer Simulat, doi:10.1016/j.cnsns.2010.05.011,16:851-862, 2011

[19] Tabatabaei SM, Vahidi B Bacterial foraging solution based fuzzy logic decision for optimal capacitor allocation in radial distribution system. Electric Power System Research, doi:10.1016/j.epsr.2010.12.002, 81:1045-1050, 2011

[20] Xu F, Fan M, Yuan L: A simple and efficient Artificial Bee Colony Algorithm. Mathematical Problem in Engineering, doi: 10.1155/2013/526315,2013:1-9, 2012

[21] Raju MR, Murthy KVSR, Ravindra K: Direct search algorithm for capacitive compensation in radial distribution systems. Electrical Power and Energy Systems, doi: 10.1016/j.ijepes.2012.03.006, 42: 24-30, 2012

[22] EL-Fergany AAE, Abdelbaiz AY: Capacitor allocations in radial distribution networks using Cuckoo Search Algorithm. IET Generation, Transmission and Distribution, doi: 10.1049/iet-gtd.2013.0290, 8:223-232, 2013

[23] Elsheikh A, Helmy Y, Abouelseoud Y, Elsherif A Optimal capacitor placement and sizing in radial electric power systems. Alexandria Engineering Journal, doi: 10.1016/j.aej.2014.09.012., 53:809-816, 2014

[24] Devi S, Geethanjali M: Optimal location and sizing determination of Distributed Generation and DSTATCOM using Particle Swarm Optimization algorithm. Electrical Power and Energy Systems, doi: 0.1016/j.epsr.2013.09.019, 62:562-570, 2014.

[25] Sultana S, Roy PK (2014): Optimal capacitor placement in radial distribution systems using teaching learning based optimization. Electrical Power and Energy Systems, doi:10.1016/j.ijepes.2013.07.011, 54:387-398, 2014

[26] Shuaib YM, Kalavathi MS, Rajan CCA (2015) Optimal capacitor placement in radial distribution system using Gravitational search Algorithm. Electrical Power and Energy Systems, doi:10.1016/j.ijepes.2014.07.041, 64:384-397, 2014

[27] Abul'Wafa AR: Optimal capacitor placement for enhancing voltage stability in distribution systems using analytical algorithm and Fuzzy-Real Coded GA. Electrical Power and Energy Systems, doi: 10.1016/j.ijepes.2013.09.01455:246-252,2014

[28] Nojavan S, Jalali M, Zare K: Optimal allocation of capacitors in radial/mesh distribution systems using mixed integer nonlinear programming approach. Electric Power System Research, doi: 10.1016/j.epsr.2013.09.019107:119-124, 2014

[29] Devabalaji KR, Ravi K, Kothari DP: Optimal location and sizing of capacitor placement in radial distribution system using Bacterial Foraging Optimization Algorithm. Electrical Power and Energy Systems, doi:10.1016/j.ijepes.2015.03.008, 71: 383-390, 2015.

[30] Lee CS, Ayala HVH, Coelho LDS: Capacitor placement of distribution system using Particle Swarm Optimization approaches. Electrical Power and Energy Systems, doi:10.1016/j.ijepes.2014.07.069, 64:839-851, 2015

[31] Chiou J P, Chang C F Development of a novel algorithm for optimal capacitor placement in distribution systems. Electrical Power and Energy Systems, doi:10.1016/j.ijepes.2015.06.003, 73:684-690, 2015

[32] Zeinalzadeh A, Mohammadi Y, Moradi MH Optimal multi objective placement and sizing of multiple DGs and shunt capacitor banks simultaneously considering load uncertainty via MOPSO approach. Electrical Power and Energy Systems, doi:10.1016/j.ijepes.2014.12.010, 67:336-349, 2015

[33] Abdelaziz AY, Ali ES, Elazim SMA: Optimal sizing and locations of capacitors in radial distribution systems via flower pollination optimization algorithm and power loss index. Engineering Science and Technology, doi:10.1016/j.jestch.2015.09.002, 19:610-618, 2016

[34] Das D, Kothari DP, Kalam A: Simple and efficient method for load flow solution of Radial Distribution Networks. Electrical Power and Energy Systems, doi: 10.1016/0142-0615(95)00050-0, 17:335-346, 1995

[35] Ghosh S, Das D: Method for load-flow solution of radial distribution networks. IEE Proc Gen Trans Dist, doi: l0.l049/ip-gtd: 1999046, 146:641-648, 1999.
[36] Chakravorty M, Das D: Voltage stability analysis of radial distribution networks. Electrical Power and Energy Systems, doi: 10.1016/S0142-0615(00)00040-5, 23:129-135, 2001.

APPENDIX-A

Table A.1 Test data for 33 node RDN [35]

Branch number	Sending End	Receiving end	Resistance	Reactance	P(kW)	Q(kVAr)
1	1	2	0.0922	0.047	100	60
2	2	3	0.493	0.2511	90	40
3	3	4	0.366	0.1864	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.819	0.707	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	0.7144	0.2351	200	100
8	8	9	1.03	0.744	60	20
9	9	10	1.044	0.74	60	20
10	10	11	0.1966	0.065	45	30
11	11	12	0.3744	0.1238	60	35
12	12	13	1.468	1.155	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.591	0.526	60	10
15	15	16	0.7463	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	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	50
23	23	24	0.898	0.7091	420	200
24	24	25	0.896	0.7011	420	200
25	6	26	0.203	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.059	0.9337	60	20
28	28	29	0.8042	0.7006	120	70

29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.963	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.341	0.5302	60	40

APPENDIX B

Table B.1 Test data for 69 node RDN [35, 36]

Branch number	Sending End	Receiving end	Resistance	Reactance	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 C

Table C.1 Test data for 141 node RDN [26]

Branch number	Sending End	Receiving end	Resistance	Reactance	P(kW)	Q(kVAr)
1	1	2	0.0577	0.0409	0	0
2	2	3	0.1725	0.1223	0	0
3	3	4	0.0009	0.0006	0	0
4	4	5	0.0092	0.0065	0	0
5	5	6	0.0068	0.0049	0	0
6	6	7	0.0469	0.0625	0	0
7	7	8	0.0736	0.0981	75	45.01
8	8	9	0.0649	0.0459	10	8.16
9	9	10	0.0507	0.0359	0	0
10	10	11	0.0116	0.0082	0	0
11	11	12	0.1291	0.0913	25	20.41
12	12	13	0.1227	0.0866	75	61.28
13	13	14	0.0488	0.0345	0	0
14	14	15	0.0957	0.0677	0	0
15	15	16	0.086	0.0609	0	0
16	16	17	0.0398	0.0282	150	122.39
17	17	18	0.0828	0.0566	0	0
18	18	19	0.0186	0.0132	0	0
19	19	20	0.0559	0.0395	75	61.25
20	20	21	0.0365	0.0246	75	62.19
21	21	22	0.0573	0.0307	0	0
22	22	23	0.0263	0.0191	75	60.69
23	23	24	0.0683	0.0497	0	0
24	24	25	0.0398	0.0282	0	0
25	27	26	0.0729	0.053	150	121.32
26	26	27	0.0335	0.0244	75	60.62
27	27	23	0.0584	0.0414	0	0
28	28	29	0.0655	0.0463	75	61.24
29	61	62	0.0411	0.0291	200	163.23
30	60	63	0.0353	0.025	0	0

31	63	64	0.1047	0.0741	300	244.88
32	64	65	0.0674	0.0477	150	122.44
33	65	66	0.0302	0.0214	225	183.58
34	66	67	0.0456	0.0323	50	40.8
35	67	63	0.0218	0.0154	100	81.68
36	29	30	0.0342	0.0248	0	0
37	30	31	0.0128	0.0091	0	0
38	31	32	0.0347	0.0245	150	122.54
39	2	33	0.0443	0.0314	0	0
40	33	34	0.002	0.0009	150	136.79
41	5	35	0.2274	0.0554	300	291.47
42	5	36	0.1265	0.1565	150	94.29
43	6	37	0.0055	0.0073	50	30.09
44	37	38	0.2036	0.144	0	0
45	38	39	0.0938	0.0663	20	16.33
46	39	40	0.0347	0.0245	0	0
47	40	41	0.0918	0.065	75	61.21
48	41	42	0.2318	0.164	0	0
49	42	43	0.1207	0.0854	0	0
50	43	44	0.0443	0.0314	50	40.79
51	44	45	0.0405	0.0288	0	0
52	45	46	0.016	0.0127	0	0
53	46	47	0.0636	0.045	0	0
54	47	48	0.0417	0.0295	125	102.05
55	48	49	0.0732	0.051	150	123.07
56	49	50	0.0828	0.0556	0	0
57	50	51	0.0398	0.0282	125	101.99
58	51	52	0.0225	0.0159	75	61.25
59	38	53	0.0841	0.0595	100	81.63
60	42	54	0.0019	0.0114	0	0
61	54	55	0.0527	0.0373	0	0
62	55	56	0.0893	0.0632	25	20.41
63	56	57	0.0867	0.0613	0	0
64	57	58	0.0674	0.0477	300	244.88
65	58	59	0.0469	0.0332	150	122.43

66	55	60	0.0334	0.0236	0	0
67	60	61	0.0327	0.0232	300	244.67
68	63	69	0.0366	0.0259	300	244.89
69	66	70	0.0231	0.0164	0	0
70	70	71	0.012	0.0029	300	291.61
71	70	72	0.07	0.0495	150	122.47
72	42	73	0.0231	0.0164	300	244.62
73	73	74	0.003	0.0064	300	127.33
74	43	75	0.0379	0.0268	45	36.74
75	44	76	0.0552	0.0391	75	61.2
76	46	77	0.0516	0.0436	150	114.58
77	76	78	0.0167	0.011	0	0
78	78	79	0.0415	0.0101	502.5	488.25
79	79	80	0.1003	0.0244	750	728.75
80	79	81	0.1513	0.037	0	0
81	81	82	0.0033	0.0008	150	145.78
82	47	83	0.0085	0.0062	75	60.59
83	49	84	0.0517	0.0449	225	169.88
84	50	85	0.0147	0.0036	0	0
85	85	86	0.0037	0.0016	500	458.93
86	86	87	0.0037	0.0016	150	137.68
87	7	88	0.0174	0.0231	75	45.12
88	88	89	0.0469	0.0625	65	39.01
89	89	90	0.0299	0.0398	0	0
90	90	91	0.0212	0.0283	0	0
91	91	92	0.0315	0.042	0	0
92	92	93	0.028	0.0373	0	0
93	93	94	0.0206	0.0274	110	66.1
94	94	95	0.0206	0.0274	0	0
95	89	96	0.0687	0.0486	150	122.46
96	96	97	0.097	0.0686	0	0
97	97	98	0.0902	0.0196	300	293.16
98	97	99	0.0033	0.0008	0	0
99	131	132	0.0347	0.0245	75	61.27
100	131	133	0.092	0.0669	45	36.39

101	121	134	0.0841	0.0612	35	28.3
102	16	135	0.0527	0.0373	25	20.41
103	16	136	0.0302	0.0214	75	61.19
104	16	137	0.0584	0.0414	55	44.87
105	23	138	0.0769	0.0559	50	40.44
106	99	100	0.0033	0.0008	300	291.56
107	91	101	0.0231	0.0164	15	12.23
108	101	102	0.0578	0.0409	0	0
109	102	103	0.0889	0.0217	125	121.43
110	103	104	0.0629	0.0153	0	0
111	104	105	0.117	0.0285	300	291.48
112	104	106	0.0114	0.0026	150	146.24
113	92	107	0.0849	0.0207	502.5	488.2
114	94	108	0.0612	0.026	0	0
115	108	109	0.0452	0.0192	750	690.3
116	94	110	0.0033	0.0008	750	728.89
117	7	111	0.0719	0.0509	25	20.4
118	10	112	0.107	0.0261	500	485.76
119	11	113	0.0347	0.0245	75	61.27
120	13	114	0.0623	0.0441	0	0
121	114	115	0.0668	0.0473	0	0
122	115	116	0.004	0.001	300	291.04
123	14	117	0.0506	0.0366	65	52.67
124	15	118	0.0161	0.0114	0	0
125	118	119	0.0462	0.0327	110	89.79
126	119	120	0.0424	0.03	0	0
127	120	121	0.0507	0.0359	0	0
128	121	122	0.0732	0.0518	0	0
129	122	123	0.0584	0.0414	100	81.58
130	123	124	0.061	0.0432	125	102.01
131	124	125	0.0783	0.0554	0	0
132	125	126	0.0834	0.0607	0	0
133	126	127	0.0347	0.0245	75	61.27
134	127	128	0.057	0.042	75	60.38
135	128	129	0.0585	0.0425	110	88.99

136	129	130	0.0103	0.0073	112.5	91.79
137	119	131	0.0355	0.0253	0	0
138	25	139	0.095	0.0673	50	40.8
139	30	140	0.0519	0.0377	150	121.36
140	31	141	0.0584	0.0414	75	61.19