IMPROVEMENT OF VOLTAGE STABILTIY INDEX OF RADIAL DISTRIBUTION NETWORKS

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in

Power Systems

Submitted by

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DECLARATION

I hereby declare that dissertation entitled "**IMPROVEMENT OF VOLTAGE STABILTY INDEX OF RADIAL DISTRIBUTION NETWORKS**" in fulfillment of the requirements for the award of degree of Master of Engineering in Power Systems, Department of Electrical and Instrumentation Engineering, Thapar University, Patiala, is an authentic record of my own work carried out under supervision and guidance of **Dr. Smarajit Ghosh and Shailesh Kumar**. The matter presented in this dissertation has not been submitted for award of any other degree of this or any other University.

Place: Patiala.

Date: 23/6/2017

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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.

Date: 23/6/2017.

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NOMENCLATURE

I_k	branch current in any branch k
V_{k+1}	Node voltage of bus k+1
IL_i	is load current at downstream node i
NB_k	set of all downstream nodes beyond node k
VSI_{k+1}	VSI of node k+1
Q_C	Capacitor size to be installed
R_k	resistance for line k
X_k	reactance for line k
$P[k + 1]$	total active power supplied beyond node $k + 1$
$Q[k + 1]$	total reactive power supplied beyond node k+1
X	position of the current individual
X_j	position of neighboring individual j
V_j	velocity of neighboring individual j
N	total neighboring individuals.
X^+	food source position
X^-	enemy position.
S	separation weight
A	alignment weight
C	cohesion weight
F	food factor
E	enemy factor
W	weight of inertia
S_i	separation of the individual i
A_i	Alignment of the individual i
C_i	Cohesion of the individual i
F_i	food source of the individual i
E_i	position of enemy of the individual i

t	Iteration counter

ABBREVIATIONS

ABC	Artificial Bee Colony
BFOA	Bacterial Foraging Optimization Algorithm
CSO	Cuckoo Search Optimization
DA	Dragonfly Algorithm
DG	Distributed Generator
DE	Differential Evolution
DSTATCOM	Distributed Static Compensator
DVR	Dynamic Voltage Restorer
FPOA	Flower Pollination Optimization Algorithm
GA	Genetic Algorithm
GSA	Gravitational Search Algorithm
HAS	Harmony Search Algorithm
IP	Interior Point
KCL	Kirchhoff's Current Law
KVL	Kirchhoff's Voltage Law
LSF	Loss Sensitivity Factor
MINLT	Mixed Integer Non Linear Technique
PGSA	Plant Growth Simulation Algorithm
PLI	Power Loss Index
PSO	Particle Swarm Optimization
RDN	Radial Distribution Network
STATCOM	Static Synchronous Compensator
VSI	Voltage Stability Index

ABSTRACT

Active and reactive power losses are a major challenge in the field of power system. Many techniques have been evolved 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. This dissertation represents Dragonfly Algorithm approach to minimize power losses and improve voltage stability index of system by optimal placement of capacitors in radial distribution networks. Firstly, load flow has been performed to determine the actual losses and voltages at different nodes of system without compensation called the base case. Next the optimal location and size of the capacitor to be installed has been found. Location has been determined by calculating the Loss Sensitivity Factor at each node. For size determination, Dragonfly optimization algorithm has been used. After installing capacitors at the candidate nodes, again the load flow had been performed to justify the objective. The suggested system is tried out on standard 33 node and 85 node radial distribution networks and results have been compared with other existing methods. The proposed Dragonfly Algorithm has been implemented to outperform the existing popular and powerful algorithms.

CHAPTER 1

INTRODUCTION

Distribution system is that part of power system, which is meant to provide electricity to end consumers from transmission system. The distribution system operates at low level of voltages. The major components of distribution system are feeder, distributor and service mains. Feeder is meant to link substation to the area for distribution of power while distributor is conductor connecting feeder and consumers centers. The final link to end consumers is via service mains that connects distributor to the end consumers. The basic structure of distribution system is shown in Fig 1.1.

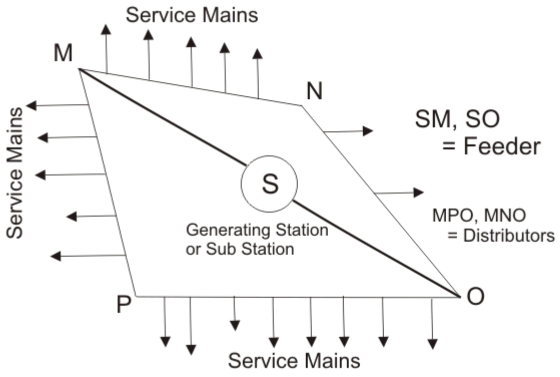

Fig1.1 Main parts of distribution system.

From high voltage transmission systems, voltage is first stepped down for primary distribution. After that distribution feeder links this voltage to distribution transformers for stepping down to lower voltages. Iron poles are used for supporting overhead primary distribution feeders. Pin insulators are used for mounting conductors on the arms of the pole. The most commonly used conductors are stranded aluminum conductors. Three phase pole mounted transformers are used as distribution transformers. Distributors are connected to the secondary side of distribution transformers. Feeders are designed according to their current carrying capacity and usually have no taps while the final distribution of electricity is via service mains and are tapped at desired points. The categorization of distributors can be done as distributors and sub distributors. The secondary of the distribution transformer is directly connected to the distributors while the sub distributors are connected to the taps from distributors. The final connection of the service mains can be to the distributor or the sub distributor depending on the desired arrangement. Both the feeder and distributor have the same basic function of supplying electrical load but the major consideration in case of feeder is constant value of current . So taps are avoided in case of feeder to make the current remain same throughout the feeder while taps are provided on distributors so distributors have varied magnitude of current along their line length.

1.1 RADIAL ELECTRIC POWER DISTRIBUTION SYSTEM

In radial distribution system the feeder have single line arrangement without any interconnections in between throughout their connection to distribution transformer as shown in Fig.1.2. Despite of having major benefits of simple construction, less maintenance and being economical radial distribution system is not much reliable because of lack of any interconnections. In case of any fault on line, the consumers have to face complete supply cut off and fault need to be cleared in order to ensure the distribution of power to the other end.

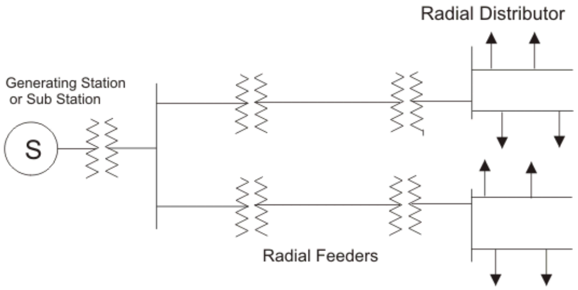

Fig1.2 Radial Distribution Feeder.

1.2 LOSSES IN POWER SYSTEM

Active and reactive power losses pose a major challenge in the field of power system. Distribution system losses form significant portion of the total losses in any system as most outages occur in distribution system. Numerous techniques are used for reducing these losses and hence improving voltage profile. 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 and reduces line loads. Power compensation has become 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 resistive losses are active power losses, which can be minimized by using phase shifting transformers .Reactive power compensation can be done by installing shunt capacitors, restructuring of power system. Combination of shunt capacitor and reactor also minimizes the losses. Capacitor installation implies shunt compensation of reactive power.

1.3 REACTIVE POWER COMPENSATION

Reactive power compensation by allocating shunt or series capacitors is possible to reduce the losses of radial distribution systems. Installing capacitors in shunt helps to reduce kVA loading on generator, make the voltage regulation better and improves stability, reduces losses and improves power factor of the system. Load ends are provided with additional reactive power and it helps to decrease the loading of the lines. Installing capacitor banks at power buses brings rise in their voltages and reduces inductive current.

1.4 RESEARCH GAP

Literature survey shows that more improvement in Voltage Stability Index(VSI) and power loss reduction of radial distribution networks(RDNs) by reactive power compensation is possible by finding solution by Dragonfly Algorithm(DA) in lesser time and lesser number of iterations.

1.5 OBJECTIVE OF THESIS WORK

The purpose of this thesis work is to find optimal location and optimal size of capacitor to be installed to improve the VSI of any RDN and reduce the power losses of the RDN. To achieve this objective, following steps have been taken:

(1) Load flow has been performed on base case using backward/ forward sweep method.

(2) Optimal node number for capacitor placement has been found using Loss Sensitivity Factor (LSF).

(3) Optimal size of capacitor in kVAr at optimal location has been found using DA.

(4) Results obtained have been compared with previous works to prove the efficacy of DA.

1.6 ORGANIZATION OF THE THESIS

Thesis structure for the research work done is discussed below:

Chapter 1: This chapter includes the overview of distribution systems, aim and organization of thesis.

Chapter 2: Literature review regarding thesis work about the basics of the research topic and existing approaches are discussed in this chapter.

Chapter 3: This chapter shows proposed methodology for optimal placement and capacitor size in radial distribution network.

Chapter 4: The results obtained from the proposed method and comparison of these results with the result obtained from other techniques have been discussed.

Chapter 5: Conclusion of the thesis work and future scope of the proposed approach is given in this chapter.

References : The already published papers related to the optimal position and value of capacitor in RDN have been presented.

Appendix A.1: Test data for 33 node RDN.

Appendix B.1: Test data for 85 node RDN.

CHAPTER 2 LITERATURE REVIEW

Load flow analysis is the first step to determine RDN losses, voltage profile and voltage stability index of the network. There are various techniques to solve load flow such as Newton Raphson method. But due to the radial nature of distribution network and high R/X ratios of distributors, conventional load flow techniques fail to converge. Backward/ forward seep technique to solve load flow has been found to be the best technique to solve load flow that gives faster convergence in lesser number of iterations. Following papers have been reviewed for load flow technique-

Sunith and Meena [1] introduced methods to solve the radial distribution power flow problem by Backward/Forward sweep. IEEE 15 bus, 33 bus, 69 bus, 85 bus systems were tested. The proposed load flow method showed improved solution and better convergence.

Singh and Ghose [2] used novel matrix transformation method that directly solved branch flows. This method eliminated the need to store branch number beyond a particular branch while solving load flow using backward/forward sweep.

Liu *et al.* [3] proposed load flow technique with tree node structure to describe connecting relationship between nodes. The depth-first search strategy using node saving queue technique had been used to for tree starting from the supply node.

Ghosh and Das [4] provided technique for solving load flow that showed good and fast convergence characteristics. The algorithm has been tested on three different RDNs to show faster convergence in lesser number of iterations.

Novel matrix transformation technique [2] to solve load flow has been observed to be the most efficient method to solve load flow and same technique has been implemented in this dissertation.

Calculation of sensitivity indexes i.e. Loss Sensitivity Factor (LSF) and Voltage Stability Index (VSI) is next step. Following papers have been reviewed for sensitivity indexes-

Wafa [5] proposed two algorithms for optimal placement of capacitor to improve the voltage stability. Fuzzy expert system was used with Power Loss Reduction Index for the location of the capacitor. Real Coded Genetic Algorithm provided capacitor size. The proposed method was validated on 33 node RDN and results were compared with other techniques.

Reddy [6] presented advantages of compensation using Loss Sensitivity Factor (LSF) method and Genetic Algorithm (GA) for placing capacitors on the primary feeders.

Murthy and Kumar [7] presented a comparison of novel method, combined power loss sensitivity, Voltage Stability Index(VSI) and index vector method to DG.

Das[8] proposed LSF to find the sensitive bus for capacitor placement and Cuckoo Search optimization (CSO) Algorithm for reducing losses and voltage profile improvement. LSF was proved to provide optimal nodes for DG placement.

Chakraborty and Das [9] proposed better Voltage stability index (VSI) for RDNs to obtain the stability indices of all nodes and the most sensitive node that is prone to voltage collapse.

LSF [8] have been observed to provide optimal nodes for compensation and have been used in this dissertation work.

Various swarm intelligence based techniques have been incorporated to determine optimal size of capacitor to be placed in radial network for reactive power compensation. Following papers have been reviewed and results till date obtained have been recorded and realized the probability of better technique that can be incorporated to get better results.-.

Prakash and Lakshminarayana [10] used Whale Optimization Algorithm (WOA) to get optimal location and size of capacitors for RDN. Reduction in operating cost and reduction of power loss were considered as objectives and validated over IEEE 34 and IEEE 85 bus systems.The results showed that the proposed algorithm was more effective in reducing the operating costs and in improving voltage profile.

Abdelaziz *et al.* [11] used Flower Pollination Optimization Algorithm (FPOA) to find optimal locations and size of capacitors in distribution systems. Candidate buses for installing capacitors were suggested using Power Loss Index (PLI). The proposed algorithm was tested on 15, 69 and 118 node distribution networks.

Dixit *et al.* [12] presented optimal node and sizing of shunt devices in radial distribution network for reducing total losses of system. LSF was used to find location and PSO to find optimal capacitor size. Total losses were reduced by placing capacitors at optimal nodes. The methodology was tested for 10 bus and 34 bus system.

Devabalaji *et al.* [13] used BFOA to find the optimal size of capacitor banks. LSF and VSI were implemented to determine the optimal location for capacitor banks. The proposed technique was applied on 34 bus and 85 bus RDNs with varied loads to enhance voltage stability.

Fergany and Abdelaziz [14] used Artificial Bee Colony Algorithm (ABC) to allocate static shunt capacitors in radial distribution networks. Maximization of VSI was considered as the solo objective. The results were validated for 34 bus and 118 bus test case.

Fergany and Abdelaziz [15] used Cuckoo Search Optimization (CSO) technique to allocate capacitors. The objective function was to minimize the operating cost for various loading conditions.

Rao and Narasimham [16] presented technique to find optimal locations and size of capacitor to improve the voltage profile using LSF to select optimal node for capacitor placement and Plant growth Simulation Algorithm (PGSA) to estimate the optimal size of capacitors The proposed method was validated over 9, 34 and 85 bus RDNs.

Khodr *et al.*[17] obtained optimal position and size for switched and static type capacitor in RDNs.The objective function was linearized and solved by Mixed Integer Linear Technique (MILT) and validated on 15 and 33 node RDN.

Huang *et al.* [18] proposed dual stage technique to get the optimal value of capacitor. The fuzzy technique gave Pareto solutions i.e. multiple solutions. Weighting factor in fuzzy logic need not be defined in this technique.

Prakash and Sydulu [19] used LSF and Particle Swarm Optimization (PSO) to find Capacitor placement and size. The proposed method was tested on 34, 69 ,10, 15 and 85 bus distribution networks. The objective was to improve voltage profile and reduce active power losses.

Elsheikh *et al.* [20] used LSF to determine optimal node and discrete PSO to find optimal size of capacitor. It dealt with discrete variables. The results had been found superior than other methods.

Babu *et al.* [21] performed sensitivity analysis for each hour of 42 bus system to determine capacitor location. It had been observed that optimal location of capacitors are insensitive to load variations.

Gnanasekran *et al.* [22] used LSF to determine optimal location and Modified ABC Algorithm to determine optimal location of capacitor. The objective was to improve voltage and reduce cost of losses. The proposed strategy was validated for 15 bus and 85 bus RDNs.

Shuaib *et al.* [23] used sensitivity analysis to find optimal node and Gravitational Search Optimization Algorithm (GSA) to find size of capacitor. The method had been tested for 33 node and 118 node RDNs. The results had been proved to be better than other methods.

Reddy and Manohar [24] used LSF to find optimal size and CSO to determine optimal location of capacitor. The methodology was tested for 15 and 33 node RDN.

Meenakshi *et al.* [25] proposed Self Adaptive HSA to determine capacitor location and size for reactive power compensation. The proposed method had been tested on 69 node RDN for three different cases.

Singh *et al.* [26] proposed Ant Colony Search algorithm to determine optimal location of capacitor. The objective was to maximize cost savings, improve voltage profile and reduce losses.

Lee *et al.* [27] proposed technique PSO that used Gaussian and Cauchy probability distribution to obtain fast convergence. The size of capacitor was obtained by chaotic sequence method.

Chiou and Chang [28] proposed hybrid CODEQ to place capacitor in RDN.Use of resistance based learning and quantic mechanics eliminated the need to find parameters as in Differential Evolution(DE).

Abdelaziz *et al.* [29] used PLI to find optimal location and Flower Pollination Optimization Algorithm (FPOA) to determine size of capacitor for RDN. The technique was validated for 15 bus, 33 bus and 118 bus RDNs.

Nojavan *et al.* [30] used Mixed Integer nonlinear Technique (MINLT) to find capacitor size and LSF to find optimal node with the objective to reduce losses and reduce cost of capacitor installation. The suggested method was tested on 34 node and 85 node RDN and compared with other techniques.

Hsiao *et al.* [31] used Genetic Algorithm(GA) to obtain optimal capacitor size. The objective was to increase the cost savings and increase the total feeder capacity.

Jabr [32] used Interior Point (IP) technique to find optimal location of capacitor to be placed in RDN. Linear programmer solver was used to solve the discrete variable objective.

Kannan *et al.* [33] used fuzzy approximate reasoning to find optimal location of capacitor and PSO to determine optimal size. The objective was to minimize cost and power loss of system and validated for 11 bus and 22 bus RDNs.

Raju *et al.* [34] proposed Direct Search Algorithm to find value of switched and shunt capacitors to be placed in RDNs to minimize the losses. The results obtained were compared with other techniques.

Literature survey shows that here is still probability to find better results for improving voltage profile by newly proposed swarm intelligence based technique named Dragonfly Algorithm.

Following paper has been proposed for Dragonfly Algorithm-

Mirjalili [35] proposed swarm intelligence optimization technique named Dragonfly Algorithm. The proposed algorithm was tested on various mathematical test functions and one real case study. The results proved that proposed algorithm improved initial random population for given problem, convergence towards global optimum and provided better results compared to other algorithms.

Dragonfly Algorithm [35] has been used in this dissertation and its comparison with solutions obtained from other meta heuristic algorithms have verified the efficacy of Dragonfly Algorithm.

CHAPTER 3

PROPOSED METHODOLOGY

Shunt capacitor is installed to improve VSI of RDN and improve stability of system. Selecting optimal location and optimal size of capacitor reduces unnecessary calculations and gives better results. In this dissertation, backward/forward sweep load flow is performed. LSF is used to determine the optimal node number where shunt capacitor is to be placed. Then DA is applied for obtaining best size of capacitor in distribution network.

3.1 OBJECTIVE FUNCTION FORMULATION

The main objective is the improvement of Voltage Stability Index (VSI) of RDN. Capacitor is the source of reactive power compensation and is used for improving VSI.

3.1.1 VOLTAGE STABILITY INDEX

Voltage Stability Index represents voltage stability pattern and helps determine the nodes that are more prone to voltage collapse.

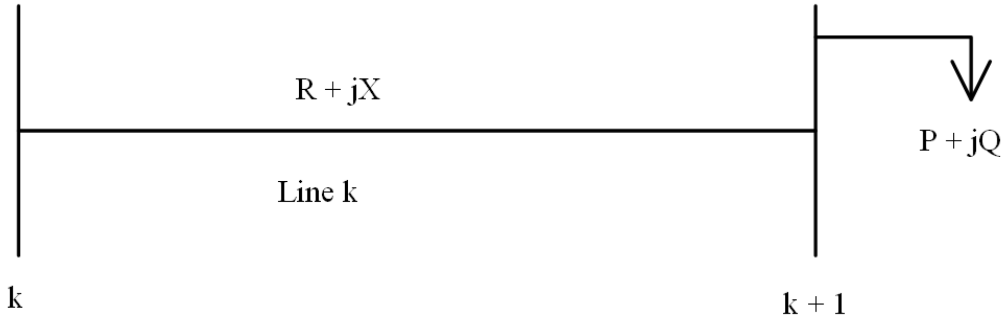

Fig. 3.1 Two bus Radial Distribution Network. [9]

Considering two bus network shown in Fig.3.1, if power flow is from bus k to k+1, the VSI can be calculated by Eq. (3.8)

Firstly, I[k] is calculated by Eq. (3.1)

$$I[k]=\frac{V[k]-V[k+1]}{R[k]+jX[k]} \tag{3.1}$$

Where k=branch numberType equation here.

V[k]= sending end voltage

V[k+1]= receiving end voltage

I[k]= current in branch k

R_k is resistance for line k.

X_k is the reactance for line k.

P[k + 1] is total active power supplied beyond node k + 1.

Q[k + 1] is total reactive power supplied beyond node k+1.

Assume

$$b(k) = |V[k]|^2 - 2 * P[k+1] * R[k] - 2 * Q[k+1] * X[k] \quad (3.2)$$

$$c(k) = \{|P^2[k+1]| + |Q^2[k+1]|\} * \{R^2[k] + X^2[k]\} \quad (3.3)$$

Then

$$|V[k+1]|^4 - b(k) * |V[k+1]|^2 + c(k) = 0 \quad (3.4)$$

The solution of Eq. (3.4) is unique and given by

$$|V[k+1]| = 0.707 [b(k) + \{b^2(k) - 4*c(k)\}^{0.5}]^{0.5} \quad (3.5)$$

Then

$$b^2(k) - 4*c(k) \geq 0 \quad (3.6)$$

on solving and simplifying

$$(V[k+1])^4 - 4(P[k+1]*X[k]-Q[k+1]*R[k])^2 - 4(P[k+1]*R[k]-Q[k+1]*X[k]) * (V[k])^2 \geq 0 \quad (3.7)$$

Thus

$$VSI_{k+1} = (V[k+1])^4 - 4(P[k+1]*X[k]-Q[k+1]*R[k])^2 - 4(P[k+1]*R[k]-Q[k+1]*X[k])^*(V[k])^2 \quad (3.8)$$

For stable operation, it is required that $VSI_{k+1} \geq 0$

.where VSI_{k+1} is the VSI of node k+1.

In this approach, VSI is computed at all the nodes or buses and these are then arranged in increasing order. The node that gives least value of VSI is more prone to suffer voltage collapse with respect to rest of nodes. The numerical value of VSI varies between 0 and 1. [9]

After evaluating VSI of all nodes, the voltage stability of the system can be improved by injecting reactive power at selective nodes.

Assuming capacitor of reactive power Q_c installed at node k+1, then Q_{k+1} changes as

$$Q_{k+1}=Q_{k+1}-Q_c \quad (3.9)$$

And hence VSI value gets improved as per Eq. (3.8)

Thus **objective function is F_{obj}=Maximize (VSI)** (3.10)

Subjected to inequality constraints:

$$V_{min} \leq V_k \leq V_{max} \quad (3.11)$$

Where V_{min} is minimum permissible voltage and V_{max} is maximum permissible voltage. And equality constraint is that that power generation should match power demand and power loss.

3.2 LOAD FLOW ANALYSIS

To perform analysis of power system under steady state, load flow is performed. Among all methods, backward/forward sweep method is the most efficient method for load flow of RDN.

Following assumptions are made before performing the load flow analysis:

1. No mutual coupling between lines.
2. All the loads are constant power loads.
3. No charging current due to the absence of shunt capacitance.
4. Load flow is evaluated in steady state condition and free from distortions.
5. Transposed distribution lines are there and in balanced condition.

3.2.1 BACKWARD/FORWARD SWEEP METHOD

The backward/ forward sweep is an iterative method of load flow using two computations. In first step, starting from end branch and moving in the back direction towards the first node, current through branches are found. In second step, voltage magnitude and angle of each node starting from substation node and moving in forward direction towards last node are computed.

The need to separately find up/down stream nodes and branches at any step of load flow gets eliminated.[2]

3.2.2 METHODOLOGY OF CURRENT FLOW BASED FORWARD/BACKWARD SWEEP METHOD:

In this method, current flows through different branches of network are used to estimate voltage values as shown in Fig.3.2

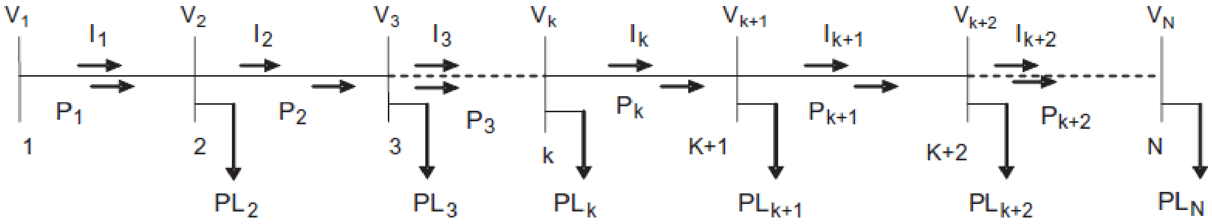

Fig.3.2 : Single Line Diagram Of Radial Distribution Feeder. [2]

The branch current I_k in any k^{th} branch can be computed by Eq. (3.12) and node voltage V_{k+1} at node k+1 can be expressed by Eq.(3.13)

$I_k=\sum IL_i \quad i=1,2,\dots.NB_k$ (3.12)

$V_{k+1}=V_k-I_kZ_k$ (3.13)

Where NB_k is the set of all downstream nodes beyond node k and IL_i is load current at downstream node i. IL_i can be calculated by Eq. (3.14),

$IL_i=(S_i/V_i)^*$ (3.14)

Node voltage can be calculated by Eq. (3.13) in forward sweep. Commencing from last branch, the upstream branch current can be evaluated in backward sweep. To perform backward sweep, nodes and branches beyond each node are required to be saved.

Load currents of different nodes are stored in matrix to find branch currents. In radial systems, source node may feed more than one node but each node is fed by single source node. In this matrix, row number implies sending end node number of a branch and column number denotes receiving end node of same branch. There is one nonzero element in each column. The algorithm for forming matrix of load current and transforming branch current matrix is given in following steps:

Step 1: Formation of load current matrix

(1) Determine the load currents by Eq. (3.14) at each node ‘j’ and store it to ILM (i, j) position in a matrix ILM, where ‘i’ is upstream node just previous to node j.

(2) The load current matrix ILM of [N x N] order made with load current values have some zero rows .The column position of non-zero numbers in any row i shows node numbers fed by node i, where row number in any column j shows feeding node of node j.

Step 2: Transformation to branch current matrix

(1) Find the sum of all elements of j^{th} row and store it in to a temporary variable ‘temp’and move from last row to top row of the load current matrix. If node i is the source node of node j then branch current ILMB (i,j) in branch (i,j) can be found by adding value saved in ‘temp’ to nonzero element of column j.

$$temp_j=\sum ILM(j,k) \quad k=1,2\ldots n \tag{3.15}$$

$$ILMB\ (i,j)=ILM\ (i,j)+temp_j \text{ where } j = n,n-1,..,2 \text{ and } i = k. \tag{3.16}$$

ILMB is the new value of corresponding element of ILM (i, j) after transformation.

(2) Repeat previous step 1 for all rows except first row. As a result, matrix ILMB containing branch currents is obtained.

The node voltages can now be calculated using Eq.(3.13). Flowchart is given in Fig.3.3

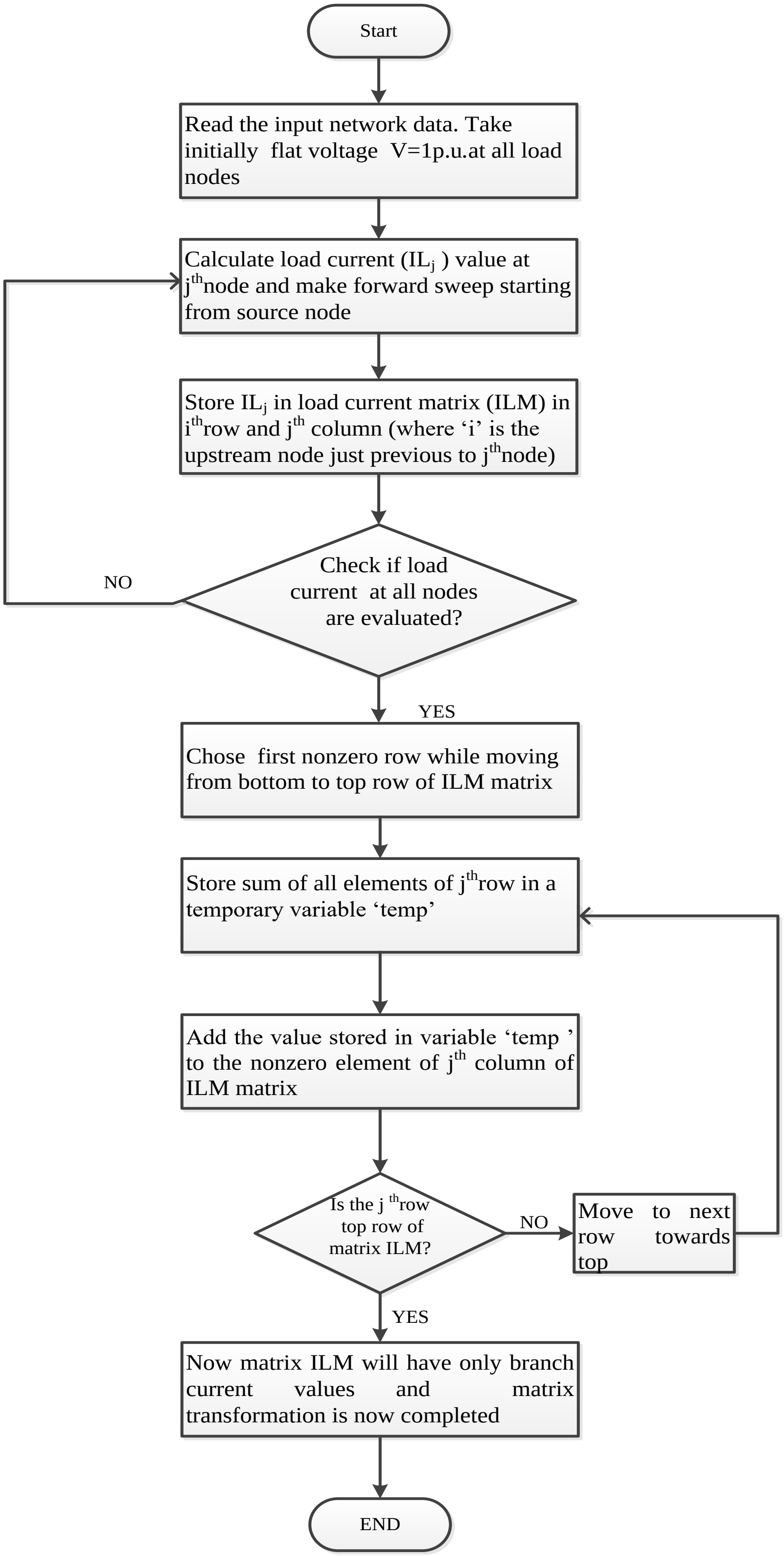

Fig.3.3 Flowchart for load flow.

3.3 NODE SELECTION

There are various techniques to select node for capacitor installation. The node selection should yield best results for improvement of VSI and cost minimization. It should also improve the voltage profile and reliability of overall system. Since the last step of improving VSI i.e. choosing the capacitor value depends upon the node or bus number selected for compensation, hence it is important to choose the right node. In the present dissertation, LSF is chosen to identify the optimal node for placing capacitor and is computed from load-flow on base test case.

3.4 LOSS SENSITIVITY FACTOR

It determines the bus having the highest or maximum loss reduction. LSF helps to select node for reactive power compensation. The estimation of candidate nodes helps to reduce search space for problem optimization. Cost for installation also reduces.[8]

Considering line between k and k+1 buses connected to load in Figure (3.1)

The total active power loss in line k will be $[I_k]^2 * [R_k]$ and this loss can be expressed as[8]-

$$P_{loss}[k+1] = \frac{((P2[k+1] + Q2[k+1]) * R[k])}{V([k+1])2} \tag{3.17}$$

Similarly for reactive power loss we can write,

$$Q_{loss}[k+1] = \frac{((P2[k+1] + Q2[k+1]) * X[k+1])}{V([k+1])2} \tag{3.18}$$

$P[k+1]$ is total active power supplied beyond node $k+1$.

$Q[k+1]$ is total reactive power supplied beyond node k+1.

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

X[k] is the reactance for line k.

LSF can be calculated by partial differentiation of P_{loss}w.r.t. Q

$$\frac{\partial \mathrm{Ploss}}{\partial \mathrm{Q}} = \frac{(2 * \mathrm{Q}[\mathrm{k}+1] * \mathrm{R}[\mathrm{k}])}{(\mathrm{V}[\mathrm{k}+1])2} \tag{3.19}$$

For selecting the optimal node for compensation the LSF is computed from load-flow on base case. These values are then arranged in decreasing order for all the lines. This sequence determines the rank of candidate nodes for power compensation.

BPOS [i] vector is calculated that decides sequence in which the nodes are considered for compensation. At these buses of BPOS [i] vector, normalized voltage magnitudes are found by considering the base case voltage magnitudes given by Eq. (3.20)

$$\text{Normal}[k] = \frac{|V[k]|}{0.95} \tag{3.20}$$

Where V[k] is the base voltages of the corresponding IEEE bus. The Normal[k] signifies whether buses need reactive power compensation . The buses whose Normal[k] value is lower than 1.01 can be selected as the possible buses for capacitor placement.

3.5. SIZE OF CAPACITOR

The conventional optimization techniques made with theoretical assumptions couldnot handle non-smooth, non-convex systems and non-differentiable objective functions and constraints. Heuristic algorithms such as Genetic Algorithm (GA)[31], Differential Evolution(DE), Harmony Search Algorithm (HSA)[25], Artificial Bee Colony (ABC) algorithm[22], Plant Growth Simulation Algorithm [16], Bacterial Foraging Optimization Algorithm(BFOA), Particle Swarm Optimization(PSO)[27] ,Flower Pollination Optimization Algorithm(FPOA)[29],Immune multi objective algorithm [18], Cuckoo Search Algorithm[15] solve the problem more efficiently. One of the latest proposed heuristic algorithms is the Dragonfly Algorithm (DA), which is based on the unique and rare swarming behavior of dragonflies. It was developed by Mirjalili [35].

3.5.1 DRAGONFLY ALGORITHM

The Dragonfly algorithm(DA) is a Swarm Intelligence based optimization technique that was first described by Seyedali Mirjalili[35].The swarm of dragonflies are attracted towards food and distracted outward enemies for survival. Dragonflies portray static and dynamic swarming behaviors which are similar to exploration and exploitation phase. Dragonflies make smaller groups in static swarm to explore. In the dynamic swarm, dragonflies fly in larger groups along single direction in the exploitation phase.

Following five main factors are used in updating position of individuals in swarm. Each of these factors is formulated by algebraic equations as follows [35]-

The separation is calculated as :

$S_i=\sum_{j=1}^{N} X - Xj$ (3.21)

Alignment is calculated as

$A_i= \frac{\sum_{j=1}^{N} Vj}{N}$: (3.22)

The cohesion is calculated as follows:

$C_i= \frac{\sum_{j=1}^{N} Xj}{N} - X$ (3.23)

Attraction towards a food source

$F_i=X^{+}-X$ (3.24)

Distraction outwards an enemy:

$E_i=X^{-} + X$ (3.25)

Where

Xi s the position of the current individual

Xj is the position of neighboring individual j

Vj denotes velocity of neighboring individual j^t

N denotes total neighboring individuals.

X^+ shows food source position

X^- shows enemy position.

To update the location of artificial dragonflies and simulate their movements, consider vectors: step (ΔX) and position X

$\Delta X_{t+1}= s\ S_i + a\ A_i + c\ C_i + f\ F_i + e\ E_i + w\ \Delta X_t$ (3.26)

Where

s shows the weight of separation

a is the weight of alignment

c indicates the weight of cohesion

f is the food factor

e is the enemy factor

w is the weight of inertia.

S_i indicates the separation

A_i is the alignment

C_i is the cohesion

F_i is the food source

E_i is the location of enemy of the individual i and

t is the iteration number.

After calculating the step vector, the position vectors are calculated as follows:

$$X_{t+1}=X_t + \Delta X_{t+1} \tag{3.27}$$

where t denotes present iteration.

For neighborhood, circle, sphere and hyper sphere in 2D,3D and nD space respectively with certain radius value is assumed around each artificial dragonfly.

Thus dragonflies with low cohesion and high alignment weights while exploring search space and high cohesion and low alignment while exploiting space is assumed. For moving between exploration and exploitation, radii of neighborhoods are incremented proportional to iteration number.

Another approach to balance exploitation, exploration is to adaptively tune all swarming factors during optimization.

The artificial dragonflies make random walk in case there is no neighboring solutions in order to improve randomness and exploitation. Then, the position is updated by Eq (3.28):

$$X_{t+1}=X_t +Levy\ (X)* X_t \tag{3.28}$$

where t denotes present iteration.

Flowchart for pseudo code of Dragonfly algorithm is given in Fig. 3.4

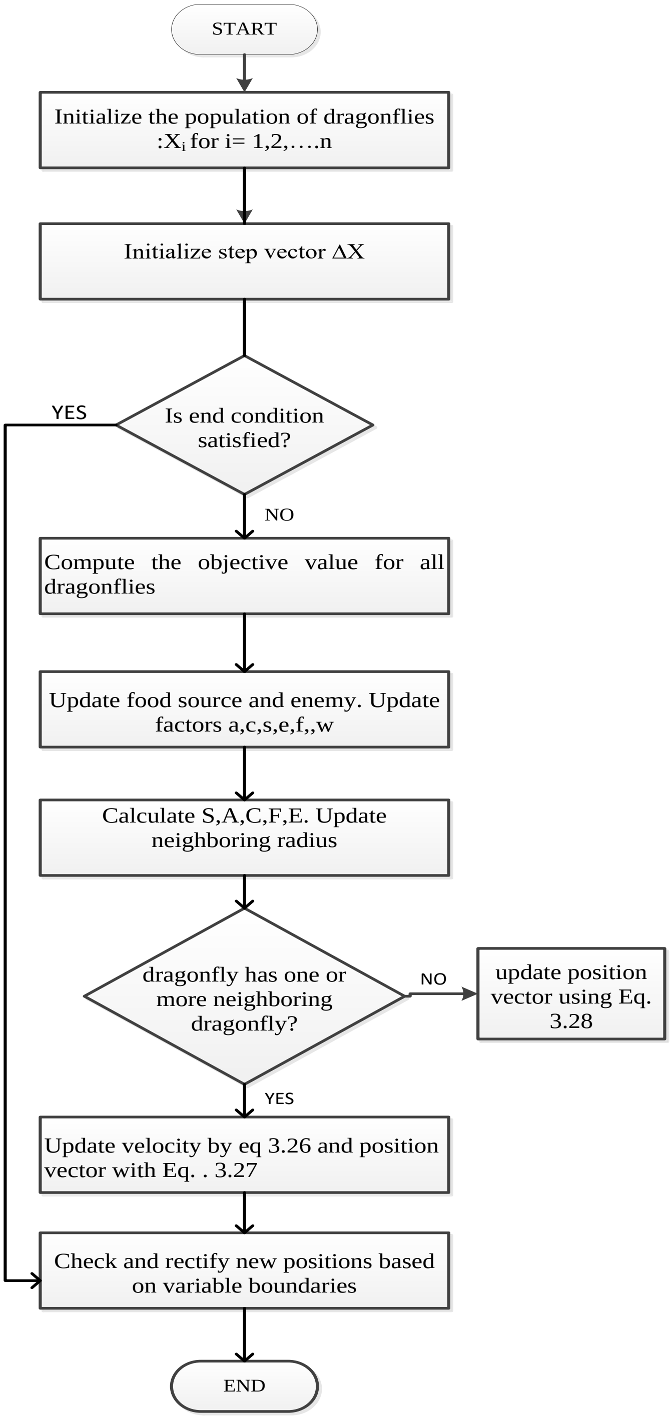

Fig.3.4 Flowchart for pseudo code of Dragonfly Algorithm.

3.6 PROCEDURE TO ALLOCATE CAPACITOR

The procedure to allocate capacitor of appropriate size for improvement of VSI in RDN can be expressed as follows:

1. Run the load flow using backward/forward sweep method for the base case without any capacitor.
2. Calculate the base losses, LSF and VSI .

3. Arrange the LSF in descending order and chose top node for allocation.

4. For choosing the optimal size of capacitor by DA-

Initialize the variables:

Maximum iteration count it max=100

Search population =150

Lower limit of capacitor size =0

Upper limit of capacitor =3000 kVAr

Food fitness=infinity

Food position=0

Enemy fitness=-infinity

Enemy position=0

Initialize factors c, a, s, e, f

Initialize the population of n dragonflies : X_i for i= 1,2,….n i.e. size of capacitor to be installed at first prospective node and initialize step vector ΔX

5. Set iteration it=1

6. Compute the objective function for all n dragonflies.

7 .Identify and update food fitness and enemy

8. Update factors a, c, s, f, e, w.

9. Compute values of A, S, C, E, F by Eq. (3.21) to Eq. (3.25).

10. Update neighboring radius.

11. In case a dragonfly has one or more dragonfly in its neighborhood, then update the velocity by means of Eq. (3.26) and position vector using Eq. (3.27) else update value of position vector using Eq. (3.28)

12. Set it=it+1

13. If difference in food fitness of two respective iteration is <0.001, move to step 14 else move to step 6.

14. End.

Repeat whole process to place 3 capacitors.

Flowchart for complete process is shown in Fig. 3.5

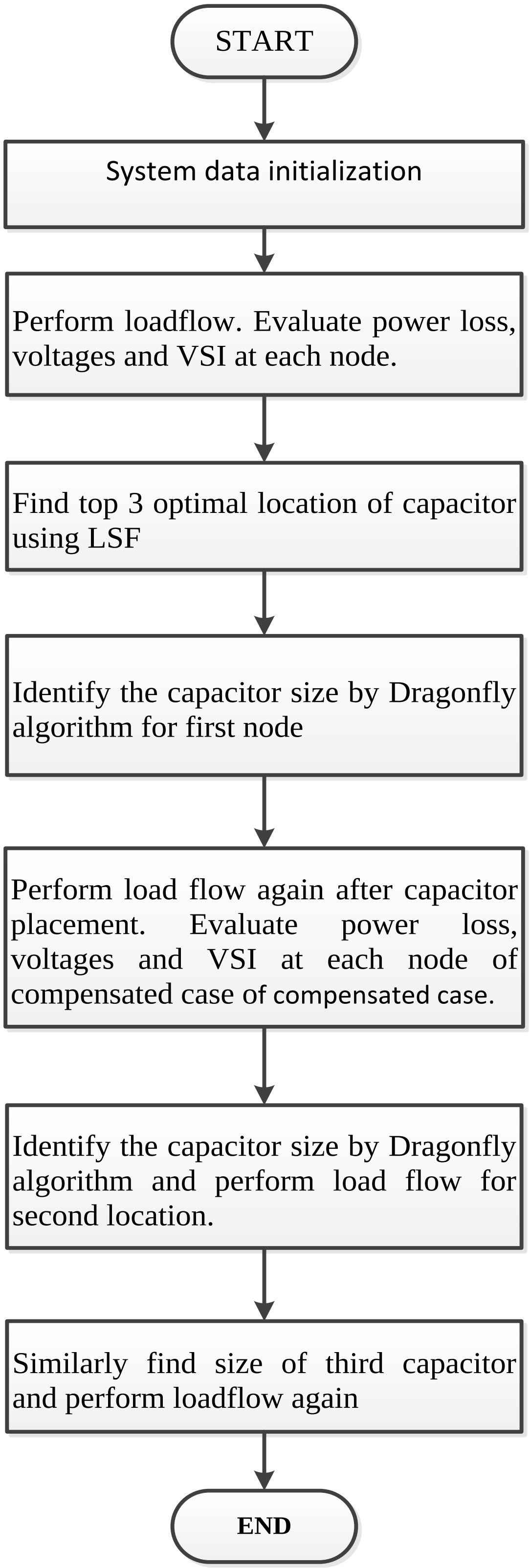

Fig.3.5 Flowchart for complete procedure.

CHAPTER-4

RESULTS

Constant power type load model has been used for the analysis of the RDN in this thesis. MATLAB is used for analyzing distribution system and load modeling done using 33 an 85 node RDNs.

4.1 33 NODE RADIAL DISTRIBUTION NETWORK

Before placing capacitor, real and reactive losses and voltage at all nodes are computed. Total loads of 33 node RDN as shown in Fig.4.1 are **3.7 MW** and **2.3 MVAr** and power losses are **202.6662 kW** and **134.1477 kVAr**. The line and load data are presented in the Appendix A.1.The 33 node network has base voltage as 12.66 kV and base power as 100 MVA .Bus 1 is reference bus. Rest all are constant power buses. [17]

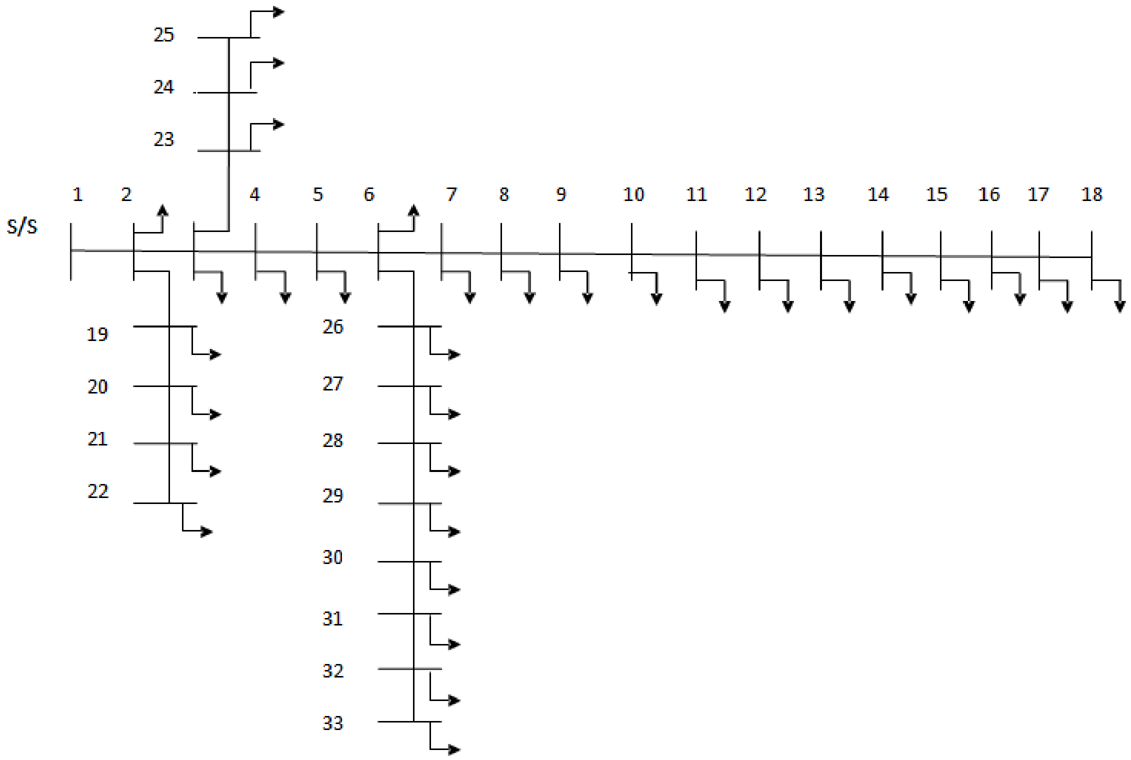

Fig.4.1 : 33 node RDN. [17]

Fig.4.2 and Fig 4.3 shows the plot of Voltage vs node number and VSI vs node number respectively for the 33 node base test case i.e. without any reactive power compensation. **Minimum voltage** obtained is **0.9131 at node 18** and **minimum VSI is 0.6963 at node 18**.

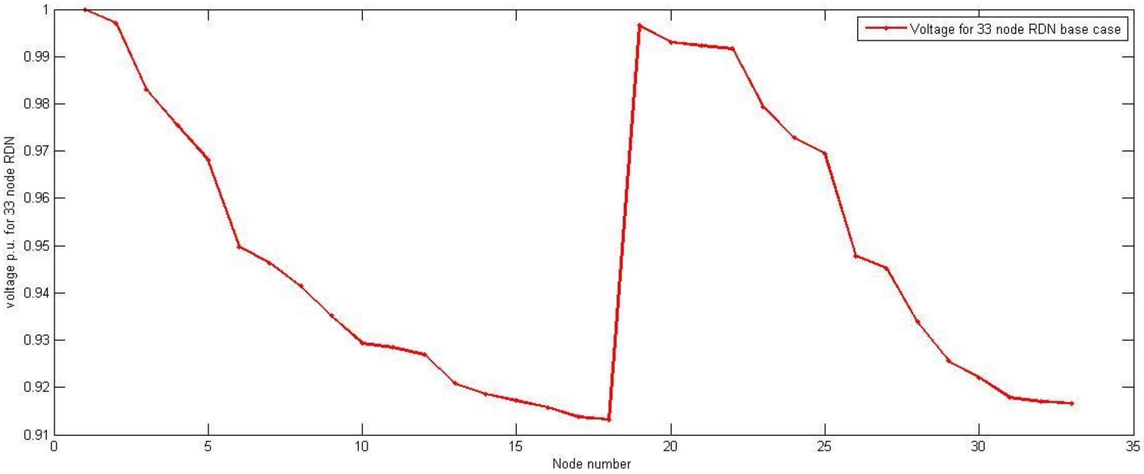

Fig.4.2 Voltage vs node number for 33 node RDN before compensation.

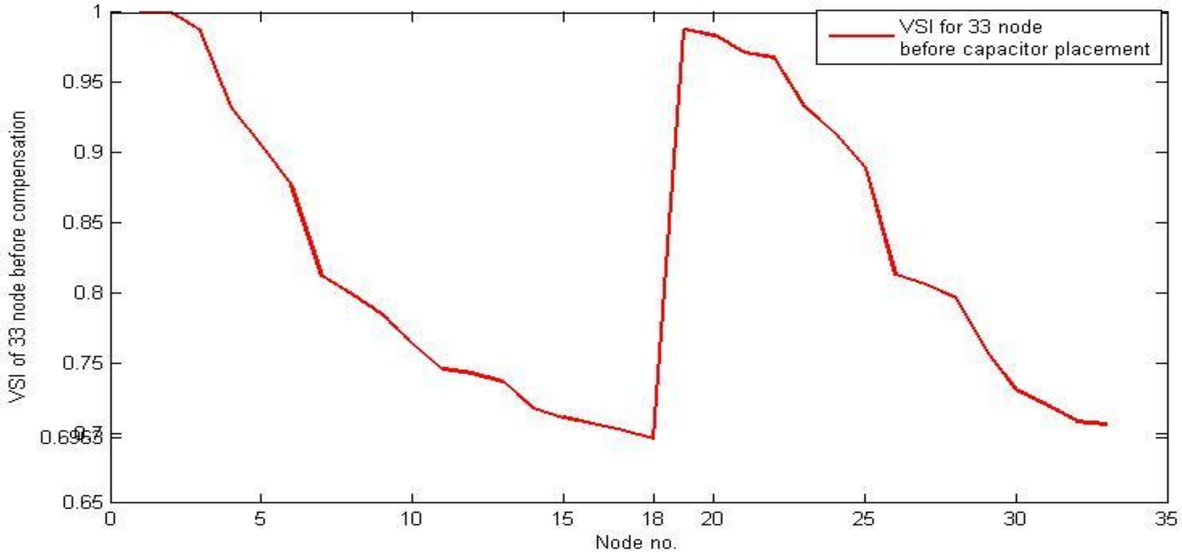

Fig 4.3 VSI vs node number for 33 node RDN before compensation.

Fig.4.4 shows plot of LSF for 33 node base case. Top 3 nodes 6, 28 and 3 have been selected as optimal locations for capacitor placement.

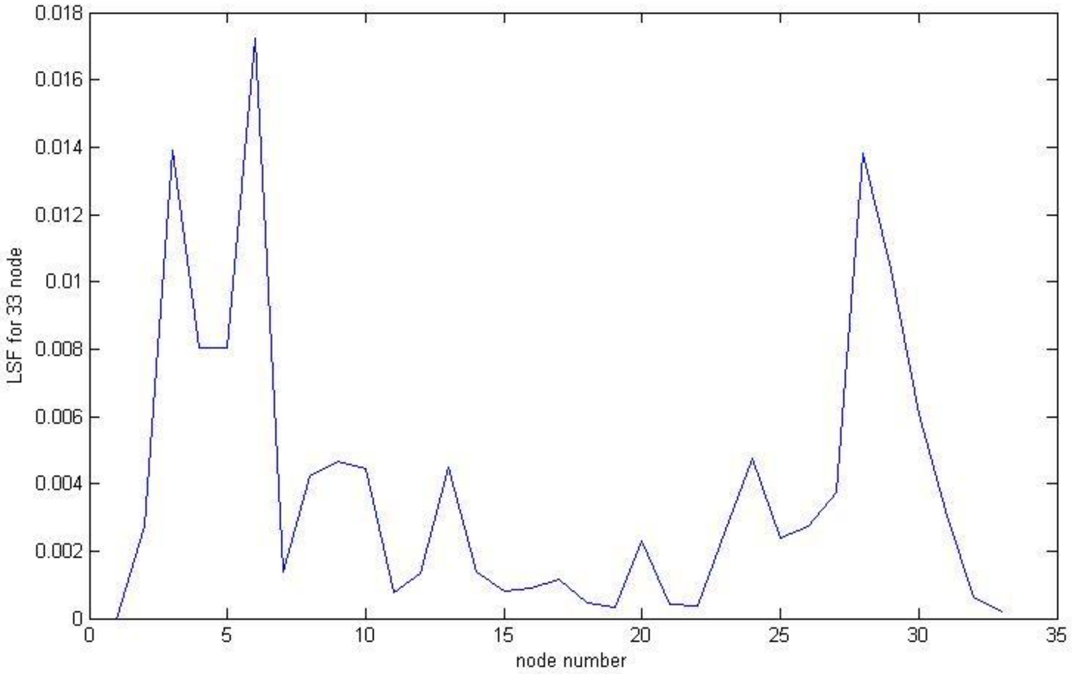

Fig.4.4 Plot of LSF of 33 node RDN before compensation.

Fig 4.5 and Fig. 4.6 shows plot of voltage vs node number and VSI vs node number respectively after placing single capacitor at node 6 and size of capacitor is 1720 kVAr as obtained by DA. Minimum voltage obtained is 0.9297 at node 18 and minimum VSI obtained is 0.7471 at node 18 .

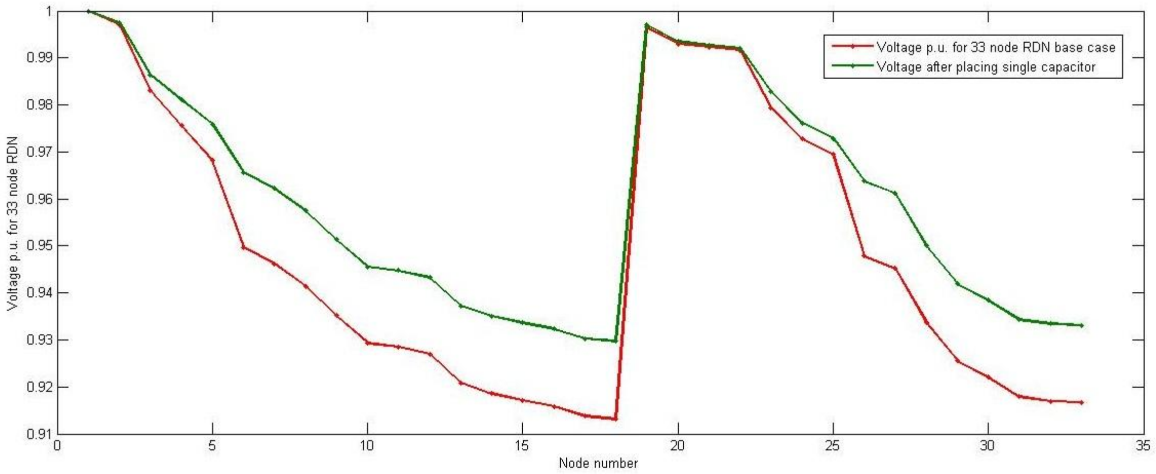

Fig: 4.5 voltage vs node number for 33 node RDN after placing single capacitor.

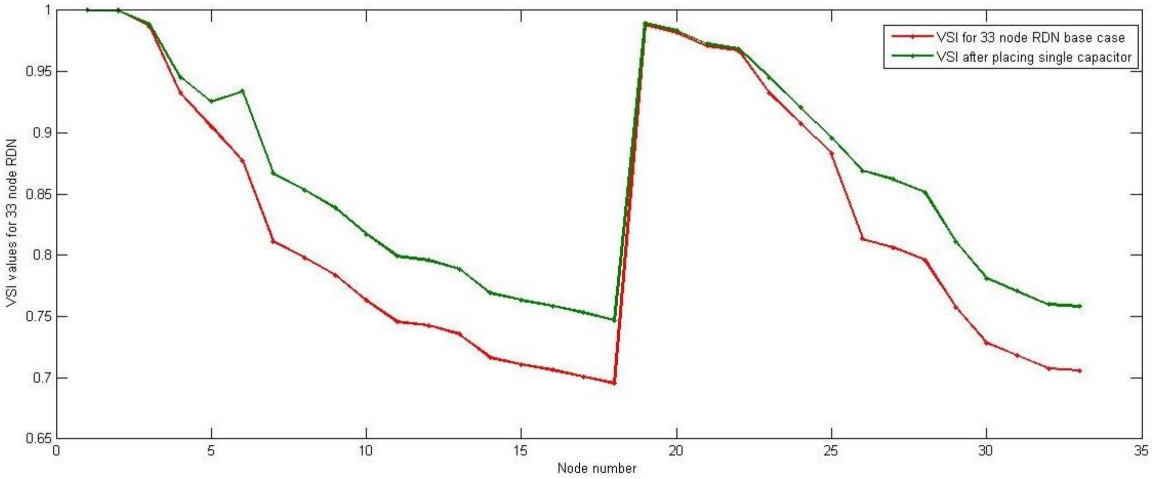

Fig 4.6 VSI vs node number for 33 node RDN after placing single capacitor.

Fig 4.7 and Fig. 4.8 shows plot of voltage vs node number and VSI vs node number respectively after placing second capacitor at node 28 and size of capacitor is 370 kVAr as obtained by DA while capacitor of size 1720 kVAr is already allocated at node 6. Minimum voltage obtained is 0.9332 at node 18 and minimum VSI obtained is 0.7585 at node 18.

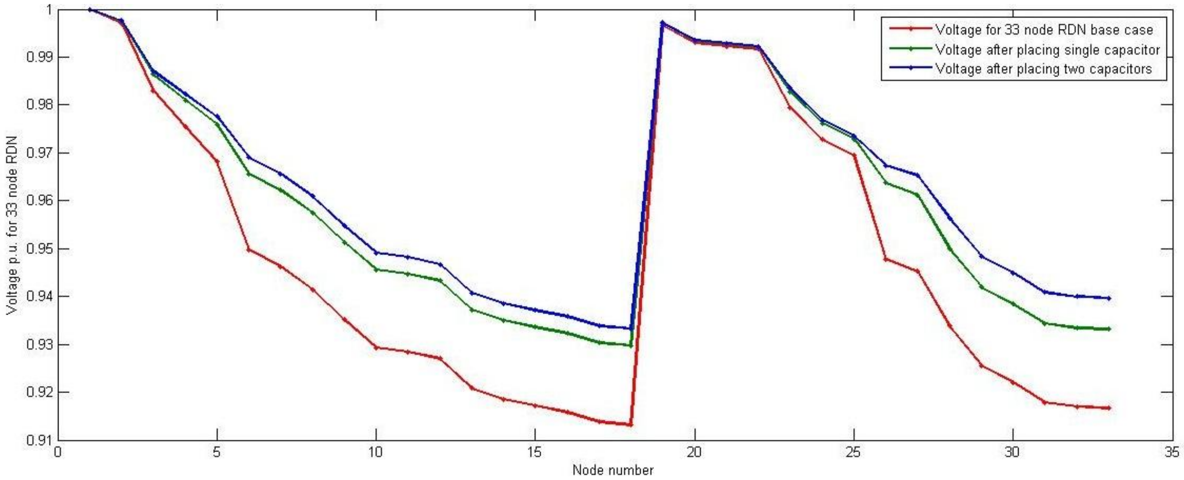

Fig 4.7 Voltage vs node number for 33 node RDN after placing two capacitors.

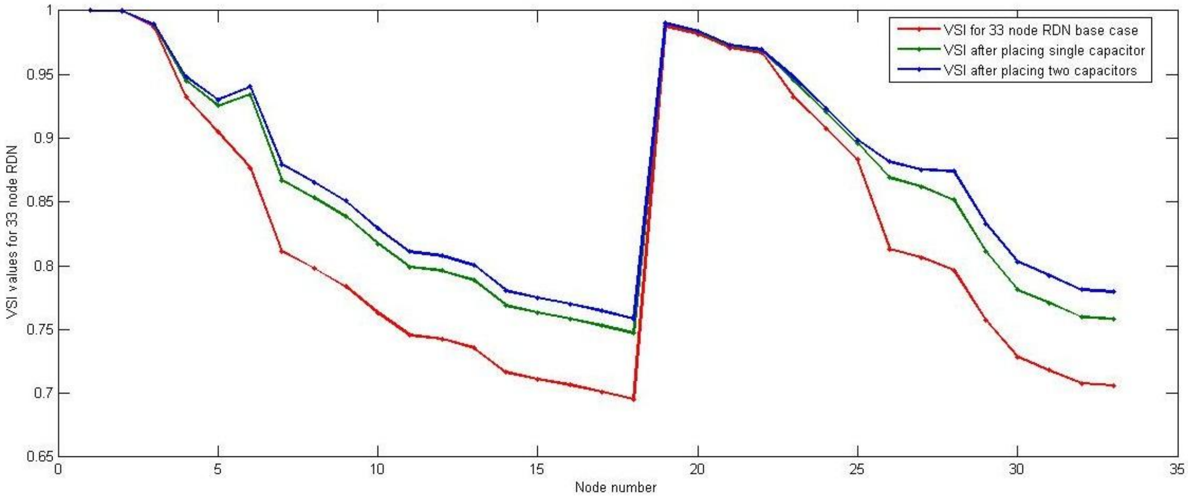

Fig: 4.8 VSI vs node number for 33 node RDN after placing two capacitors.

Fig 4.9 and Fig. 4.10 shows plot of voltage vs node number and VSI vs node number respectively after placing third capacitor at node 3 and size of capacitor is 110 kVAr as obtained by DA while capacitor of size 1720 kVAr is placed at node 6 and capacitor of size 370 kVAr is placed at node 28. Minimum voltage is 0.9357 at node 18 and minimum VSI obtained is 0.7592 at node 18 .

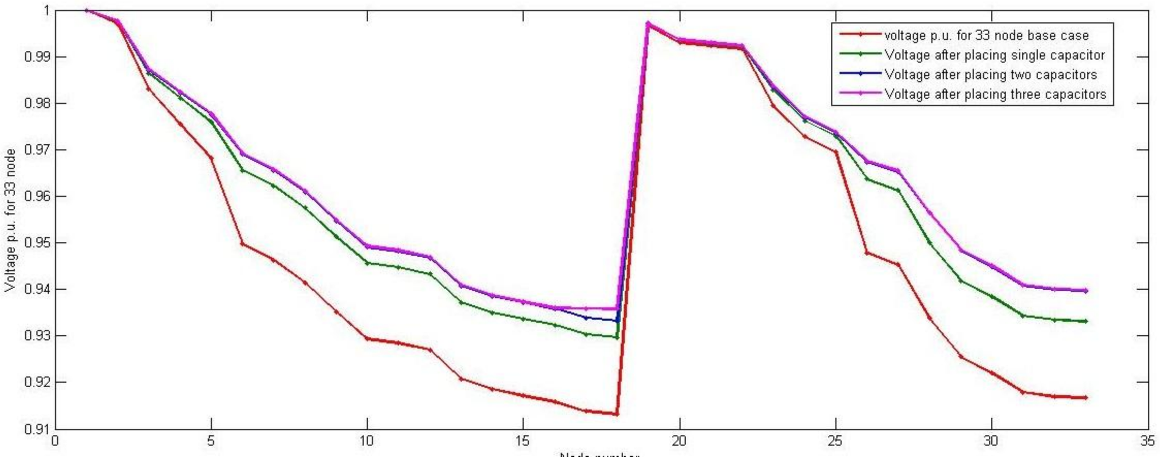

Fig 4.9 Voltage vs node number for 33 node RDN after placing three capacitors.

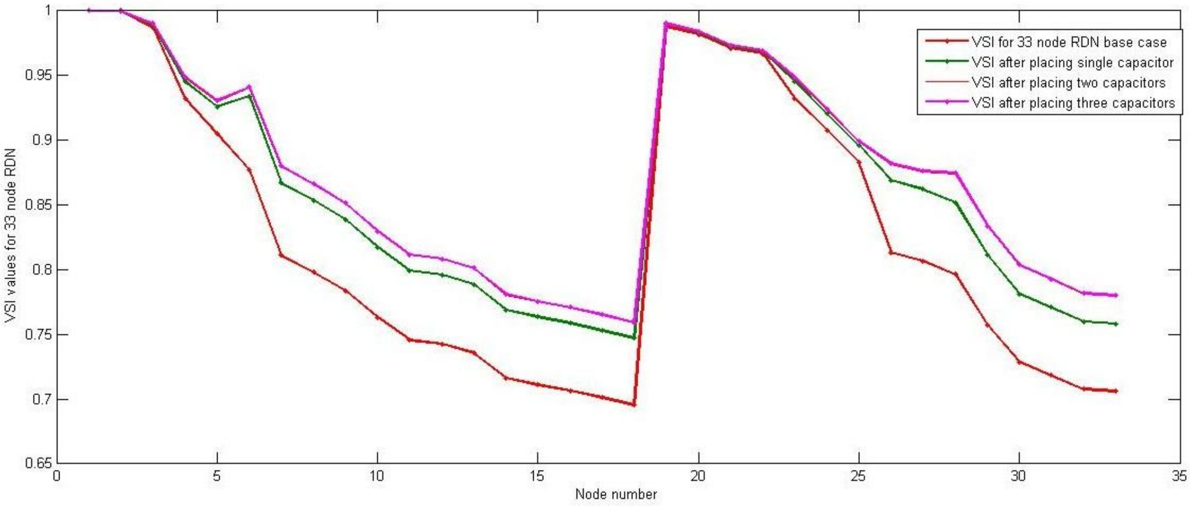

Fig 4.10 VSI vs node number for 33 node RDN after placing three capacitors.

Table 4.1 contains values for voltage of all cases and Table 4.2 shows VSI values of all cases.

Table 4.1 Voltage values for 33 node RDN

Node no.	Voltage (p.u.) base case	Voltage after placing single capacitor	Voltage after placing 2 capacitors	Voltage after placing 3 capacitors
1	1.000000	1.000000	1.000000	1.000000
2	0.997108	0.997574	0.997687	0.997718
3	0.983015	0.986382	0.987102	0.987304
4	0.975534	0.981053	0.982229	0.982429
5	0.968138	0.975904	0.977559	0.977758
6	0.949739	0.965635	0.969041	0.969232
7	0.946254	0.96221	0.965629	0.96582
8	0.94141	0.95745	0.960886	0.961079
9	0.935142	0.951292	0.954751	0.954944
10	0.929328	0.945579	0.94906	0.949255
11	0.928468	0.944734	0.948218	0.948413
12	0.926959	0.943252	0.946741	0.946936
13	0.920846	0.937247	0.940759	0.940956
14	0.91858	0.935021	0.938541	0.938738
15	0.917168	0.933634	0.937159	0.937357
16	0.9158	0.93229	0.935821	0.936018
17	0.913773	0.930299	0.933837	0.935835
18	**0.913166**	**0.929703**	**0.933243**	**0.935742**
19	0.99658	0.997046	0.997159	0.99719
20	0.993002	0.99347	0.993584	0.993615
21	0.992298	0.992766	0.992879	0.992911
22	0.99166	0.992129	0.992242	0.992274
23	0.97943	0.982809	0.983532	0.983734
24	0.972759	0.976162	0.97689	0.977093
25	0.969434	0.972849	0.973579	0.973783

26	0.94781	0.96374	0.967411	0.967601
27	0.945247	0.961221	0.965262	0.965451
28	0.933809	0.949983	0.956368	0.956545
29	0.925592	0.94191	0.94835	0.948529
30	0.922035	0.938415	0.944879	0.945059
31	0.917874	0.934328	0.94082	0.941001
32	0.916959	0.933428	0.939927	0.940108
33	0.916675	0.93315	0.939651	0.939831

Table 4.2 VSI values for 33 node RDN

Node no.	VSI value for base case	VSI after placing single capacitor	VSI after placing 2 capacitors	VSI after placing 3 capacitors
2	0.982136	0.9997	0.9997	0.9997
3	0.987132	0.98898	0.989427	0.99023
4	0.932353	0.945203	0.947968	0.948743
5	0.90499	0.925652	0.930098	0.930856
6	0.877035	0.934166	0.940385	0.941139
7	0.811375	0.867152	0.879467	0.880161
8	0.798031	0.853365	0.865584	0.866272
9	0.783751	0.838607	0.850722	0.851405
10	0.763044	0.817196	0.829159	0.829834
11	0.745659	0.79921	0.811043	0.81171
12	0.742554	0.795996	0.807806	0.808472
13	0.735559	0.788755	0.800511	0.801174
14	0.71645	0.768968	0.780578	0.781232
15	0.711122	0.763449	0.775017	0.77567
16	0.706443	0.7586	0.770132	0.770783
17	0.70106	0.753022	0.764512	0.76516
18	**0.696342**	**0.747096**	**0.758541**	**0.759186**
19	0.98796	0.98981	0.990257	0.990382
20	0.981688	0.983532	0.983978	0.984102
21	0.970924	0.972757	0.9732	0.973324
22	0.967056	0.968886	0.969328	0.969452
23	0.932421	0.945272	0.948037	0.948811
24	0.907796	0.920478	0.923206	0.923971
25	0.883208	0.895718	0.89841	0.899164

26	0.81328	0.869122	0.88145	0.882145
27	0.806559	0.86218	0.875395	0.876083
28	0.796494	0.85178	0.874261	0.874896
29	0.757214	0.811169	0.833243	0.833862
30	0.728473	0.781421	0.803093	0.803701
31	0.718219	0.770802	0.792327	0.792932
32	0.707662	0.759864	0.781238	0.781838
33	0.706093	0.758238	0.779589	0.780188

Table 4.3 shows the proposed capacitor sizes and reduction in losses as proposed by Dragonfly algorithm

Table 4.3 Results for 33 node after capacitor placement

Parameter	Uncompensated	Using single capacitor	Using two capacitors	Using three capacitors
Node	--	6	6,28	6,28,3
Capacitor Value (kVAr)	--	1720	1720,370	1720,370,110
PLoss (kW)	202.1821	153.314	142.8327	140.92
Q loss (kVAr)	135.0091	105.182	100.92	98.36
V min (p.u.)	0.9131 (node 18)	0.9297 (node18)	0.9332 (node 18)	0.9357 (node 18)
VSI min	0.6963 (node 18)	0.7471(node 18)	0.7585 (node 18)	0.7592 (node 18)

Table 4.4 depicts the comparison of results obtained by proposed method with other methods and shows that how Dragonfly Algorithm outperforms the other methods.

Table 4.4 Comparison of results for 33 node of proposed technology with other methods

	GSA[23]	FPOA [29]	PROPOSED METHODOLOGY
Optimal Size Of Capacitor (kVAr)	900 at node 8 760 at node 30 250 at node 31	450 at node 9 800 at node 29 900 at node 30	1720 at node 6 370 at node 28 110 at node 3
Real Power loss (kW)	143.76	171.78	140.92
Minimum voltage(p.u.)	0.9295	0.9201	0.9357 (node 18)
Minimum VSI	0.735	0.7123	0.7592 (node 18)

4.2 85-NODE RADIAL DISTRIBUTION NETWORK

85 node RDN as shown in Fig.4.11 is taken having total load of 2.569 MW and 2.621 MVAr respectively. The base values are 11 kV and 100 MVA. The line and load data of this system is given in Appendix B.1. Total active power loss is 315.7525 kW and reactive power loss is 198.3637 kVAr before compensation.[10]

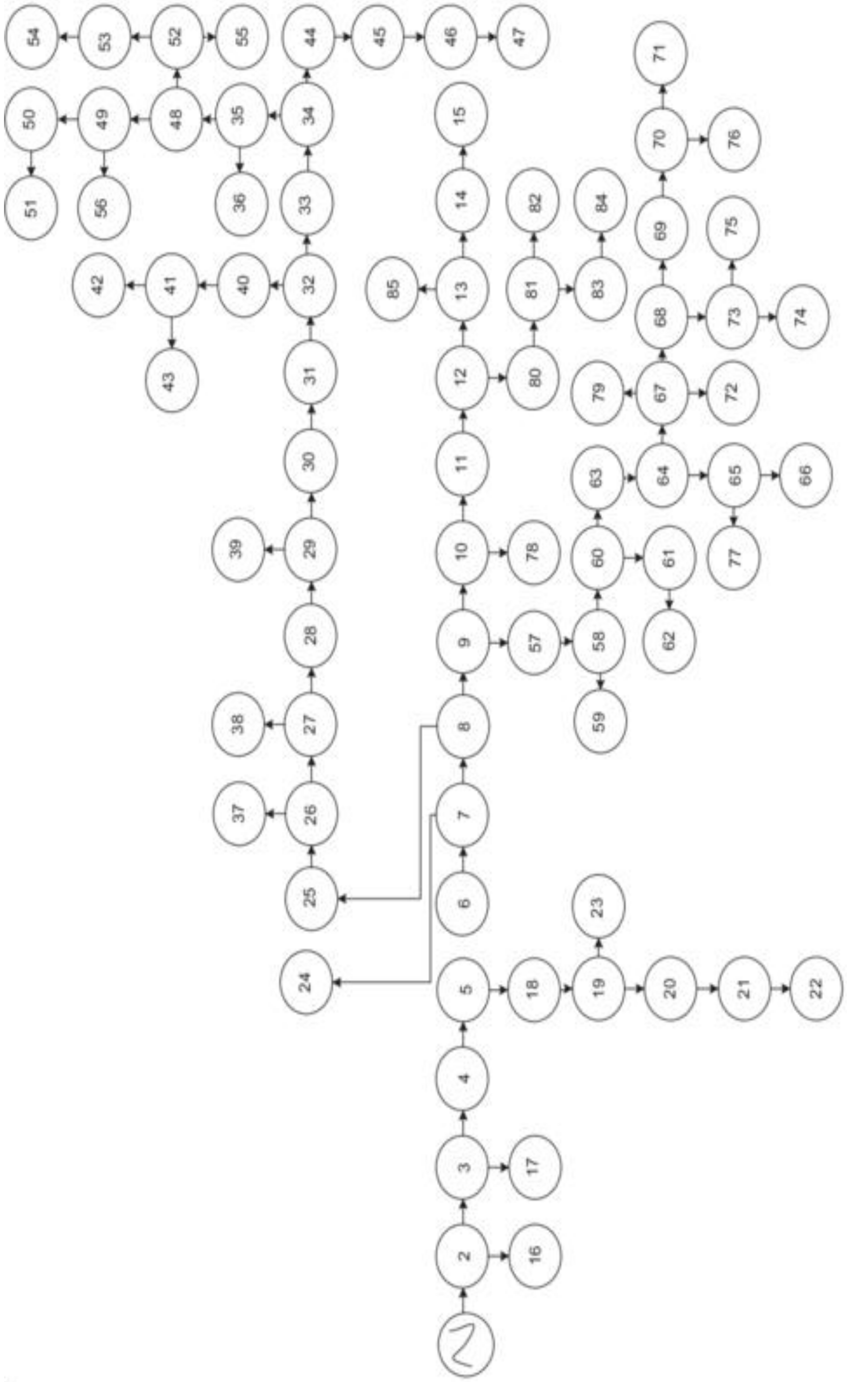

Fig 4.11: 85 node RDN .[10]

Fig.4.12 and Fig4.13 shows the plot of Voltage vs node number and VSI vs node number respectively for the 85 node base test case i.e. without any reactive power compensation. **Minimum voltage** obtained is **0.8714 at node 54** and **minimum VSI is 0.5772 at node 54**.

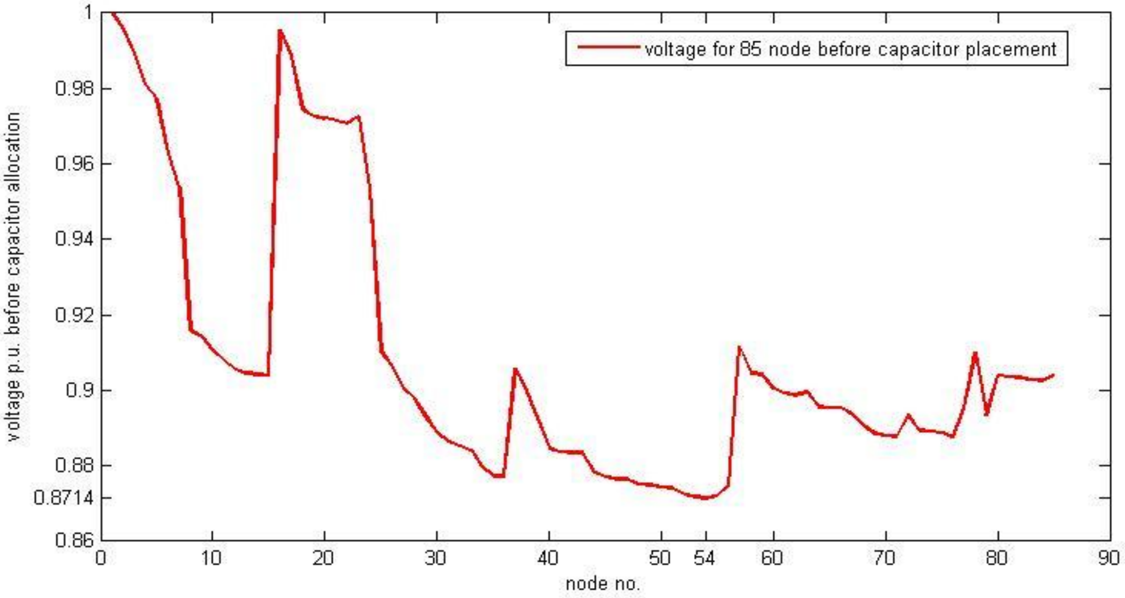

Fig. 4.12 Voltage vs node number for 85 node RDN before compensation.

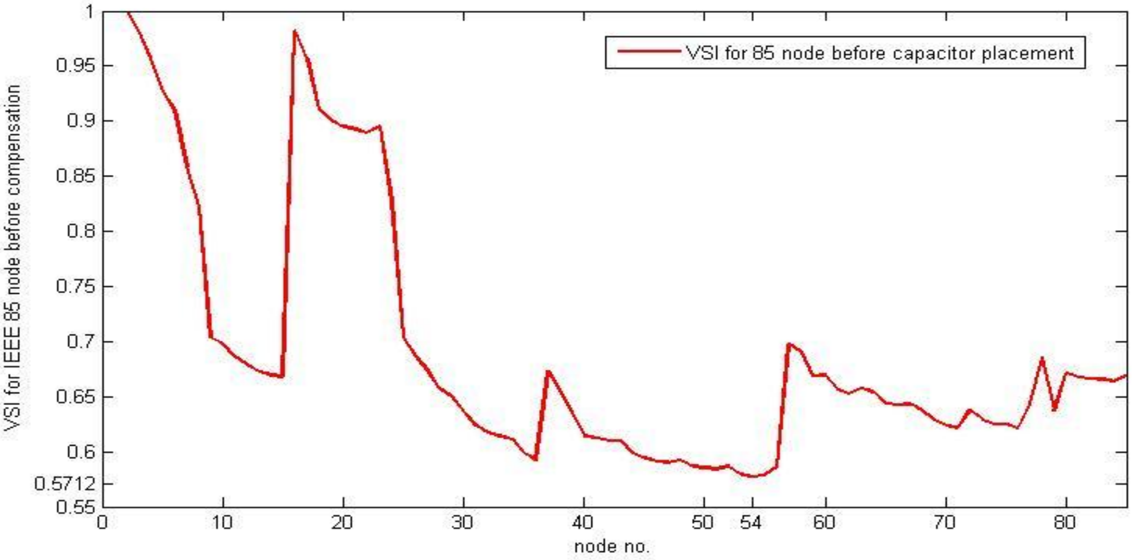

Fig. 4.13 VSI vs node number for 85 node RDN before compensation.

Fig 4.14 shows LSF plot for 85 node RDN. Top 3 nodes- 8, 58, 27 have been selected for capacitor placement.

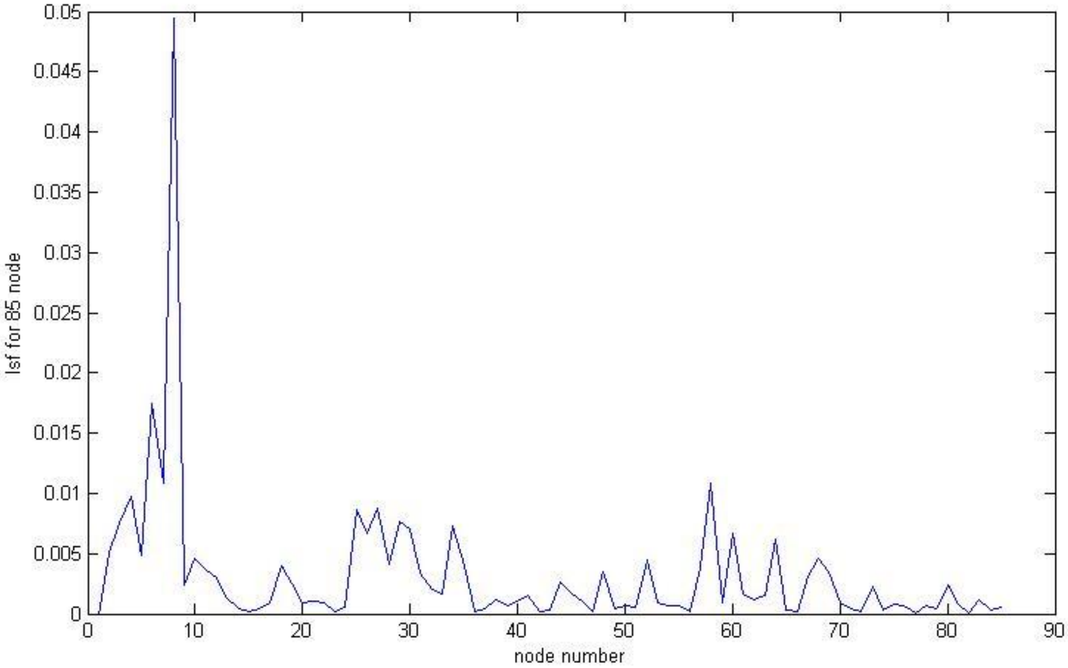

Fig 4.14 Plot of LSF of 85 node RDN before compensation.

Fig 4.15 and Fig. 4.16 shows plot of voltage vs node number and VSI vs node number respectively after placing single capacitor at node 8 and capacitor size is 2200 kVAr as obtained by DA. . Minimum voltage obtained is 0.9087 and minimum VSI obtained is 0.6825 .

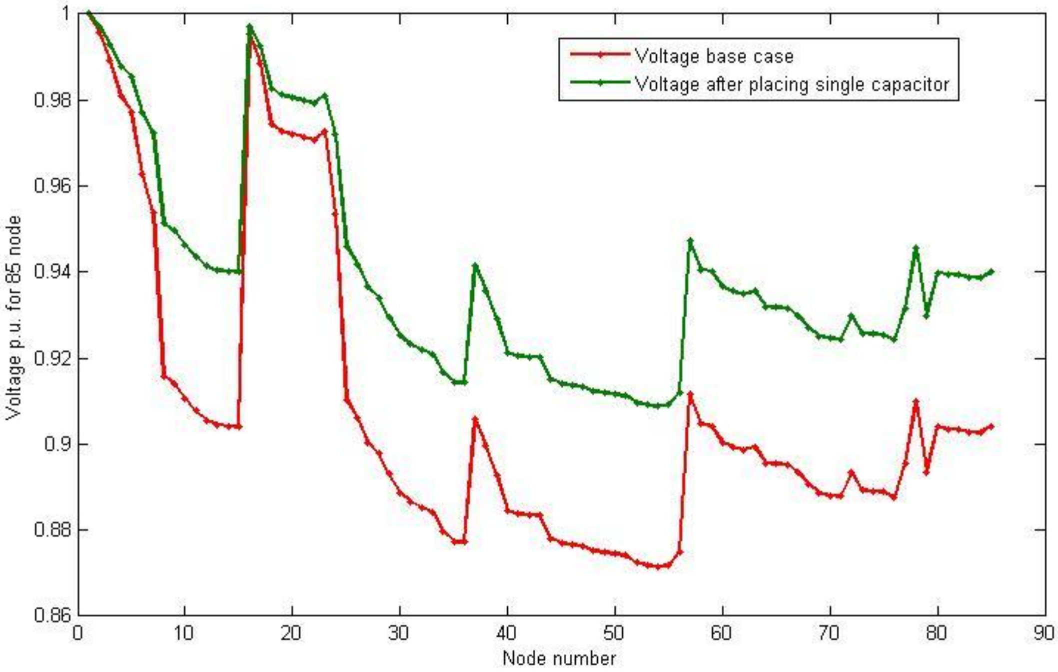

Fig.4.15 :Voltage vs node number for 85 node RDN after placing single capacitor.

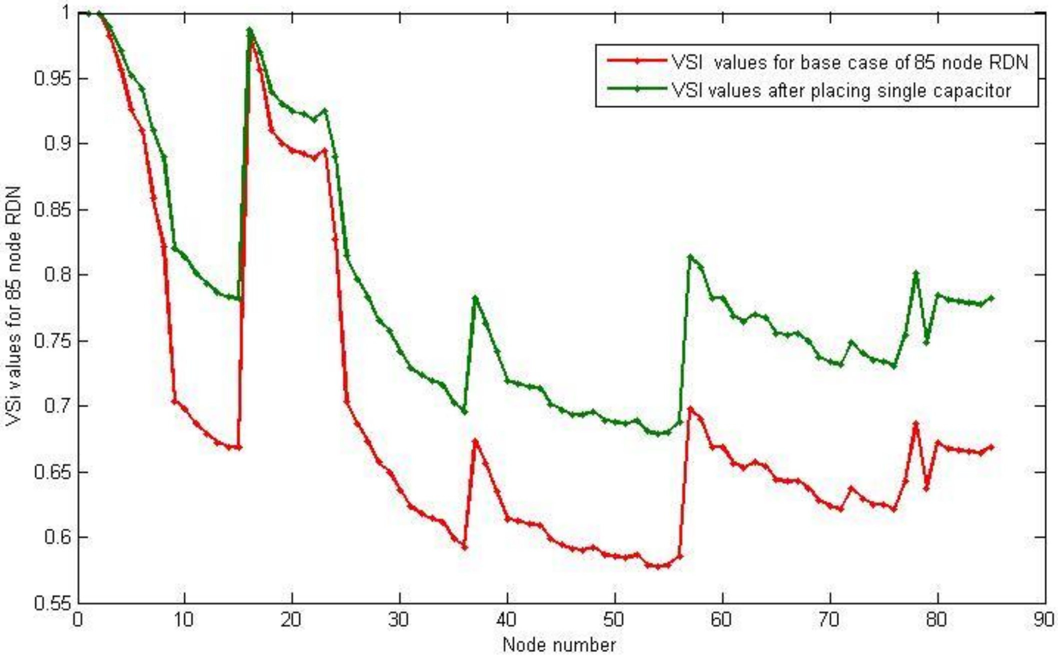

Fig. 4.16: VSI vs node number for 85 node RDN after placing single capacitor.

Fig 4.17 and Fig. 4.18 shows plot of voltage vs node number and VSI vs node number respectively after placing second capacitor at node 58 and size 130 kVAr as obtained by DA while capacitor of size 2200 kVAr is allocated at node 8. Minimum voltage is 0.9128 and minimum VSI obtained is 0.694 at node 54 .

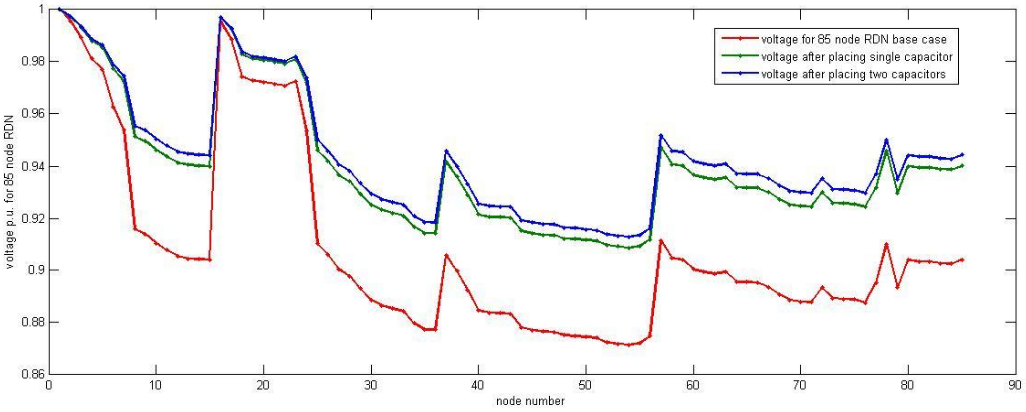

Fig 4.17: voltage vs node number for 85 node RDN after placing two capacitors.

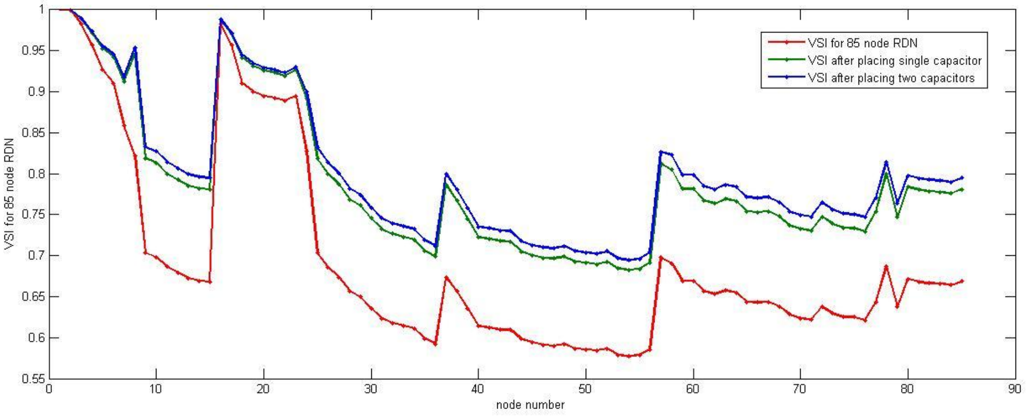

Fig. 4.18. VSI vs node number for 85 node RDN after placing two capacitors.

Fig 4.19 and Fig. 4.20 shows plot of voltage vs node number and VSI vs node number respectively after placing third capacitor at node 27 and size 130 kVAr as obtained by DA while capacitor of size 2200 kVAr at node 8 and capacitor of size 130 kvAr is placed at node 58.. Minimum voltage is 0.9150 at node 54 and minimum VSI obtained is 0.7134 .

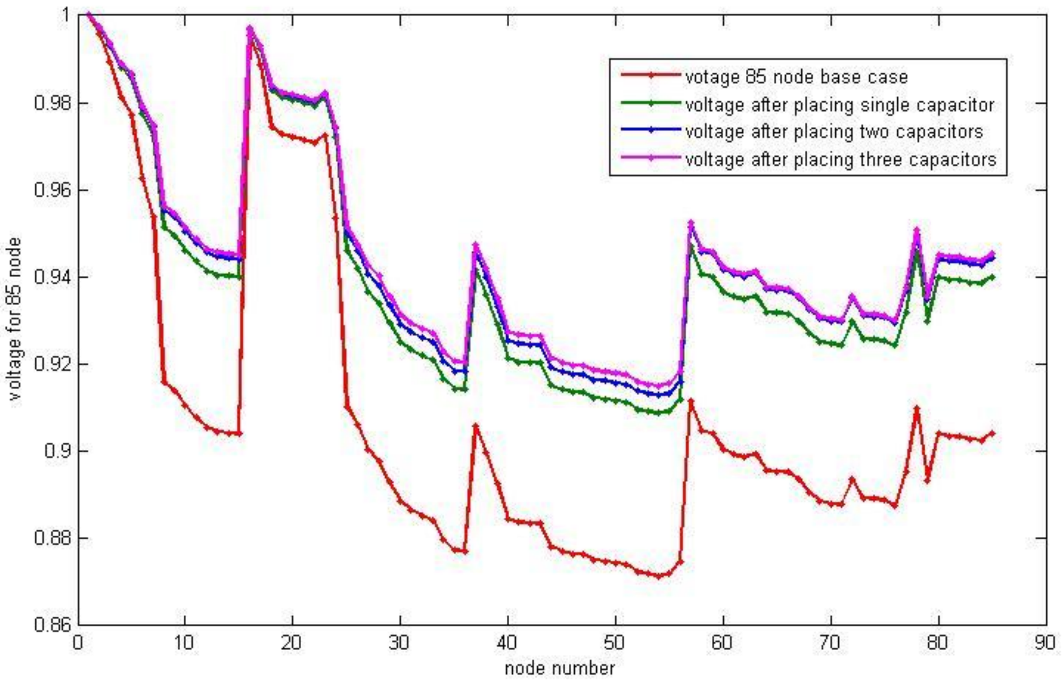

Fig: 4.19 Voltage vs node number for 85 node RDN after placing three capacitors.

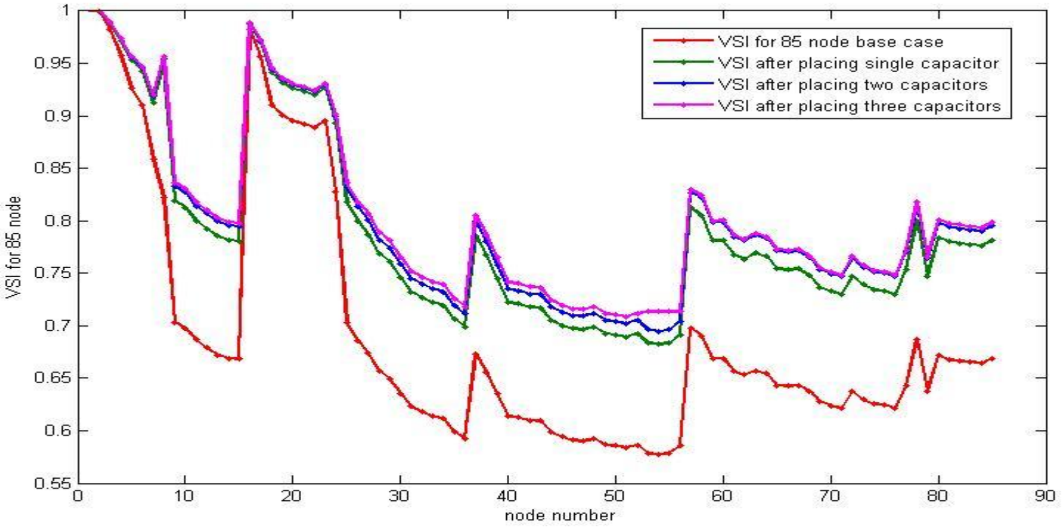

Fig: 4.20 VSI vs node number for 85 node RDN after placing three capacitors.

Table 4.5 and Table 4.6 shows Voltage and VSI values for each case respectively.

Table 4.5 Voltage values for 85 node RDN

Node no.	Voltage (p.u.)base case	Voltage after placing single capacitor	Voltage after placing two capacitors	Voltage after placing three capacitors
1	1.000000	1.000000	1.000000	1.000000
2	0.995678	0.997219	0.997384	0.997428
3	0.989264	0.99311	0.993524	0.993635
4	0.981076	0.98799	0.988737	0.988937
5	0.977091	0.985531	0.986444	0.986688
6	0.962768	0.97735	0.978938	0.979363
7	0.953962	0.972389	0.974404	0.974943
8	0.915833	0.951323	0.955275	0.956332
9	0.914021	0.949581	0.953711	0.954685
10	0.910503	0.946197	0.950341	0.951319
11	0.907772	0.943571	0.947727	0.948707
12	0.905513	0.941398	0.945564	0.946547
13	0.90453	0.940453	0.944622	0.945606
14	0.904232	0.940166	0.944337	0.945321
15	0.904054	0.939995	0.944166	0.945151
16	0.995374	0.996915	0.997081	0.997125
17	0.988658	0.992506	0.99292	0.993031
18	0.974374	0.982837	0.983753	0.983998
19	0.972695	0.981173	0.98209	0.982335
20	0.972112	0.980594	0.981512	0.981757
21	0.971411	0.9799	0.980819	0.981064
22	0.97075	0.979244	0.980163	0.980409
23	0.972572	0.981051	0.981968	0.982213
24	0.953566	0.972	0.974016	0.974555

25	0.910285	0.945997	0.949972	0.951375
26	0.906017	0.941901	0.945895	0.94757
27	0.900419	0.936529	0.940547	0.942626
28	0.897822	0.934037	0.938066	0.940151
29	0.893031	0.929441	0.933491	0.935587
30	0.888648	0.925236	0.929304	0.93141
31	0.886585	0.923257	0.927334	0.929444
32	0.885297	0.922021	0.926104	0.928217
33	0.884265	0.921031	0.925118	0.927234
34	0.879766	0.916716	0.920823	0.922948
35	0.877295	0.914346	0.918464	0.920594
36	0.877209	0.914264	0.918381	0.920513
37	0.905752	0.941647	0.945641	0.947317
38	0.899685	0.935824	0.939844	0.941925
39	0.892629	0.929054	0.933105	0.935202
40	0.884655	0.921405	0.925491	0.927605
41	0.883714	0.920501	0.924591	0.926707
42	0.883586	0.920378	0.924468	0.926585
43	0.8835	0.920296	0.924387	0.926504
44	0.878155	0.91517	0.919284	0.921413
45	0.877121	0.914179	0.918297	0.920428
46	0.876518	0.913601	0.917721	0.919854
47	0.876416	0.913502	0.917623	0.919756
48	0.875126	0.912266	0.916393	0.918529
49	0.874868	0.912019	0.916147	0.918283
50	0.874421	0.91159	0.91572	0.917858
51	0.874078	0.911261	0.915393	0.917531
52	0.87241	0.909661	0.9138	0.915942
53	0.871849	0.909124	0.913265	0.915408
54	**0.871436**	**0.908728**	**0.912871**	**0.915015**

55	0.871997	0.909266	0.913407	0.915549
56	0.874766	0.911921	0.916049	0.918186
57	0.911528	0.947185	0.951587	0.952434
58	0.904638	0.940566	0.94578	0.946243
59	0.904183	0.940128	0.945345	0.945808
60	0.900451	0.936543	0.94178	0.942245
61	0.899384	0.935517	0.94076	0.941226
62	0.89865	0.934812	0.940059	0.940525
63	0.899457	0.935588	0.940831	0.941297
64	0.895608	0.931891	0.937155	0.937622
65	0.895441	0.931731	0.936995	0.937463
66	0.895308	0.931602	0.936868	0.937335
67	0.893622	0.929983	0.935258	0.935726
68	0.890744	0.92722	0.93251	0.93298
69	0.888614	0.925173	0.930475	0.930946
70	0.888063	0.924644	0.929949	0.93042
71	0.887808	0.924399	0.929706	0.930177
72	0.893488	0.929854	0.93513	0.935598
73	0.889314	0.925846	0.931144	0.931615
74	0.889112	0.925652	0.930951	0.931422
75	0.888846	0.925397	0.930697	0.931168
76	0.887658	0.924255	0.929563	0.930034
77	0.895425	0.931715	0.936979	0.937447
78	0.910042	0.945753	0.9499	0.950878
79	0.893368	0.92974	0.935016	0.935484
80	0.903984	0.939928	0.9441	0.945084
81	0.903485	0.939448	0.943622	0.944607
82	0.903419	0.939384	0.943559	0.944544
83	0.902784	0.938773	0.942951	0.943936
84	0.902601	0.938598	0.942776	0.943761

85	0.904154	0.940091	0.944262	0.945247

Table 4.6 VSI values for 85 node RDN

Node no.	VSI base case	VSI after placing single capacitor	VSI after placing two capacitors	VSI after placing three capacitors
2	0.999926	1.00000	1.000000	1.000000
3	0.98266	0.98892	0.989578	0.989753
4	0.957154	0.972049	0.973672	0.974106
5	0.926364	0.952818	0.955703	0.956475
6	0.910294	0.94253	0.94603	0.946967
7	0.858901	0.912433	0.918378	0.919972
8	0.822102	0.946318	0.953977	0.956032
9	0.703492	0.819054	0.832748	0.836441
10	0.697911	0.813072	0.827307	0.830694
11	0.686536	0.800009	0.814131	0.817491
12	0.679042	0.79268	0.806738	0.810082
13	0.672322	0.785405	0.799399	0.802728
14	0.669189	0.781778	0.795739	0.799061
15	0.668265	0.780731	0.794683	0.798002
16	0.982223	0.987719	0.988376	0.988551
17	0.956569	0.970357	0.971979	0.972412
18	0.910412	0.941268	0.944767	0.945702
19	0.900565	0.931475	0.934955	0.935886
20	0.894814	0.926063	0.929533	0.930461
21	0.892383	0.9233	0.926764	0.927691
22	0.889244	0.919525	0.922982	0.923907
23	0.894946	0.92633	0.9298	0.930729
24	0.827491	0.892618	0.900046	0.90204

25	0.703087	0.81837	0.832058	0.83575
26	0.686154	0.800007	0.813546	0.818363
27	0.67372	0.787084	0.800518	0.807522
28	0.657011	0.768651	0.781931	0.788873
29	0.649698	0.761127	0.774343	0.781252
30	0.635596	0.745474	0.758557	0.765396
31	0.623426	0.732453	0.745424	0.752205
32	0.617842	0.726591	0.739511	0.746265
33	0.614214	0.722607	0.735492	0.742228
34	0.611342	0.71961	0.732469	0.739192
35	0.599038	0.706219	0.71896	0.72562
36	0.592238	0.698692	0.711365	0.717991
37	0.673429	0.786234	0.79966	0.805343
38	0.656252	0.766966	0.780231	0.787165
39	0.635441	0.745014	0.758093	0.764931
40	0.613967	0.722066	0.734946	0.74168
41	0.612484	0.72078	0.733649	0.740377
42	0.609706	0.717573	0.730413	0.737126
43	0.609588	0.717316	0.730154	0.736866
44	0.598408	0.704821	0.717549	0.724203
45	0.594096	0.700201	0.712887	0.71952
46	0.591304	0.697168	0.709827	0.716446
47	0.590123	0.696367	0.709019	0.715634
48	0.59234	0.698944	0.711619	0.718246
49	0.586518	0.692605	0.705223	0.711821
50	0.585597	0.691354	0.70396	0.710552
51	0.584174	0.689559	0.70215	0.708733
52	0.586496	0.692605	0.705223	0.711821
53	0.578983	0.684104	0.696645	0.713602
54	**0.577236**	**0.682523**	**0.694444**	**0.71341**

55	0.578724	0.68354	0.696075	0.71363
56	0.585691	0.691557	0.704166	0.713758
57	0.697633	0.812424	0.826654	0.830039
58	0.690209	0.804896	0.822594	0.824208
59	0.669055	0.781174	0.798659	0.800226
60	0.669089	0.781358	0.798845	0.800412
61	0.656636	0.767644	0.784979	0.786533
62	0.653238	0.763653	0.780943	0.782492
63	0.657364	0.769222	0.786575	0.78813
64	0.65447	0.766194	0.783513	0.785065
65	0.643387	0.754155	0.77134	0.77288
66	0.642715	0.75322	0.770394	0.771933
67	0.643374	0.754155	0.77134	0.77288
68	0.637671	0.747998	0.765112	0.766646
69	0.628373	0.736672	0.753658	0.75518
70	0.623521	0.732642	0.749582	0.7511
71	0.621621	0.730194	0.747106	0.748622
72	0.637507	0.747584	0.764694	0.766227
73	0.629518	0.739146	0.75616	0.757685
74	0.625207	0.73416	0.751117	0.752637
75	0.624833	0.73335	0.750298	0.751817
76	0.621411	0.729739	0.746646	0.748161
77	0.642883	0.753584	0.770762	0.772301
78	0.68657	0.80004	0.814162	0.817521
79	0.637336	0.747214	0.76432	0.765853
80	0.671533	0.783705	0.797684	0.801009
81	0.667794	0.780509	0.794459	0.797778
82	0.666224	0.778705	0.79264	0.795955
83	0.665581	0.777316	0.791238	0.79455
84	0.663986	0.7761	0.790011	0.793321

85	0.668853	0.781051	0.795006	0.798326

Table 4.7 shows the proposed capacitor sizes and reduction in losses as proposed by Dragonfly algorithm. Table 4.8 depicts the comparison of results obtained by proposed method with other methods and shows that how Dragonfly Algorithm outperforms the other methods for 85 node RDN.

Table 4.7 Results for 85 node after capacitor placement

Parameter	Uncompensated	Using single capacitor	Using two capacitors	Using 3 capacitors
Node	--	8	8,58	8,58,27
Capacitor Value (kVAr)	--	2200	2200,130	2200,130,130
PLoss (kW)	315.7525	180.8821	166.3	160.7890
Q loss (kVAr)	198.3637	107.2545	100.2827	97.23
V min (p.u.)	0.8714	0.9087	0.9108	0.915015
VSI min	0.5772 at node 54	0.6825 at nod 54	0.694 at node 54	0.7134 at node 54

Table 4.8 Comparison of results for 85 node of proposed technology with other methods

	PSO[19]	MODIFIED ABC [22]	BFOA [13]	MINLT[30]	PROPOSED METHODOLOGY
Optimal Size Of Capacitor (kVAr)	796 at node 8 314 at node 7 901 at node 27 453 at node 58	600 at node 8 600 at node 58 150 at node 7 900 at node 27	840 at node 9 660 at node 34 650 at node 60	300 at node 7 700 at node 8 900 at node 29 500 at node 58	2200 at node 8 130 at node 58 130 at node 27
Real Power loss (kW)	163.54	163.22	162.28	164.5	160.7890
Minimum voltage(p.u.)	0.9136 at node 54	0.9143 at node 54	0.9147	0.9138	0.9150 at node 54
Minimum VSI	0.635	0.6821	0.6921	0.6846	0.7134

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

Voltage profile and voltage stability of RDN has been improved and net losses reduced by the installation of capacitors in this dissertation work. Backward/forward sweep method has been used to perform load flow that gives fast convergence to load flow and gives solution in lesser iteration than other methods. LSF has been used in this dissertation work to find the optimal location for placing capacitor. Sensitive node identification has reduced the search space for finding the optimal location to place capacitor. DA has been used to get the appropriate size of the capacitor .The recommended approaches are validated on 33 node and 85 node RDN. The results of the DA are compared with the result of other meta heurisitic methods. The proposed method provides best results for the curtailment of loss and improvement of voltage profile.

5.2 FUTURE SCOPE

Various other modifications are possible such as:-

1. Other swarm intelligence based optimization techniques can be used to determine the position and size of capacitor.
2. The problem for optimal position and size of capacitor can also be extended for three phase balanced and three phase unbalanced systems.
3. DG units and DSTATCOM, DVR can also be installed to improve voltage stability index.

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APPENDIX

Table A.1 Test data for 33 node RDN [17]

Branch no.	Sending end	Receiving end	Resistance (ohms)	Reactance (ohms)	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	0.7114	0.2351	200	100
8	8	9	1.03	0.74	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	0.1298	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 85 node RDN [10]

Branch no.	Sending end	Receiving end	Resistance(ohms)	Reactance (ohms)	Active power (kW)	Reactive power (kVAr)
1	1	2	0.108	0.075	0	0
2	2	3	0.163	0.112	0	0
3	3	4	0.217	0.149	56	57.1314
4	4	5	0.108	0.074	0	0
5	5	6	0.435	0.298	35.28	35.9928
6	6	7	0.272	0.186	0	0
7	7	8	1.197	0.82	35.28	35.9928
8	8	9	0.108	0.074	0	0
9	9	10	0.598	0.41	0	0
10	10	11	0.544	0.373	56	57.1314
11	11	12	0.544	0.373	0	0
12	12	13	0.598	0.41	0	0
13	13	14	0.272	0.186	35.28	35.9928
14	14	15	0.326	0.223	35.28	35.9928
15	2	16	0.728	0.302	35.28	35.9928
16	3	17	0.455	0.189	112	114.2628
17	5	18	0.82	0.34	56	57.1314
18	18	19	0.637	0.264	56	57.1314
19	19	20	0.455	0.189	35.28	35.9928
20	20	21	0.819	0.34	35.28	35.9928
21	21	22	1.548	0.642	35.28	35.9928

22	19	23	0.182	0.075	56	57.1314
23	7	24	0.91	0.378	35.28	35.9928
24	8	25	0.455	0.189	35.28	35.9928
25	25	26	0.364	0.151	56	57.1314
26	26	27	0.546	0.226	0	0
27	27	28	0.273	0.113	56	57.1314
28	28	29	0.546	0.226	0	0
29	29	30	0.546	0.226	35.28	35.9928
30	30	31	0.273	0.113	35.28	35.9928
31	31	32	0.182	0.075	0	0
32	32	33	0.182	0.075	14	14.2829
33	33	34	0.819	0.34	0	0
34	34	35	0.637	0.264	0	0
35	35	36	0.182	0.075	35.28	35.9928
36	26	37	0.364	0.151	56	57.1314
37	27	38	1.002	0.416	56	57.1314
38	29	39	0.546	0.226	56	57.1314
39	32	40	0.455	0.189	35.28	35.9928
40	40	41	1.002	0.416	0	0
41	41	42	0.273	0.113	35.28	35.9928
42	41	43	0.455	0.189	35.28	35.9928
43	34	44	1.002	0.416	35.28	35.9928
44	44	45	0.911	0.378	35.28	35.9928
45	45	46	0.911	0.378	35.28	35.9928

46	46	47	0.546	0.226	14	14.2829
47	35	48	0.637	0.264	0	0
48	48	49	0.182	0.075	0	0
49	49	50	0.364	0.151	35.28	35.9928
50	50	51	0.455	0.189	56	57.1314
51	48	52	1.366	0.567	0	0
52	52	53	0.455	0.189	35.28	35.9928
53	53	54	0.546	0.226	56	57.1314
54	52	55	0.546	0.226	56	57.1314
55	49	56	0.546	0.226	14	14.2829
56	9	57	0.273	0.113	56	57.1314
57	57	58	0.819	0.34	0	0
58	58	59	0.812	0.075	56	57.1314
59	58	60	0.546	0.226	56	57.1314
60	60	61	0.728	0.302	56	57.1314
61	61	62	1.002	0.415	56	57.1314
62	60	63	0.182	0.075	14	14.2829
63	63	64	0.728	0.302	0	0
64	64	65	0.182	0.075	0	0
65	65	66	0.182	0.075	56	57.1314
66	64	67	0.455	0.189	0	0
67	67	68	0.91	0.378	0	0
68	68	69	1.092	0.453	56	57.1314
69	69	70	0.455	0.189	0	0

70	70	71	0.546	0.226	35.28	35.9928
71	67	72	0.182	0.075	56	57.1314
72	68	73	1.184	0.491	0	0
73	73	74	0.273	0.113	56	57.1314
74	73	75	1.002	0.416	35.28	35.9928
75	70	76	0.546	0.226	56	57.1314
76	65	77	0.091	0.037	14	14.2829
77	10	78	0.637	0.264	56	57.1314
78	67	79	0.546	0.226	35.28	35.9928
79	12	80	0.728	0.302	56	57.1314
80	80	81	0.364	0.151	0	0
81	81	82	0.091	0.037	56	57.1314
82	81	83	1.092	0.453	35.28	35.9928
83	83	84	1.002	0.416	14	14.2829
84	13	85	0.819	0.34	35.28	35.9928

LIST OF PUBLICATIONS

Namita Gupta, Smarajit Ghosh and Shailesh Kumar “Improvement of Voltage Stability Index of Radial Distribution Networks” presented in “National Conference on Recent Trends in Electronics & Electrical Engineering (NCRTEEE-2017)” held at Inderprastha Engineering College ,Ghaziabad (16-17 February,2017).

National Conference on Recent Trends in Electronics and Electrical Engineering (NCRTEEE-2017) 16th - 17th FEB-2017

Certificate

This is to certify that

Prof./Dr./Mr./Ms. NAMITA GUPTA of THAPAR UNIVERSITY PATIALA

presented paper on IMPROVEMENT OF VOLTAGE STABILITY INDEX OF RADIAL DISTRIBUTION NETWORK in

National Conference on Recent Trends in Electronics and Electrical Engineering (NCRTEEE-2017)

held on 16-17 February 2017

at Inderprastha Engineering College, Ghaziabad.

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onvener (NCRTEEE-2017)

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