OPTIMAL SITING AND SIZING OF DG IN BALANCED RADIAL DISTRIBUTION NETWORKS USING BFOA

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

MASTER OF ENGINEERING
in
Power Systems

Submitted by

Gaurav Somani
801441010

Under the Guidance of
Dr. Smarajit Ghosh
Professor, EIED

2016

Electrical and Instrumentation Engineering Department
Thapar University, Patiala
(Declared as Deemed-to-be-University u/s 3 of the UGC Act., 1956)
Post Bag No. 32, Patiala – 147004
Punjab (India)

DECLARATION

I hereby certify that the work which is presented in dissertation entitled, **"Optimal Siting and Sizing of DG in Balanced Radial Distribution Networks using 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.

Gaurav

(Gaurav Somani)
Roll No.: 801441010

Place: Patiala
Date: 15/7/16

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

S-Ghosh

(Dr. Smarajit Ghosh)
Professor
Electrical & Instrumentation Engineering Department
Thapar University, Patiala

Date: 15-7-2016

Countersigned by:

(Dr. Ravinder Agarwal)
Professor &Head
Electrical & Instrumentation Engineering Department
Thapar University, Patiala

(Dr. S.S Bhatia)
Dean (Academic Affairs)
Thapar University, Patiala

ASwarup
05/8/16
(A. SWARUP)
EED, NIT Kurukshetra

CERTIFICATE

Certified that the dissertation entitled, "**Optimal Siting and Sizing of DG in Balanced Radial Distribution Networks using BFOA**", which is being submitted by Gaurav Somani 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.

Place: **(Dr. Smarajit Ghosh)**
Date: **Supervisor**

ACKNOWLEDGEMENT

With great pleasure and privilege, I wish to express my heartfelt sense of gratitude and indebtedness to Dr. SmarajitGhosh, Professor, EIED, Thapar University, Patiala for his patient guidance and support throughout this report. I found this guidance valuable and more importantly his supportive and motivating approach. It was a great experience working with him.

Gratitude is accorded to all the authorities of Thapar University, Patiala for providing the necessary facilities to complete my M.E. thesis work.I wish to thank my friends who devoted their valuable time and helped me in all possible ways towards successful completion of this work. I thank all those who have contributed directly or indirectly to this work.

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

(Gaurav Somani)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

Main symbols and notations used in this study are listed below.

P_{Loss} - Total real power losses
Q_{Loss} - Total reactive power losses
V - Voltage of bus
V_{min} - Minimum voltage limit for bus
V_{max} - Maximum voltage limit for bus
I_{max} - Maximum current carrying capacity of branch
I - Current through branch
NBr - Total number of branches
R - Resistance of branch
X - Reactance of branch
Z - Impedance of branch
Pd - Real power load
Qd - Reactive power load
Max(DV) - Maximum difference in voltage of node
$P_{m+1,}eff$ - Effective real power delivered beyond the node ‘m+1’
$Q_{m+1,}eff$ - Effective reactive power delivered beyond the node ‘m+1’
SE - Sending end node
RE - Receiving end node
N - Total number of nodes in RDS
$d_{attract}$ - Attractant depth
$w_{attract}$ - Attractant width
$h_{repellent}$ - Repellent effect height
$w_{repellent}$ - Repellent effect width

LIST OF ABBREVIATIONS

RDN - Radial Distribution Network
DG - Distributed Generation
CIGRE - International Council on Large Electric Systems
DPCA - Distributed Power Coalition of America
ENIRDG - European Network for Integration of Renewable Source and DG
GA - Genetic Algorithm
PSO - Particle Swarm Optimization
CAPSO - Centripetal Accelerated Particle Swarm Optimization
SIMBO-Q - Swine Influenza Model Based Optimization with Quarantine
BFOA - Bacterial Foraging Optimization Algorithm
TLBO - Teaching Learning Based Optimization
SA - Simulated Annealing
KHA - Krill Herd Algorithm
CSA - Common Scrambling Algorithm
LSF - Loss Sensitivity Factor
VSI - Voltage Stability Index
MINLP - Mixed Integer Nonlinear Programming
NR - Newton Raphson
FDNR - Fast Decoupled Newton Raphson
KCL - Kirchhoff's Current Law
KVL - Kirchhoff's Voltage Law
FWA - Fireworks Algorithm
HAS - Harmony Search Algorithm

ABSTRACT

The distribution system is mainly radial, in that type of systems the voltage at nodes decreases when moving towards consumer end and I^2R losses increase. Practical systems are becoming bulky and complicated which increase I^2R losses and reduce voltage of nodes. So 13% of the total power generated is used as I^2R losses. The best technique for power loss reduction in distribution systems is the DG installation, where the DG unitsare properly placed. The amount of power delivered hasbetter effects on the performance of the distribution system. The placement of a DG unit can form lots of advantages such as line losses minimization, stability improvement and voltage profile enhancement.

The main objective of this thesis work is to allocatethe suitable size of the multiple DG'sat appropriate location,which minimizes total line losses of the distribution network. Therefore, the Backward / Forward Sweep algorithm for power flow calculation technique is used to calculate line losses for the radial network and constant power loading condition.

In my thesis work, loss sensitivity factor is used to select the suitable location and bacterial foraging optimization is used to obtain the appropriate size of DG to minimize the line losses. The outcomes obtained by the proposed method have been compared with other techniques and tested with 69 node and 119 RDNs.

CHAPTER 1

INTRODUCTION

Power System is a combination of generation, transmission, distributed generation, subtransmission system and distribution network. The generation and transmission systems are known as “bulk power supply” and distributed generation, subtransmission system and distribution network are final way of relinquish electric energy to the consumer.

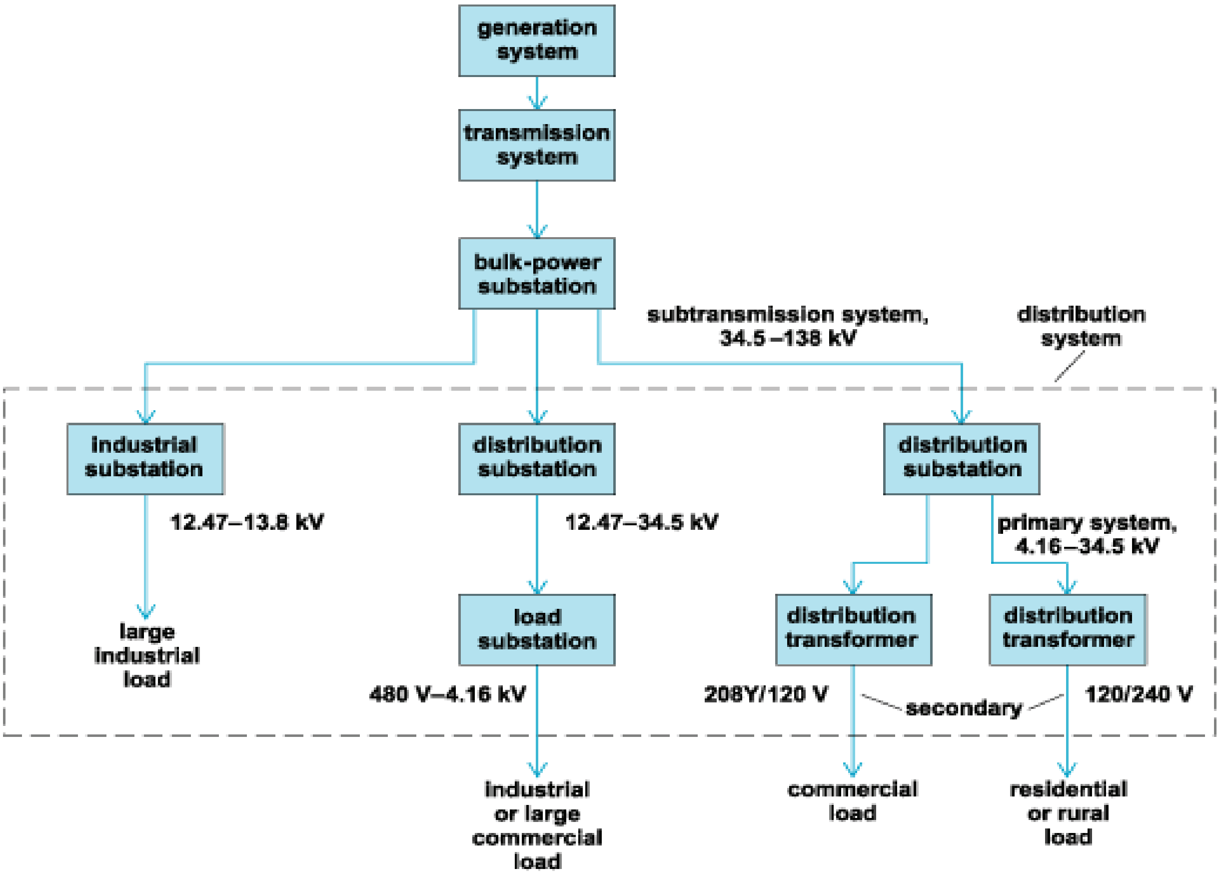

Fig.1.1 Schematic diagram of power system

The consumers take power through the distribution system. A distribution system generally has substation and sub-transmission. Substation usually situated at low voltage side of the transformer and close to the consumer center. Service mains are supplying power to consumers and connected to the secondary circuit.

1.1 Distribution System

A distribution system is a unit of the power system.Distribution system supplies electric power from the substation to consumers. It is further classified in following subparts as shown in Fig. 1.2.

1.1.1 Classification of Distribution System

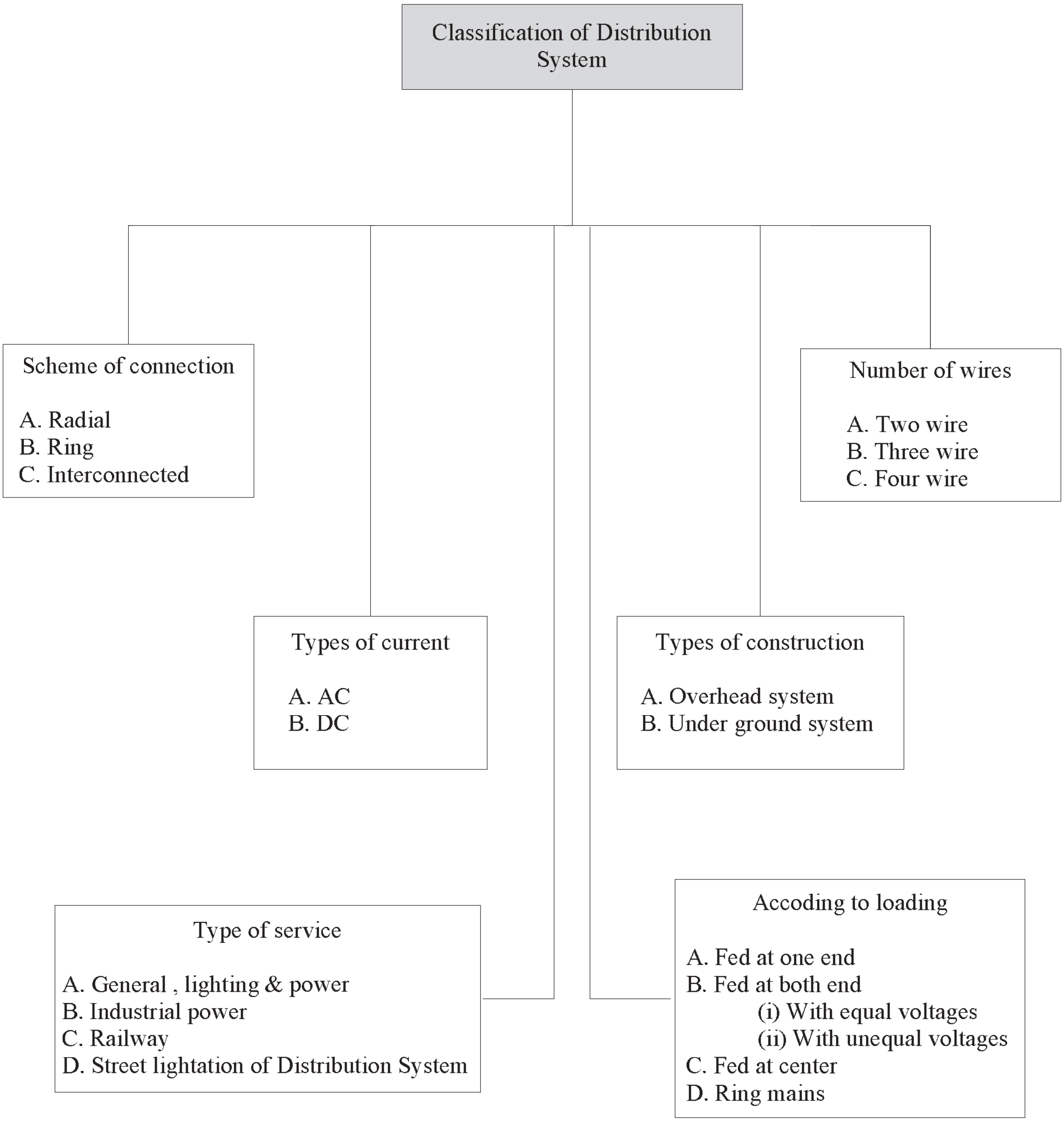

Fig.1.2 Flow chart for classification of distribution system

1.1.1.1 Scheme of connection

1.1.1.1.1 Radial distribution system

In this system substation to each area independent feeder radiates as represented by Fig. 1.3 and it feeds one end of a distributor only. So between each consumer and substation only one way for electric power flow. If any contingency occur in a system, which resultsthecomplete system collapse. This is used only where the substation is placed in the center and low voltage is generated. Theradial distribution system has simple design and low installation cost.

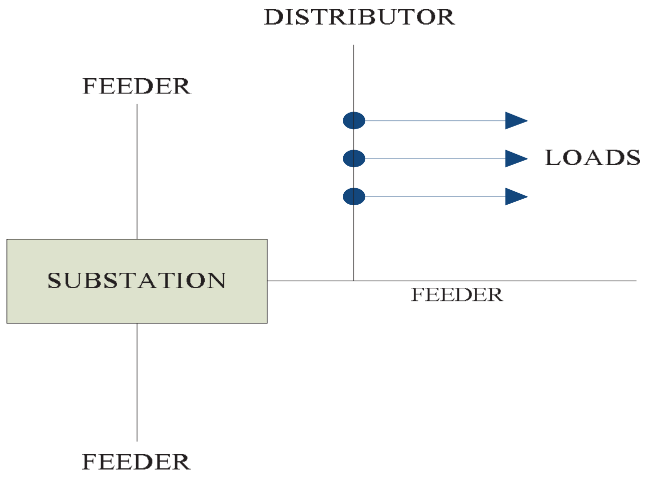

Fig.1.3 Radial distribution system

1.1.1.1.2 Ring distribution system

This consists of two or many paths for supplying electric power between substation and consumer represented in Fig. 1.4. This system forms a ring by connecting the line ends back to the substation, which is feeding to the consumers. The feeder is closed on itself. The advantage of this type of system is that it gives a better reliability of power supply and if any contingency occurs in any part of the feeder, the power supply can flow to all consumers by isolating the faulty part.

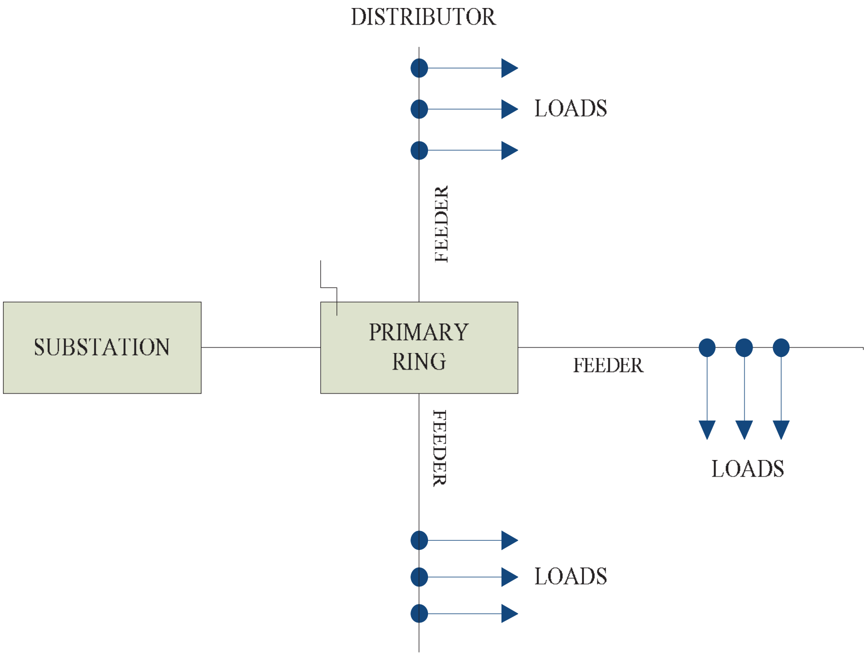

Fig.1.4 Ring distribution system

1.1.1.1.3 Interconnected distribution system

In this system the feeder ring is supplied by two or severalsubstations and radial feeders are tapped off from ring as presented in Fig. 1.5. The advantage of this type of system is that the losses are less, reliability of supply is high. Hencequality of service is improved.

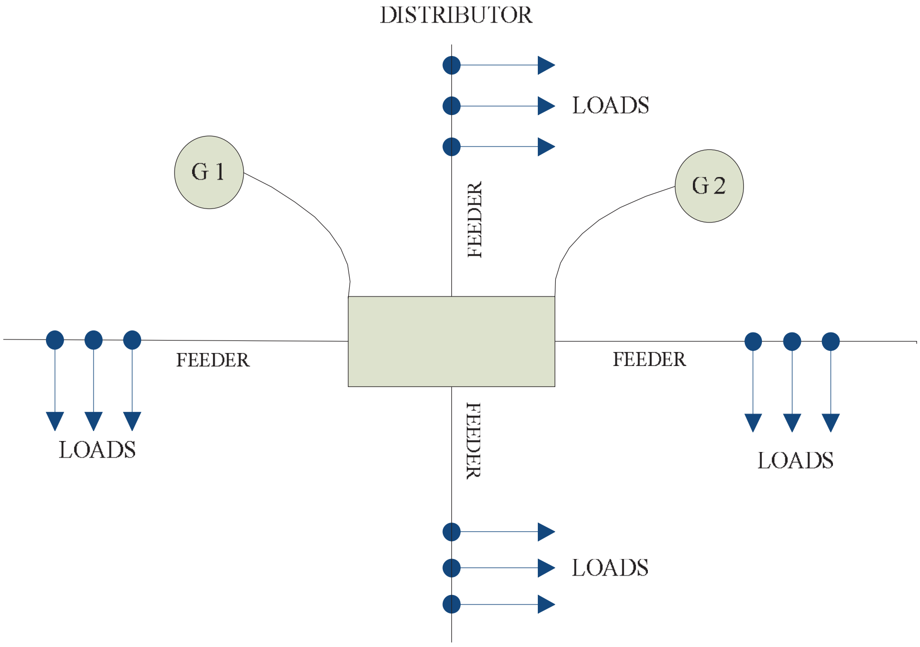

Fig.1.5 Interconnected distribution system

1.2 Distributed Generation

The ratio of distributed generators units in power systems is growing day by day in these years. In 2010 EPRI study gives results that 25 % of share in ageneration by DG units and Natural Gas Foundation also forecasts that 31 % of the new generation by DGs only in 2010. Even policies of countries are like to promote DG installation that indicates the number will increase very fast.

1.2.1 Definition of Distributed Generation

A many definitions of DG were presented by different organizations such as CIGRE, IEEE, IEA,DPCA etc. are:

CIGRE

"Distributed generation (or DG) generally refers to small-scale (typically 1 kW – 50 MW) electric power generators that produce electricity at a site close to customers or that are tied to an electric distribution system."

Or

US Department of Energy

"Distributed generation - small, modular electricity generators sited close to the customer load that can enable utilities to defer or eliminate costly investments in transmission and distribution (T&D) system upgrades, and provide customers with better quality, more reliable energy supplies and a cleaner environment."

Or

DPCA

"Distributed power generation is any small-scale power generation technology that provides electric power at a site closer to customers than central station generation. A distributed power unit can be connected directly to the consumer or to a utility's transmission or distribution system."

Or

ENIRDG

"Distributed Generation is a source of electric power connected to the distribution network or to the customer site."

1.2.2 Rating of DG:

Furthermore, in respect to the ratings of DG, the different definitions presented by different organizations are following:

1. Preston and Rastler
   "Ranging from a few kW to above 110 MW".
2. EPRI (Electric Power Research Institute)
   "A few kW up to 50 MW".
3. Cardell
   "Between 400 kW and 1.1 MW".
4. Gas Research Institute
   "Between 30 kW and 30 MW".

Table 1.1 Distributed Generation technologies rating [1]

Technology	Typical Rating
Biomass	100 kW–20 MW
Photovoltaic arrays	30 Watt–300 kW
Ocean energy	200 kW-2 MW
Solar thermal, central receiver	1–10 MW
Renewable Small hydro	1–100 MW
Fuel cells, phosacid	300 kW-3 MW
Combined cycle gas T	30-500 MW
Solar thermal	10–80 MW
Battery storage	400 kW-4 MW
Micro hydro	25 kW–1 MW
Fuel cells, proton exchange	10 kW–300 kW
Micro-Turbines	30 kW- 2 MW
Geothermal	10–200 MW
Wind turbine	100 Watt–3 MW
Fuel cells, solid oxide	150 kW–4 MW

1.2.3 Distributed Generator types:

Distributed generation can be categorized intothe following types:

DG I only injects real power to the system.

DG II only injects reactive power to the system.

DG IIIinjectsreal as well as reactive power to the system.

DG IVinjects real power but absorb reactive power from system.

1.2.4 Benefits of Distributed Generators:

DG provides many benefits on the distribution system, it reduces both cost and power losses. Allocation of DGs in a distribution network offers the following advantages.

- DG units can supply both active and reactive power, which enhances the voltage of buses and power factor. This decreasesthe number of capacitorrequired for loss compensation.
- In a RDN, DGs are placed closer to the consumer side that results in reduction transmission power. Itdecreases the transmission and distribution losses and due to which, cost related to power loss is reduced.
- Increase in load demand needs more amount of generation and that power demand couldbe fulfilled by installed DG units, without changing the conventional generating unit capacity.
- DGs are flexible devices. In DG installation geographical location and availability of resources are not major problems. So, they can be simply placed close to the consumer side rather than substation.
- DG gives the flexibility of placement in small and medium distribution networks because DG units are available in few kW to 15 MW capacity range.
- DG units can be started without using another electricity source that gives anadvantageinrestoring power to local area blackouts.

1.3 Literature Review:

Ackermann*et al.* [1] discussed a definition of distributed generation and relevant issue related to distributed power generation. They presented system and connection of DG issue too.

Furthermore, the distributed capacity, distributed utility and distributed resource terms had been also explained.

Acharya *et al.* [2]suggested a methodology for DG placementin distribution network. Appropriate DG size is computed by analytical expression and optimal site of DG is identifying by an effective methodology for total loss minimization. That proposed method also examined theconsequence of DG size and site with respect to total power losses in primary distribution network. That method was studied on three different distribution networks with variable size of DG. That approach also shows that the LSFwas used for identifying node not lead to thecorrect location of DG allocation.

Hossam and Al-Ammar [3] introduced the optimization problem of allocation of DG unit in RDN using GA. Three GA's were developed to decrease the active and reactive linelosses of RDNs.

Rao *et al.* [4] presented a method to explain distribution networkreconfigurationproblem in theexistence of DG using HSA. Loss sensitivity analysis was used for identifying locations of DG installation.

Moradi and Abedini[5] explained a hybrid GA-PSO technique to find best position and rating of DG in RDNs. The aim of research work was to decrease losses and increase the voltage profile. The hybrid technique performance examined on 33 node and 69 node RDNs.

Vijayabaskar and Manigandan [6] introduced a "Self-Adaptive Hybrid Differential Evolution Algorithm" in RDNs for sizing of FACTS devices and sensitivity factor for placement of FACTS devices to reduce the cost of RDN. The performance of proposed method was validated through 10 node, 34 node and 85 node RDNs.

Biju and Anitha [7] implemented a BFOA for reliability performance enhancement of RDN with DG. The main aim of proposed methodology contains (i) improvement of failure rates/repair time cost (ii) charge of power supply by DG. The proposed algorithm was tested on an 8 node RDN and results were analyzed with other techniques like DE, PSO and CAPSO.

Lee and Park [8]developed a selection of site and rating of multiple DG units in a distribution network. Selection of locations were done byusing power loss sensitivity and sizing of DG units were based on “Kalman Filter Algorithm” by using 10 KW step size. “Optimal Locator Index”was introduced for selecting an optimal location.

Seker *et al.* [9]performed DG-unit placement for improving voltage profile and decreasing loss by using ABC. In this method 33 node, 69 node and 119 nodetest networks were analyzed for performanceof ABC algorithm.

Injeti and Kumar [10] presented a novel methodology to identify suitable place and rating of several DG’s in different RDNs. The objective of presented methodology was line loss minimization. The effectiveness analysis was done on 33 node, 69 node and 118 node RDNs.

Sharma *et al.* [11] explained siting and sizing of distributed Generation to reduce line loss of RDN using SIMBO-Q. SIMBO-Q was used for finding optimal site and rating of DG unit. The explained approach was examined on 33 node RDN.

Devi and Geethanjali [12] proposed a method for find out the suitableposition and rating of DG and DSTATCOM with the help of PSO. The main aim of proposed method was to decrease total loss with voltage enhancement of RDN. The optimal location of DG and DSTATCOM was carried out with “Loss Sensitivity Factor”. That method was analysed on 12 node,34 node and 69 node RDNs.The proposed method shows that both DG and DSTATCOM decrease the real power loss same if install at same bus or not.

Devi and Geethanjali [13] proposed a new technique of modified BFOA for total losses reduction and improvement of voltage profile in radial networks. The aim of modified BFOA was to improve the performance of BFOA. To increase the performance of BFOA, a change was done in elimination and dispersal. That method of loss minimization was applied on 12 node, 34node and 69 node RDNs. The outcomes were compared with other methods and BFOA was found better in convergence.

Imran *et al.* [14] implemented a novel integration method (‘Fireworks algorithm’) for optimizing network problem and DG allocation in RDN. The objective of method was power loss and voltage stability. Simulations were applied on 33 node and 69 node RDNs at three different loading conditions.

Sultana and Roy [15] employed a TLBO technique in order to solve DG allocation problem. The objective of employed technique was to find the best location for DG placement and rating of DG. The employed technique was analyzed on 33 node, 69 node and 118 node RDNs and compared with PSO, GA and SA.

Imran and Kowsalya [16] proposed a methodto install DG unit and capacitor bank together in power distribution networks for loss reduction. DG units and capacitor installation location were selected by sensitivity analysis. BFOA was applied for DGs and capacitor size selection. Proposed method applied on 33 node RDN for different size of DGs and capacitor.

Kaur *et al.* [17] employed MINLP method for efficient employment of single and multiple Distributed generation units to inject active or together active and reactive power. The perfect sites for employment of DG units were found by sensitivity factor to reduce the computational memory.

Muttaqi *et al.* [18]addressed a novel method for governing Distributed Generation characteristics to support voltage profile of RDN by placing a DG unit of appropriate size, at best position. An algebraic method contained algebraic equations for governing the ideal operation, suitable rating and suitable position of the DG.

Kaur *et al.* [19] developed a "Harmony Search Algorithm"(HAS) and "Optimal Power Flow"(OPF) based hybrid approach for suitable connection of multiple DG units. The hybrid method was implemented for suitable allocation of one DG and several DG's capable of injecting real or reactive power or both.

Naik *et al.* [20] presented amethod for suitable place and suitable size of DG in RDN to reduce line losses. They derived analytical expression based on variations of branch currents due to DG allocation. In the proposed method suitable size of DG was determined by only base case load flow solution.

Murthy and Kumar [21] discussed a comparison of suitable DG placement methods in RDN using "Loss Sensitivity Approach". They presented sensitivity based, combined loss sensitivity based and modified novel approach for selection of DGs site. The results of all methods were verified on 33 node and 69 node RDN and compared at lagging and unity power factors.

Devabalaji and Ravi [22] implemented multiple DG and DSTATCOM in RDN using BFOA. "Loss Sensitivity Factor" (LSF) was used for determining theplace for DG and DSTATCOM installation. BFOA was used to determine the exact DG and DSTATCOM size. The implemented method was tested on 33 node and 119 nodeRDNs.

Pradeep *et al.* [23]suggested anappropriateplacement of both capacitor and DG units together for voltage profile enhancement. In this approach base load flow was done by "Forward/Backward Sweep Algorithm" on 33 node RDN.

Sasanka and Guntupalli [24]presented a scheme for connection of several DG units in distribution system for real and reactive loss reduction. A suitable location was selected by analytical approach and appropriate DG rating was determined by LSF and IA method.

Nguyen *et al.* [25] proposed a meta-heuristic CSA technique to optimize network problem and DG allocation in RDN. The main objective of proposed technique was to reduce power loss of the system. The performance of proposed technique was checked on three different RDNs.

Sultana and Roy [26] employed a "Krill Herd Algorithm"(KHA) technique to solve optimal DG placement in RDN. The simulation results of KHA was checked on 33 node, 69 node and 118 node RDNs and compared with existing algorithm like GA, PSO,GA/PSO and LSFSA.

Chakravorty and Das [27] presented a new "Voltage StabilityIndex" (VSI) for finding appropriate bus, which hadhigher chance of voltage collapse. They also showeda unique technique for load flow solution.

Passion [29] developed BFOA which included an overview of the methodology behind bacterial foraging .They also presented application and future scope of BFOA. The proposed algorithm was compared with GA.

Nasiraghdam [30] proposed a method for optimal DG sources allocation using BFOA. There was two main purposes of DG source allocation,these were first total power loss minimization and thesecond is reliability enhancement.

Ghasemi and Moshtagh [31] explained a distribution system reconfiguration for total line loss reduction and damage cost minimization due to power interruption in distribution system. They considered improvement in the reliability of system and increased benefits of distribution companies. In that proposed method new heuristic approach was used for reconfiguration.

Muthukumar *et al.* [32] applied shunt capacitor in RDNfor total power loss minimization using HSA. They injected reactive power by shunt capacitors. A backward/forward sweep technique was adopted for a load-flow solution. The proposed methodology had been examined on 22 node and 119 node RDNs.

Devabalaji*et al.* [33] introduced a scheduling for position and sizing of capacitor bank in RDN.In that proposed method main objective was loss minimization in RDNs. They used LSF and VSI techniques to determine the suitable position for allocation of capacitor bank and BFOA was applied to discover the appropriate size of capacitor bank. The proposed methodology tested on 85 node and 34 node RDNs and also applied on these networks with all available load changes. The simulation outcomes were compared with PSO, PGS and MINLP.

Abdelaziz *et al.* [34] proposed new and influential technique FPA for sizing and siting of capacitors in various radial networks. The location of capacitor installation is given by “Power Loss Index” (PLI). The applied methodology was examined on 15 node, 69 node and 118 node RDNs and results were compared with GA, PSO, TLBO, “Plant Growth Simulation Algorithm” (PGSA), “Direct Search Algorithm” (DSA) and HSA.

Ghosh and Das [35] formulated an efficient and easy technique for load-flow solution of RDN. The proposed technique had used only simple algebraic expression of receiving-end. Performance of that technique was demonstrated through three examples.

Augugliaro *et al.*[36] explained a backward /forward sweep methodology for weakly meshed or radial distribution system analysis. This method was very iterative and at everystage, by means of impedances loads were simulated.

Rana *et al.* [37] presented Backward/Forward sweep methodology for RDN. In backward sweep, KCL and KVL were used to find out the bus voltage from far away node of RDN. In Forward sweep, from generation end bus voltage was updated.

1.4 Research gap

Literature survey shows that there is still chance to find suitableplace and proper rating of DG units to be installed in RDN using BFO Algorithm by less computation time and less number of iterations.

1.5Aim of thesis work:

That work introduces a DG placement technique to enhance the node voltage and decrease thetotal real power loss of RDN using BFO algorithm. The main aim is to reduce total real power losses while maintaining the specified limit of the voltage of nodes in the network by installing suitable rating of DG Units in theRDNfor different loading conditions.

1.6 Organization of the thesis:

Chapter-1	This chapter presentsintroduction about distribution systems and distributed generation, literature review regarding the DG placement and sizing in distribution system, aim and organization of thesis.
Chapter-2	This chapter explains about objective function formulation and constraints of theproblem.
Chapter-3	This chapter explains a load-flow analysis technique for RDN. (Backward/Forward sweep method).
Chapter-4	This chapter explains a technique to identify suitable site of DG’s (LSF).
Chapter-5	This chapter explains a technique to decide suitable size of DG’s (BFOA).
Chapter-6	This chapter shows the results of 69 node and 119 node RDNs and comparison of proposed method with other techniques.
Chapter-7	This chapter presents conclusions of thesis work and Future Scope.
References	
Appendix-A	Shows the system data for 69 node and 119nodeRDNs.

CHAPTER 2

OBJECTIVE FUNCTION AND CONSTRAINTS

2.1 Objectivefunction

The aim of this thesis is to reduce the real line losses by injecting real power, i.e. placement of optimal DG, subjected to certain constraints specified in Eq.(2.1). Thus, the objective of thesis is stated as:

$$\text{Min (f)} = \text{Min } (P_{Loss}) \qquad (2.1)$$

Where

$$P_{Loss} = \sum_{i=1}^{NBr} |I(i)|^2 * R(i) \qquad (2.2)$$

NBr = No. of branches in RDN

I(i) = Current through branch-i

R(i) = Resistance of branch-i.

2.2 Constraints

The objective function presented in Eq. (2.1) has two constraints:

2.2.1 Equality constraints

Power constraints:

$$P_{Loss} + \sum P_{Di} = \sum P_{DGi} \qquad (2.3\ )$$

$$Q_{Loss} + \sum Q_{Di} = \sum Q_{DGi} \qquad (2.4)$$

where, P_{Loss} = Total real power losses

Q_{Loss} = Total reactive power losses

$\Sigma P_{D\mathrm{i}}$ = Total demand of real power

$\Sigma Q_{D\mathrm{i}}$ = Total demand of reactive power

ΣP_{DGi} = Total generated real power by DG

ΣQ_{DGi} = Total generated reactive power by DG.

2.2.2 Inequality constraints

Voltage constraints:

$$|\mathrm{V_{jmin}}| \geq |\mathrm{V_j}| \geq |\mathrm{V_{jmax}}|, \ \mathrm{j}= 1, 2, 3, \ldots\ldots., \mathrm{N} \quad (2.4)$$

where, N = Number of nodes in RDN

$\mathrm{V_j}$ = Voltage at bus ‘j’

$\mathrm{V_{jmin}}$ = Minimum voltage limit for bus ‘j’

$\mathrm{V_{jmax}}$ = Maximum voltage limit for bus ‘j’

Current constraints:

$$|\mathrm{I_j}| \leq |\mathrm{I_{jmax}}|, \mathrm{j}= 1, 2, 3, \ldots\ldots., \mathrm{N} \quad (2.5)$$

Where, $\mathrm{I_{jmax}}$ = Maximum current carrying capacity of branch-j

$\mathrm{I_j}$ = Current through branch-j.

CHAPTER 3

LOAD FLOW ANALYSIS

The load-flow solutionof the network functioning in thesteady state requires anoptimal approach,which is known as theload-flow study that gives voltage profile of nodes and the total line lossesof the network.In the present days, proper planning can be achieved by the appropriate load-flow study. The transmission system is a loop in shape because of this they have very high X/R ratio, whereas the distribution system is radial in shape having less X/R ratio. Therefore, distribution system variables are different compared to a transmission system for load flow. Because of very high R/X ratios of RDN conventional Gauss-Seidel, NR and FDNR load-flows are not capable of resolving such RDN.

Characteristics of distribution system are:
(i) Very high values of reactance and resistance
(ii) Number of branches, nodes and bus are large
(iii) Meshed or Radial in nature
(iv) Distributed and unbalanced loads.

3.1 Classification of loads

3.1.1 Constant current load

In a constant current type of load, the resistance varies as the voltage fluctuates to maintain the current constant.

3.1.2 Constant power load

In a constant power type of load, the resistance is varied to increase the current in the inverse ratio of load voltage. So voltage and current product are constant, which defines power.

3.1.3Constant impedance load

In an impedance type of load, voltage and current change in the proposition to maintain impedance fixed.

3.2Load-flow analysis methodology

A new methodology proposed by Ghosh and Das [35] for solving ill-conditioned RDNs,based on Forward/ Backward Sweep method is used. The proposed method includes only simple expression of algebraic equations of receiving-end voltages. This methodology is better than other methods and shows fast convergence performance.

In backwardsweep, KCL and KVL are employed to find the bus voltage from the far node. In the forward sweep, from source bus to downstream bus voltage is determined. The procedure repeats till convergence tolerance is less or equal to the divergence of the specified voltages at the nodes and the calculated voltage.Afterward real and reactive losses are calculated by updated bus voltage.

3.3Assumption

1. The 3-phase RDN is balanced in nature and converted in corresponding single line diagram.
2. Shunt capacitances has been neglected
3. Loads are considered as constant power load
4. All node voltages are flat

3.4Algorithm of load-flow analysis

Step 1 Read system data, IT number, Convergence factor (€)

Step 2 Set base MVA and base KV

Step 3 Calculate Zpu, Ppu and Qpu

Step 4 Assume flat voltage V(i)=1Pu for i=1,2,3,……,NB

Step 5 Node current loop: j=j+1

Step 6 Calculate node current form Backward sweep

$$\mathrm{Id(j)} = \frac{\mathrm{Pd(j) - iQd(j)}}{\mathrm{V(j)^*}} \text{for j=1,2,3,…….,NL} \qquad (3.1)$$

Step 7 If j < NBr, goto step 5

Step 8 Calculate branch current

$$\mathrm{Id(SE(j))} = \mathrm{Id(SE(j))} + \mathrm{I(j)} \qquad (3.2)$$

Step9 Voltage loop :k=k+1

Step 10 Update node voltage from Forward Sweep

$$\mathrm{V(RE(k)) = V(SE(k)) - I(k) * Zpu(k)} \tag{3.3}$$

Step 11 If k < NB , goto step 9

Step 12 Calculate absolute change in voltage

DV= V-Vspec

Step 13 IT=IT+1

Step 14 Chack Accuracy= max(DV)

Step 15 If € >1e-7 goto step 5

Otherwise goto step 12

Step 16 Calculate real power loss

$$\mathrm{Ploss(j) = I(j)^2 * R(j)} \tag{3.4}$$

Step 17 Calculate reactive power loss

$$\mathrm{Qloss(j) = I(j)^2 * X(j)} \tag{3.5}$$

Step 18 Stop

CHAPTER 4

SITING OF DG

A technique has been applied to recognize the appropriate buses for the allocation of DG units known as“Loss Sensitivity Factors”. The aim of this analysis is to identify the suitable node of DG units. Calculation ofloss sensitivity factor [33] is done for estimation of appropriate buses suitablefor placement of DG in the RDN.This reduces the computational time and decreases the search space for the optimization problem. Based on loss sensitivity analysis, topmost ranking nodes from the list are approved for DG placement in theRDN. The main principle ofLSFmethod is established on linearization of thenonlinear equation for the early effective node that benefits to decrease the count of iterations.

4.1 Loss Sensitivity Factor methodology

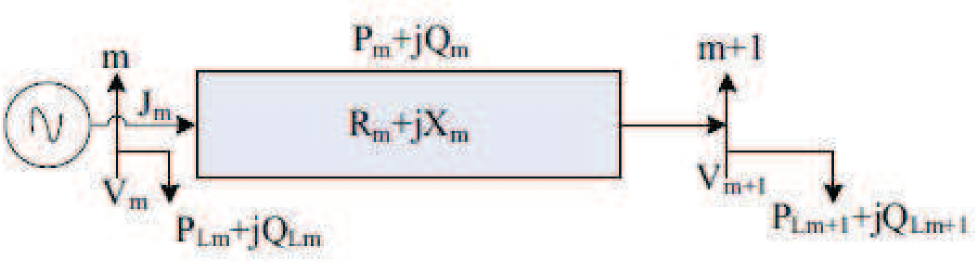

Fig.4.1 Line between ‘m’ and ‘m+1’ buses

The real line loss in the mth line is specified as

$$\text{Ploss}[m] = \frac{(P^2[m+1]+Q^2[m+1])R[m]}{V[m+1]^2} \tag{4.1}$$

Similarly for reactive line loss

$$\text{Qloss}[m] = \frac{(P^2[m+1]+Q^2[m+1])X[m]}{V[m+1]^2} \tag{4.2}$$

Now, the above Eq. (4.1) differentiated with respect to real power and reactive power respectively. So LSF is got as expressed below:

$$\frac{\partial \mathrm{Ploss[m,m+1]}}{\partial \mathrm{P}} = \frac{2*\mathrm{P[m+1],eff}*\mathrm{R[m]}}{|\mathrm{V[m+1]}|^2} \qquad (4.3)$$

$$\frac{\partial \mathrm{Ploss[m,m+1]}}{\partial \mathrm{Q}} = \frac{2*\mathrm{Q[m+1],eff}*\mathrm{R[m]}}{|\mathrm{V[m+1]}|^2} \qquad (4.4)$$

Where, $P_{m+1,}$eff = Effective realpowerdelivered beyond the node 'm+1'

$Q_{m+1,}$eff = Effective reactivepowerdelivered beyond the node 'm+1'.

The LSF ($\frac{\partial Ploss}{\partial Q}$) is evaluated using the load-flow solution and ranked in descendingorderto create priority list of nodes for DG allocation. A node matrix 'dlsf [m]' was used to upload the particular nodes of the system ranked in descending order of the LSF ($\frac{\partial Ploss}{\partial Q}$). The 'dlsf[m]' matrix concludes the order in which the system nodes are used for allocation. This order is only computed by the LSF ($\frac{\partial Ploss}{\partial Q}$) and the suggested 'LSF' method is very effectivein DG allocation. Nodesfrom the 'dlsf[m]' matrix and normalized voltage profile are governed by using the base case voltage profile (normV[m] = V[m]/0.95), for the nodes having normV[m] less than 1.01 are taken as the appropriatenodesfor the DG allocation. These nodes are placed in 'DG node' matrix. If the normV[m] at a node is greater than 1.01 such node not requires DG allocation. So 'normV[m]' 'decides nodes requiring DG allocation or not and LSF decide rank in which buses are to be considered for DG allocation.

4.2 Algorithm for siting of DG

Step 1 Run load-flow

Step 2 Calculate effective real and reactive power (Qm,eff) for j=1,2,3,…..,NB

Step 3 Loss sensitivity loop: j=j+1

Step 4 Calculate Loss Sensitivity Factor using Eq. (4.3) or Eq. (4.4)

Step 5 If $j<NB$, goto step 3
Otherwise goto step 6

Step 6 Arrange the loss sensitivity factors in descending order to create priority list.

Step 7 Identify the node which hasmaximum loss sensitivity factor from priority list and store that bus for DG installation.

Step 8 Stop

CHAPTER 5

SIZING OF DG

In distribution systems, appropriate size of DG plays a significant role in system power losses.Figure 5.1 shows the characteristics of RDN with respect to position and size of DG on system losses. Conclusion of Fig. 5.1 is that the high DG size value is not advisable because in starting losses will reduce with DG size but after certain point system exporting power beyond the substation, will increase system losses. Soallocation of the appropriate size of DG required.

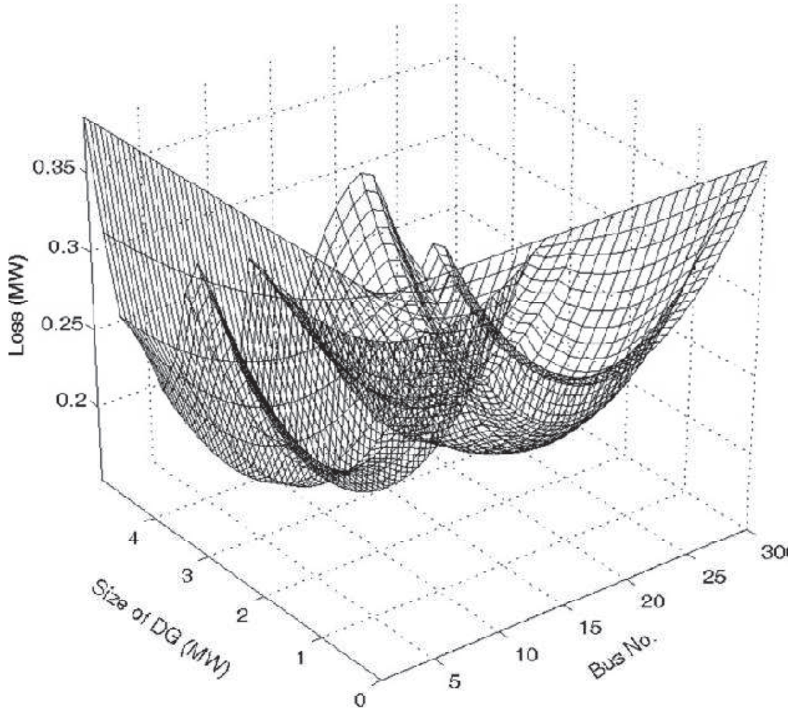

Fig.5.1 Effect of bus no. and size of DG on line losses[2]

For finding optimal size of DG many techniques are proposed like BFOA [13],FPA [14], CSA [25],HSA [19], MINLP [17],PSO [12], QOTL[15],ANN, GA [5], DSA [34], KHA [26],TS,and ABC [9]. In this thesis work optimal size of DG is selected by BFOA.

Thereasons behind selecting the BFOAareas follows:

1. The non-linearity or the system size doesn't matter in BFOA.
2. This algorithm provides satisfactory results in a number of areas and gives improved results, where most of the algorithmnot converges.
3. This algorithm required less run time and less computational memory.
4. This algorithm gives global convergence.
5. This algorithm can control many numbers of the objectives together.
6. This method gives bacteria with a plenty numbers of nutrients and also maintains same population size.

5.1 BFO Algorithm

BFOA is introduced by Kalvin passion in 2002 [29]. BFOA algorithm is nature encouraged optimization technique. This algorithm is built on aswarm of E.coli bacteria in multi-optimization function. In BFOA bacteria hunt for obtaining healthy food to maximizetheir energy (E) per unit time (T). Each bacterium also connects with other bacteria by sending messages. Hence, themain aim of BOFA is to maximize E/T function. Maximization of E/T function also gives nutrient energy to fight, survive and reproduce. This is due to of E.coli bacterium, which finds its healthy nutrient quicker than others to minimize line losses, cost minimization andto enhance the voltage profile.

BFOA theory is presented by following steps.

1. Chemotaxis:

Chemotaxis mimic the moment of an E.coli bacterium by tumbling and swimming. Swimming means bacteria travels in a predefined path and tumbling means bacteria travels in the random path.

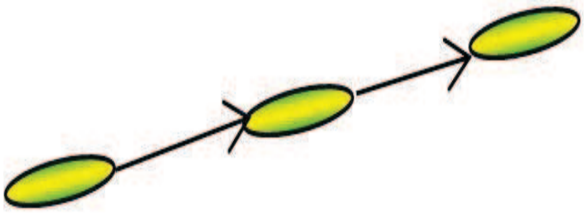

Fig.5.2 Swim of a bacterium

Tumble = (Random direction unit span x Bacteria step size)

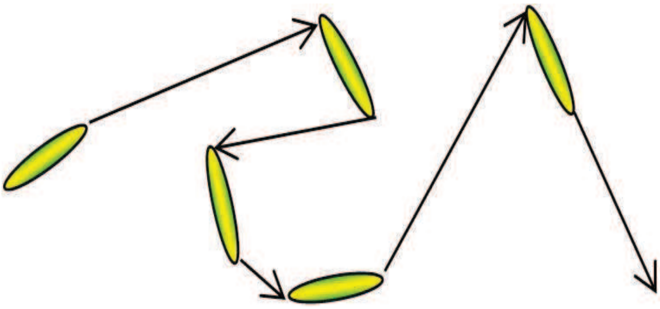

Fig.5.3 Tumble of a bacterium

In chemotaxis, the movement of bacterium is represented by

$$X^{n}(a+1,b,c) = X^{n}(a,b,c) + C(n)\frac{\Delta(n)}{\sqrt{\Delta^{T}(n)\Delta(n)}} \tag{5.1}$$

Where $\Delta(n)$ is random direction vector between [-1, 1]

2. Swarming:

This step combines a number of E.coli bacteria, which move towards healthy nutrient in a concentric shape through a large density of bacteria.

3. Reproduction:

The novel group of E-coli bacterium goes through different steps of chemotaxis and reaches the reproduction step. E-coli bacterium getsseparatedinto two sets. The healthier set will remain as it is and the minimum healthy set will die. The better bacteria separated into two bacteria, which sited in the unchangedsite of eliminated bacteria. So at the end bacteria population remain constant.

4. Elimination and dispersal:

Due to particular effect, bacteria in the nearest environment are died or removed and at random location dispersal the same number of bacteria in order to maintain a constant population. This process is called elimination and dispersal. This improves the strength of global optimization. The elimination process is done in BFOA with Ped probability.

5.2 Algorithm for sizing of DG

Step1 Initialization of the parameters

P: Optimization variable numbers

S: Number of bacteria

Nc: Chemotactic stages

Ns: Span of swimming

Nre: Reproduction stages

Ned: Number of elimination dispersal incident

C: The size of step deviations in arbitrary path

N: The number of iteration

Ped: Elimination dispersal event probability

X: Assign DG size

Step 2 Iteration loop: P=P+1

Step3 Elimination-dispersal loop: c=c+1

Step 4 Reproduction loop: b=b+1

Step 5 Chemotactic loop: a=a+1

For bacteria n chemotactic steps as follows where n=1,2,3,…..,S

(a) Calculate the fitness function J(n,a,b,c).

Let $$\mathrm{J(n,a,b,c) = J(n,a,b,c) + Jcc(Xn(a,b,c), P(a,b,c)} \quad (5.2)$$

Where $\mathrm{Jcc(X, P(a,b,c) = \sum_{n=1}^{S} Jcc(X, X(a,b,c)}$

$$= \sum_{n=1}^{S} \left[-\mathrm{d_{attract}} \exp\left(-\mathrm{w_{attract}} \sum_{m=1}^{p} \theta_m - \theta_m^n\right)^2\right] + \sum_{n=1}^{S} \left[\mathrm{h_{repellent}} \exp\left(-\mathrm{w_{repellent}} \sum_{m=1}^{p} \theta_m - \theta_m^n\right)^2\right] \quad (5.3)$$

Where $\mathrm{d_{attract}}$ = Attractant depth
$\mathrm{w_{attract}}$ = Attractant width
$\mathrm{h_{repellent}}$ = Repellent effect height
$\mathrm{w_{repellent}}$ = Repellent effect width

(b) Let $\mathrm{J_{last}}$= J(n,a,b,c) to store this computed cost then the improved cost can be computed by a run.

(c) Tumble: It will create a arbitrary matrix Δ(n) for all element m(n) where m=1,2,3,….,P.

(d) Move: Let $\mathrm{X}^n\mathrm{(a+1,b,c) = X}^n\mathrm{(a,b,c) + C(n)}\frac{\Delta(\mathrm{n})}{\sqrt{\Delta^{\mathrm{T}}(\mathrm{n})\Delta(\mathrm{n})}}$ (5.4)

This will give the C(n) result in which direction bacteria n will tumble

(e) Compute J(n,a+1,b,c)

(f) Swim :

(i) Initialize swim count m=0

(ii) Swim loop m=m+1

(iii) If J(n,a+1,b,c) < Jlast

Store Jlast = J(n,a+1,b,c) and move X(a+1,b,c)

(iv) If $m < Ns$ goto step (ii)

Otherwise end the swim loop

(g) If $n < S$ then increase bacterium count $n=n+1$

Step 6 If a less than Nc,thenswitch to step 5

Step 7 Reproduction:

The 1/2 bacterial, which has maximum J values, will die and the 1/2 bacterial, which have finest values, split and sited at unchanged position.

Step 8 If b less than Nre then switch to step 4.

Step 9 Elimination-dispersal:

Elimination and dispersal of every bacterium for $n=1, 2, 3,\ldots,S$ with Ped on random location is such that bacterium maintains thesame population even after elimination and dispersion.

Step 10 If $c < Ned$, go to step 3.

Else stop the loop

Step 11 If $P< N$ then go to step 2.

Else stop the loop

Step 12 Calculate the total power loss with the best bacterium. Find the final bacterium, which gives minimum total power loss. Final bacterium gives optimal DG size.

Step 13 Using appropriate DG sizerun the load-flow and compute total line loss.

Step 14 Stop

CHAPTER 6

RESULTS

In this chapter performance analysis of multiple DG allocation of various types are presented and compared with existing research works. The proposed technique is executed on 69 node and 119 nodeRDNs. MATLAB platform has been used for development of load flow, for finding power losses and to obtained DG best location and size.

6.1 69 node RDN

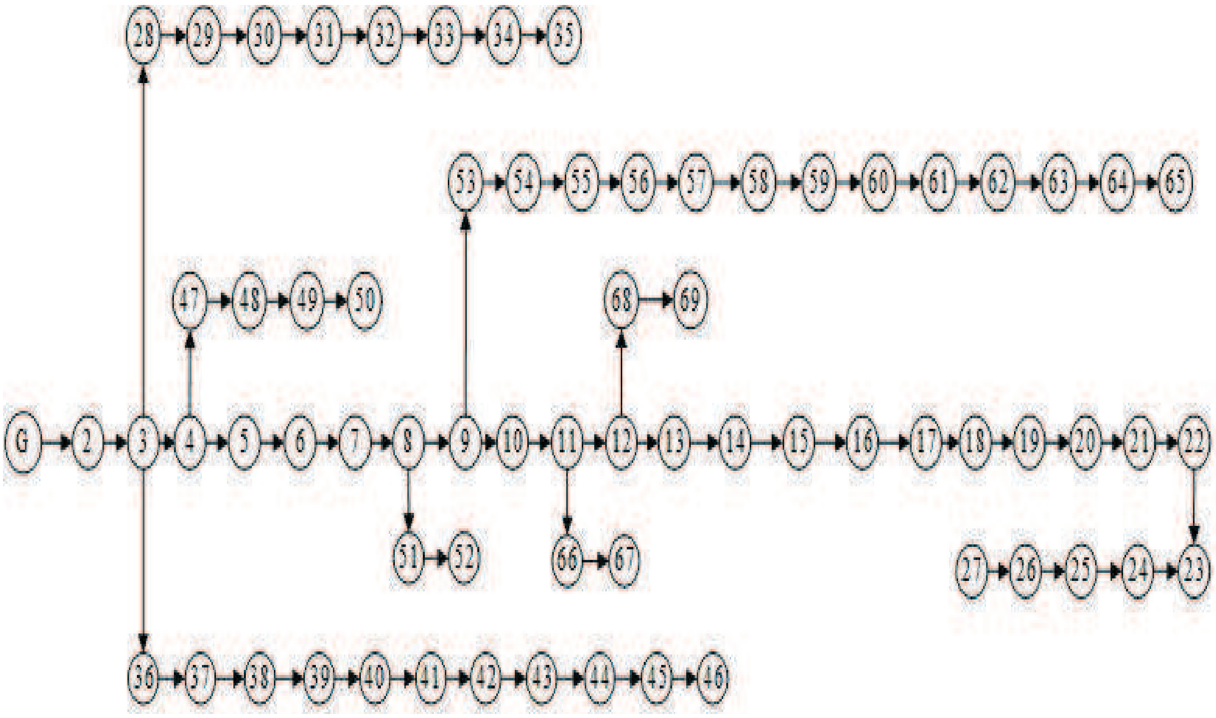

Fig.6.1 The schematic figure of the 69 node RDN

In this proposed methodology, 69 node RDN shown in Fig. 6.1 is selected. This RDN has 68 branches and 69 nodes. The base voltage and base power oftest system is 12.66 kV and 100 MVA respectively. The test system data is given in [39]. In Table 6.1, the results of best location, DG size, real and reactive line losses, percentage loss reduction, least voltage and bus number are presented for single DG, double DG and three DG. The base case real power loss is 0.2249 MW and after single DG, double DG's, three DG's allocation real line losses are 0.0832 MW, 0.0725 MW and 0.06958 MW respectively. The best locations for DG allocation are 61, 12 and 21. In Table 6.2, the performance of applied methodology is analyzed with GA [5], PSO [5], SA [10], ACSA [25], FWA [14] and HAS [4]. In Table 6.3, Table 6.4 and Table 6.5, the multiple DG allocation of different DG types for 50%, 75% and 100% loading conditions are presented respectively. Figure 6.3, Fig. 6.4 and Fig. 6.5 show comparison in voltage profile of different types of DG's for 50%, 75% and 100% loading conditions respectively, where 100% loading is the normal loading.

Table 6.1 Results of multiple DG allocation for 69 node RDN

	Base Case	Single DG	2 DG	3 DG
DG Size (node) (MW)	-	1.879(61)	1.735(61) 0.813(12)	1.734(61) 0.498(12) 0.312(21)
Ploss (kW)	224.9804	83.21	72.51	69.58
Qloss(kVAr)	102.1562	40.52	36.02	35.05
% reduction in Ploss	-	63.01%	67.77%	69.07%
Vmin (p.u) (node)	0.9092(65)	0.9684(27)	0.9790(65)	0.9789(65)

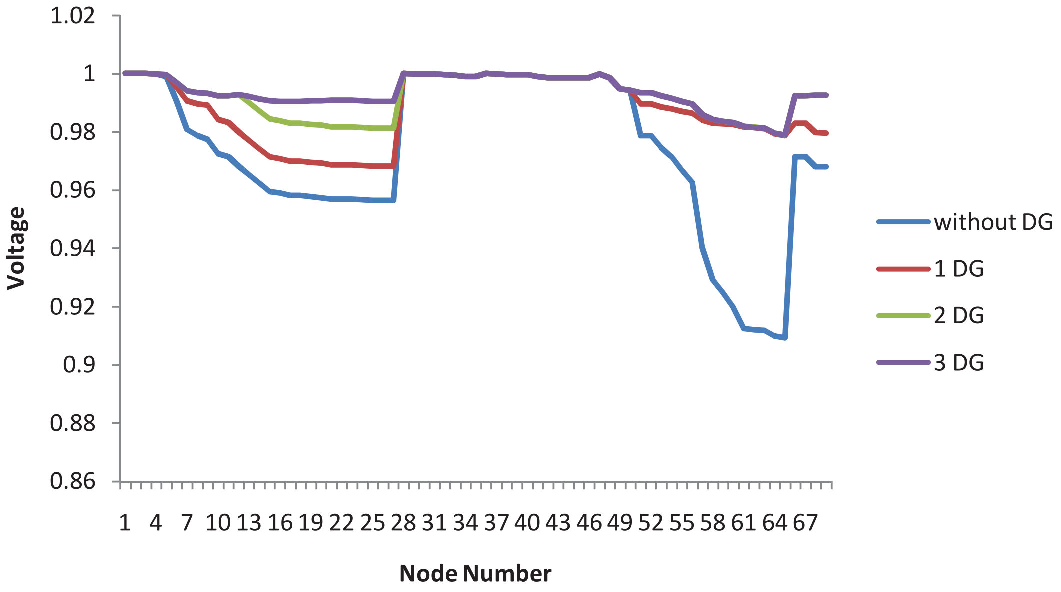

Fig.6.2Voltage profile for 69 node RDN.

Table 6.2 Comparison of results with other methods for 69 node system.

Method	TPloss (kW)	% Loss reduction	Vmin (p.u) (node)	DG location	DG size (MW)
GA [5]	89.00	60.44	0.9936(57)	21	0.9297
				62	1.0752
				64	0.9925
PSO [5]	83.20	63.02	0.9901(65)	61	1.1998
				63	0.7956
				17	0.9925
GA/PSO [5]	81.10	63.95	0.9925(65)	63	0.8849
				61	1.1926
				21	0.9105
SA [10]	77.10	65.73	0.9811(61)	18	0.4204
				60	1.3311
				65	0.4298
ACSA[25]	72.44	67.79	0.9890(65)	11	0.6022
				18	0.3804
				61	2.0000
FWA [14]	77.85	65.39	0.9740(62)	65	0.4085
				61	1.1986
				27	0.2258
HAS [4]	86.77	61.43	0.9677(26)	65	0.1018
				64	0.3690
				63	1.3024
Proposed BFOA	69.58	69.07	0.9789(65)	61	1.7340
				12	0.4969
				21	0.3107

Table 6.3 Performance analysis for different types of multiple DG's in 69-bus system at 50% load condition

	Without DG	DG I	DG II	DG III
DG size in MW (node)	-	0.336(12) 0.162(21) 0.838(61)	-	0.281(12) 0.139(21) 0.838(61)
DG size in MVAr (node)	-	-	0.156(12) 0.110(21) 0.613(61)	0.170(12) 0.102(21) 0.603(61)
Ploss(kW)	51.60	17.08	34.08	1.11
Qloss(kVAr)	23.54	8.60	15.97	1.70
Vmin (p.u.)(node)	0.9567(65)	0.9893(65)	0.9666(65)	0.9971(50)
% Ploss reduction	-	92.40%	84.85%	99.50%

Fig.6.3 presents the graph of voltage profile vs node number without DG allocation and different type of DG's allocation at 50% load condition.

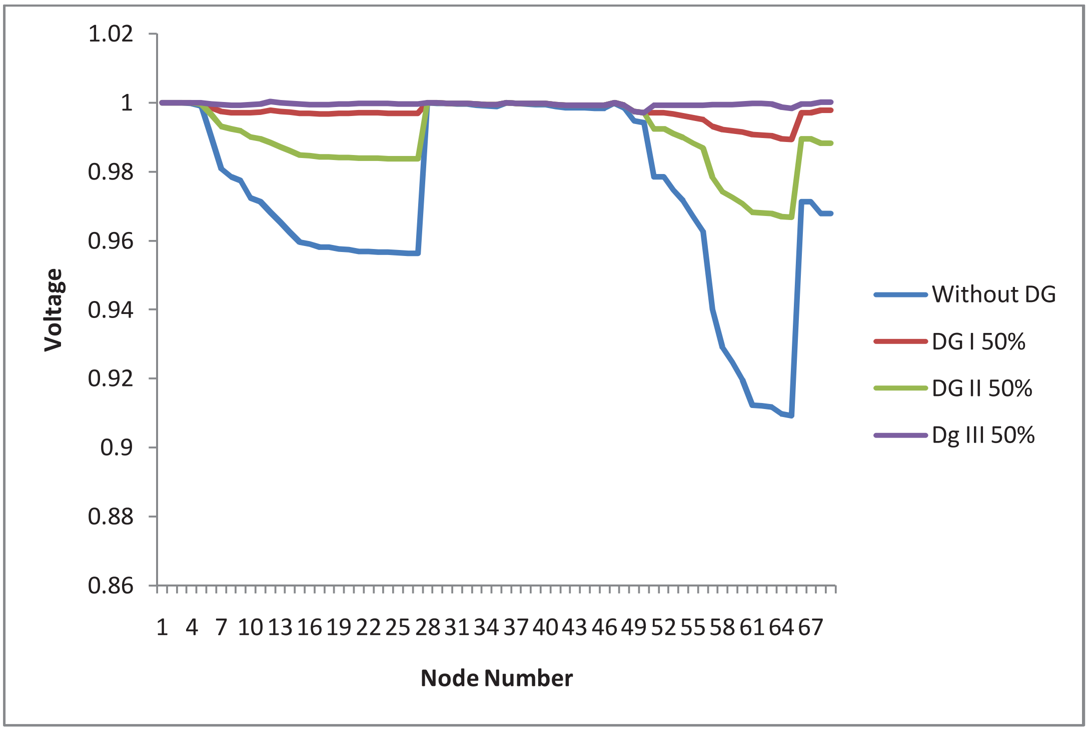

Fig.6.3 Comparison of voltage profile vs node number at 50% loading

Table 6.4 Performance analysis for different types of multiple DG's in 69 node system at 75% load condition

	Without DG	DG I	DG II	DG III
DG size in MW (node)	-	0.359(12) 0.242(21) 1.292(61)	-	0.387(12) 0.201(21) 1.263(61)
DG size in MVAr (node)	-	-	0.230(12) 0.170(21) 0.930(61)	0.263(12) 0.151(21) 0.903(61)
Ploss(kW)	121.0192	38.77	79.08	2.50
Qloss(kVAr)	55.0933	19.55	36.97	3.85
Vmin (p.u.)(node)	0.9335(65)	0.9841(65)	0.9493(65)	0.9957(50)
% Ploss reduction	-	82.76%	64.85%	98.89%

Fig.6.4 presents the graph of voltage profile vs node number without DG allocation and different type of DG's allocation at 75% load condition.

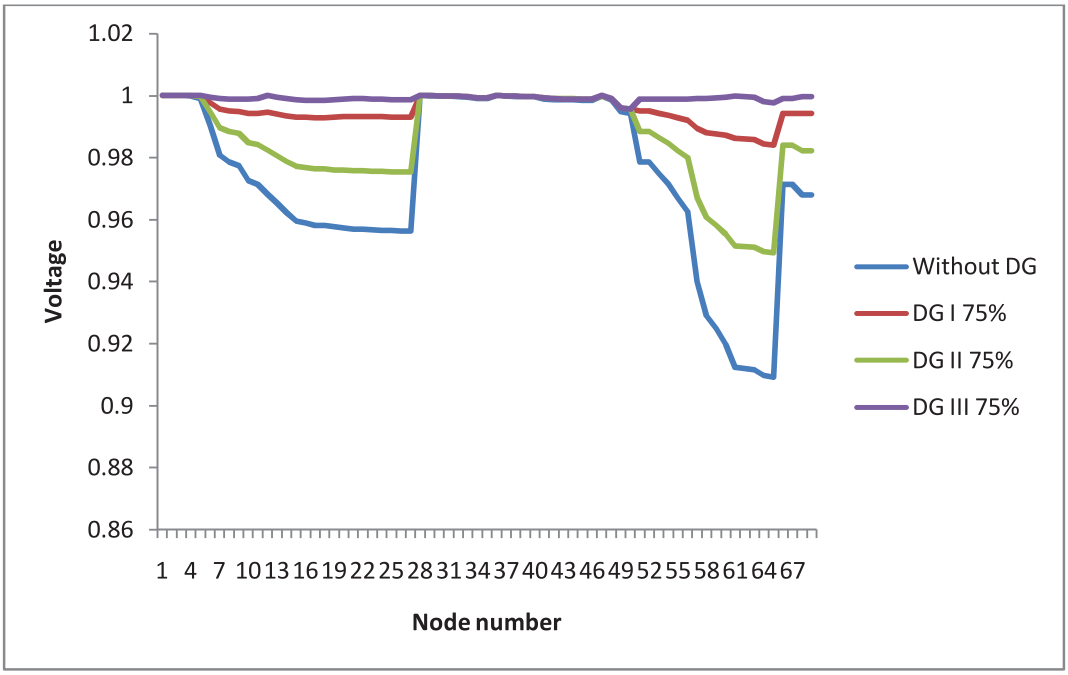

Fig.6.4 Comparison of voltage profile vs node number at 75% loading

Table 6.5 Performance analysis for different types of multiple DG's in 69 node system at 100% load condition

	Without DG	DG I	DG II	DG III
DG size in MW (node)	-	0.498(12) 0.312(21) 1.734(61)	-	0.546(12) 0.242(21) 1.692(61)
DG size in MVAr (node)	-	-	0.370(12) 0.204(21) 1.242(61)	0.340(12) 0.200(21) 1.202(61)
Ploss(kW)	224.9804	69.58	145.20	4.53
Qloss(kVAr)	102.1562	35.05	67.70	6.89
Vmin (p.u.)(node)	0.9092(65)	0.9789(65)	0.9313(65)	0.9943(50)
% Ploss reduction	-	69.07%	35.46%	97.98%

Fig.6.5 presents the graph of voltage profile vs node number without DG allocation and different type of DG's allocation at 100% load condition.

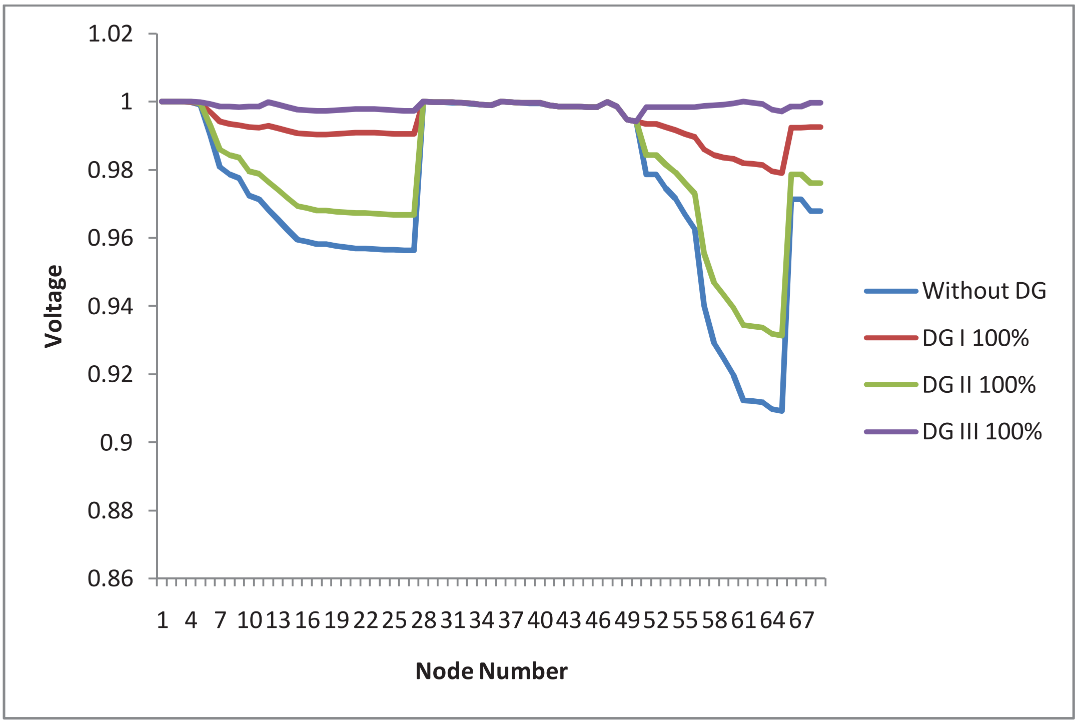

Fig.6.5 Comparison of voltage profile vs node number at 100% loading

6.2 119 node RDN

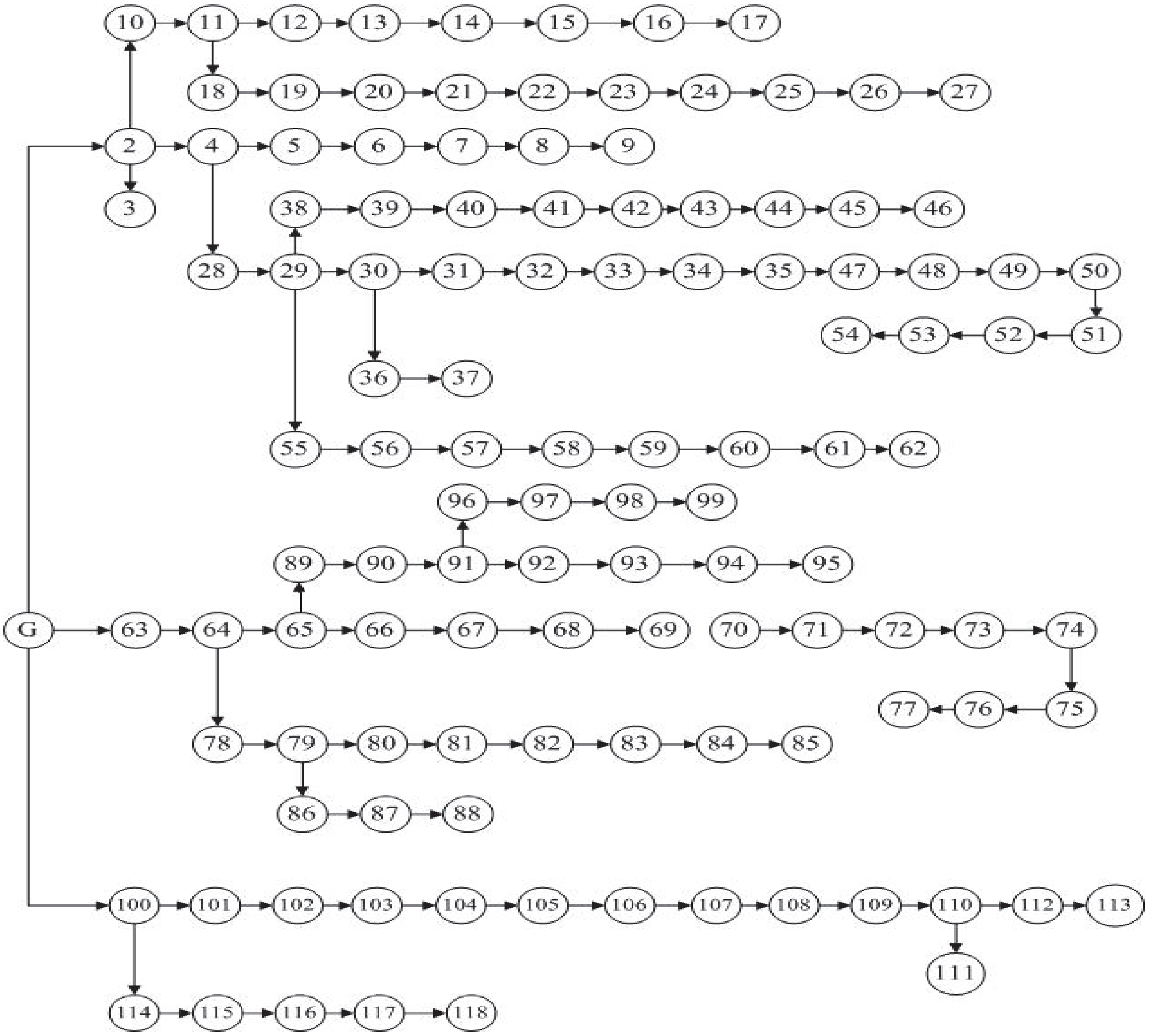

Fig.6.6 The schematic figure of the 119 node RDN

In this proposed methodology, 119 node RDN shown in Fig 6.6 is selected. This RDN has 117 branches and 118 nodes. The base voltage and base power of test system is 11.00 kV and 100 kVA respectively. The test system data is given in [28]. In Table 6.6, the results of best location, DG size, active and reactive line losses, percentage loss reduction, least voltage and bus number are presented for single DG, double DG and three DG. The base case real power losses are 1.2981 MW and after single DG, double DG's, three DG's allocation real power losses are 1.0168 MW, 0.8124 MW and 0.6745 MW respectively. The best locations for DG allocation are 71, 111 and 50. In Table 6.7, the performance of proposed methodology is compared with SA [10], QTLBO [15] and KHA [26]. In Table 6.8, Table 6.9 and Table 6.10, the multiple DG allocation of different DG types for 50%, 75% and 100% loading conditions are presented respectively. Figure 6.7, Fig. 6.8 and Fig. 6.9 show analysis in voltage profile of different types of DG's for 50%, 75% and 100% loading conditions respectively, where 100% loading is normal loading.

Table 6.6 Results of multiple DG allocation for 119 node RDN.

	Base Case	Single DG	2 DG	3 DG
DG Size in MW (node)	-	2.930(71)	2.980(71) 2.660(111)	2.980(71) 2.655(111) 2.884(50)
Ploss (kW)	1298.10	1016.8	812.48	674.52
% reduction in Ploss	-	21.67%	37.41%	48.03%
Vmin (p.u) (node)	0.8688(77)	0.9053(111)	0.9095(118)	0.9545(99)

Table 6.7 Comparison of results with other methods for 119 node system.

Method	TPloss (kW)	% Loss reduction	Vmin (p.u) (node)	DG location (node)	DG size (MW)
SA [10]	858.81	33.84	0.9190(54)	36 56 75 103 116	4.5353 1.1329 2.1318 4.9452 0.7501
QTLBO [15]	581.40	55.21	-	49 72 82 91 109	3.0135 2.5435 1.6655 1.7662 3.1376
KHA [26]	576.46	55.59	0.9558(53)	50 74 81 96 110	2.8720 2.4340 1.8113 1.6900 2.8796
Proposed BFOA	574.65	55.70	0.9541(54)	50 72 80 96 109	2.8815 2.5420 2.1030 1.6613 3.1188

Table 6.8 Performance analysis for different types of multiple DG's in 119 node system at 50% load condition

	Without DG	DG I	DG II	DG III
DG Size in MW (node)	-	1.431(50) 1.242(72) 1.033(80) 0.861(96) 1.518(109)	-	1.427(50) 1.230(72) 1.028(80) 0.814(96) 1.507(109)
DG Size inMVAr (node)	-	-	1.291(50) 0.810(72) 0.802(80) 0.535(96) 1.249(109)	1.287(50) 0.785(72) 0.779(80) 0.525(96) 1.242(109)
Ploss(kW)	297.14	138.77	203.65	52.64
Qloss(kVAr)	225.22	104.43	152.44	37.07
Vmin (p.u.)(node)	0.9385(77)	0.9775(54)	0.9560(77)	0.9807(46)
% Ploss reduction	-	52.30%	31.46%	82.28%

Fig.6.7 presents the graph of voltage profile vs node number without DG allocation and different type of DG's allocation in 119 bus RDN at 50% load condition.

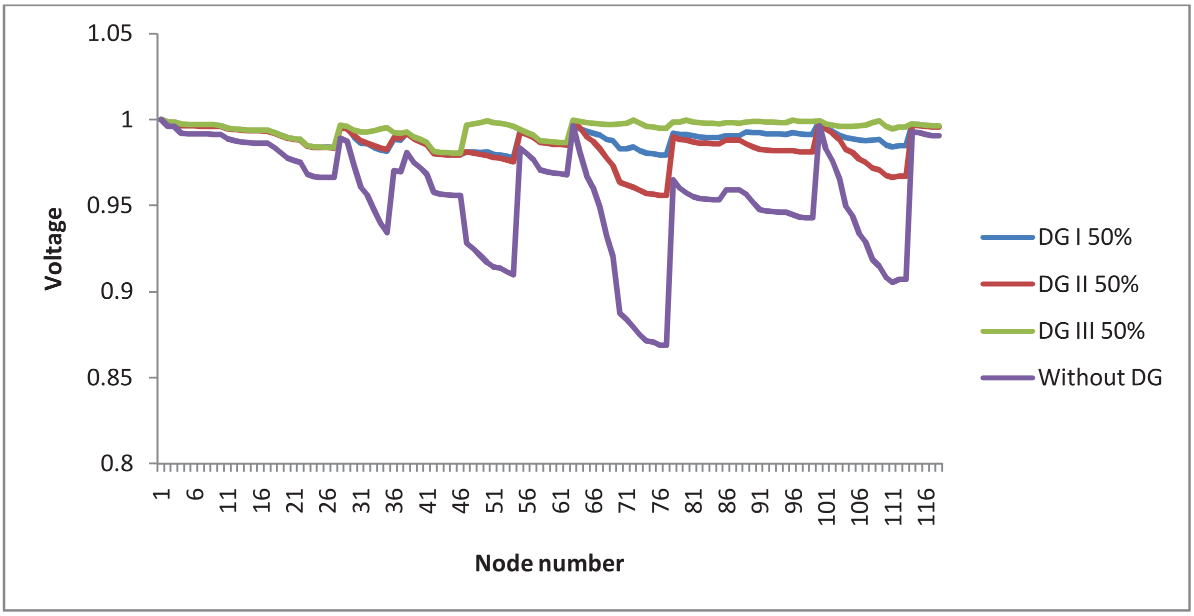

Fig.6.7 Comparison of voltage profile vs node number at 50% loading

Table 6.9 Performance analysis for different types of multiple DG's in 119 node system at 75% load condition

	Without DG	DG I	DG II	DG III
DG size in MW (node)	-	2.151(50) 1.882(72) 1.563(80) 1.241(96) 2.138(109)	-	2.147(50) 1.850(72) 1.548(80) 1.224(96) 2.267(109)
DG size in MVAr (node)	-	-	1.947(50) 1.230(72) 1.222(80) 0.815(96) 1.884(109)	1.930(50) 1.195(72) 1.179(80) 0.785(96) 1.862(109)
Ploss(kW)	697.32	317.58	471.63	119.56
Qloss(kVAr)	527.25	238.98	352.22	84.18
Vmin (p.u.)(node)	0.9049(77)	0.9659(54)	0.9327(77)	0.9708(46)
% Ploss reduction	-	54.45%	32.37%	82.85%

Fig.6.8 presents the graph of voltage profile vs node number without DG allocation and different type of DG's allocation in 119 node RDN at 75% load condition.

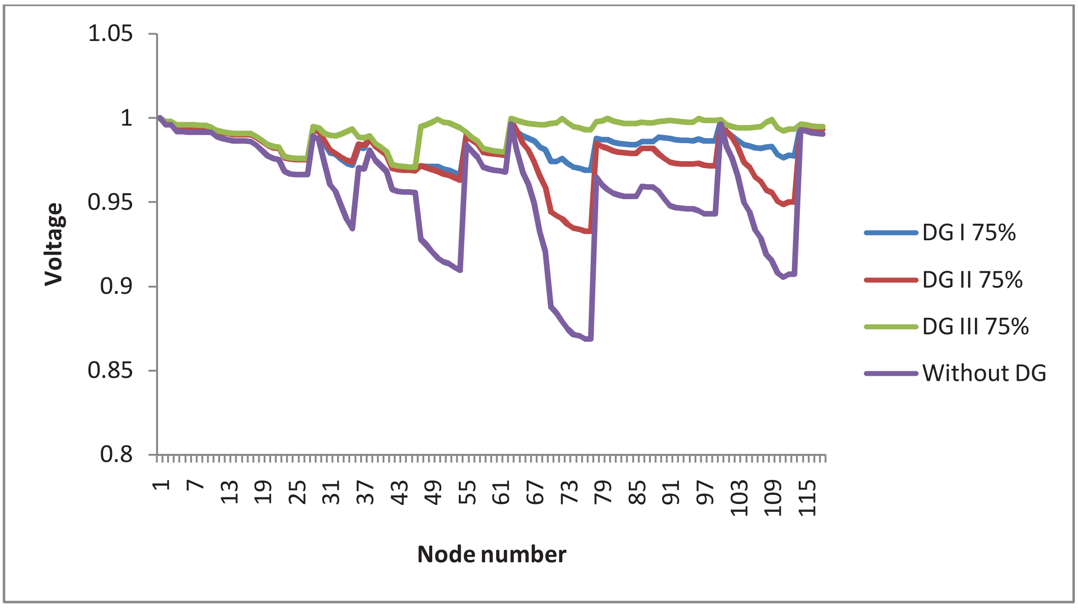

Fig.6.8 Comparison of voltage profile vs node number at 75% loading

Table 6.10 Performance analysis for different types of multiple DG's in 119 node system at 100% load condition

	Without DG	DG I	DG II	DG III
DG size in MW (node)	-	2.881(50) 2.542(72) 2.103(80) 1.661(96) 3.118(109)	-	2.870(50) 2.479(72) 2.068(80) 1.629(96) 3.039(109)
DG size in MVAr (node)	-	-	2.610(50) 1.669(72) 1.658(80) 1.109(96) 2.529(109)	2.590(50) 1.589(72) 1.568(80) 1.049(96) 2.489(109)
Ploss (kW)	1298.10	574.65	864.57	214.59
Qloss (kVAr)	978.73	432.37	644.02	151.01
Vmin (p.u.)(node)	0.8688(77)	0.9541(54)	0.9085(77)	0.9607(46)
% Ploss reduction	-	55.73%	33.39%	83.46%

Fig.6.9 presents the graph of voltage profile vs node number without DG allocation and different type of DG's allocation in 119 node RDN at 100% load condition.

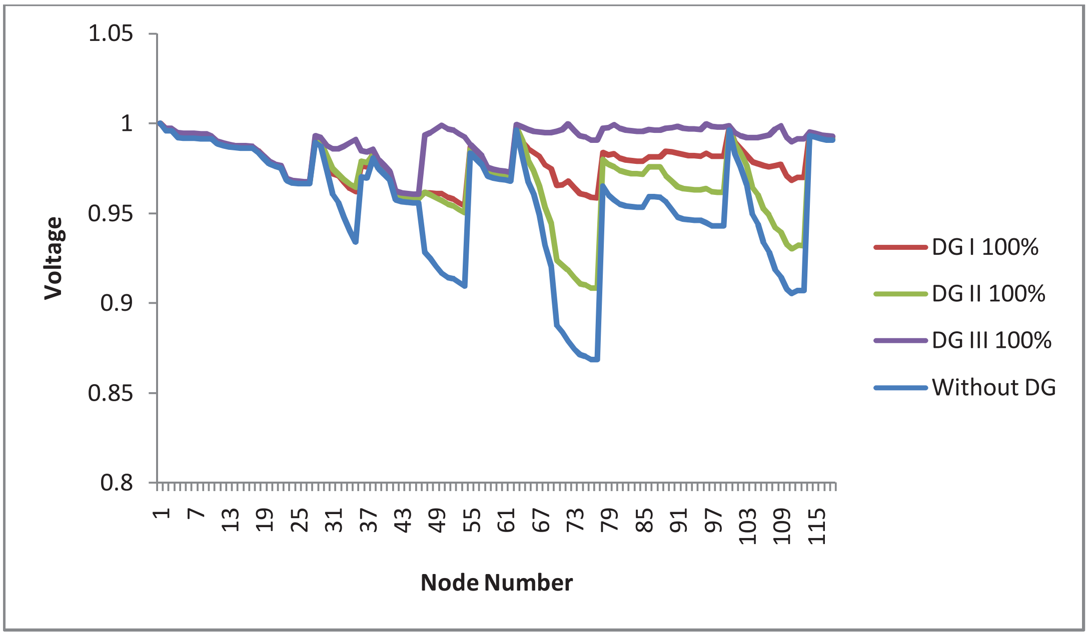

Fig.6.9 Comparison of voltage profile vs node number at 100% loading

CHAPTER 7

CONCLUSIONS AND FUTURE SCOPE

7.1 Conclusion

The objective of thesis is to reducethe net real power lossesusing several DG units placement with constant power loadand different loading condition in a balanced RDN. The objective was achieved by identifying different suitable locations for DG units allocation with the use of LSF and determination of appropriate DG size using BFOA. The obtained results thus show that allocation of multiple DG units in respect to allocation of single DG unit can reduce more power loss. The performance of proposed methodology wasverified on 69 node and 119 node RDNs with different loading conditions and outcomes obtained were compared with other techniques was found to be more effective. A coding scheme was developed in MATLAB.

7.2 Future scope

The conclusion of thesis work gives the following possibility in associated areas.

1. The DG placement will be protracted from balanced network to unbalanced distribution network.
2. The optimal DG and DSTATCOM units together can be placed using hybrid algorithm, which will be give better performance.

LIST OF PUBLICATIONS

1. Gaurav Somani and Smarajit Ghosh, “A Review on Distributed Generation Allocation in Radial Distribution System”, Communicated to International Journal of Scientific Research and Education.

REFERENCES

---

[1] Ackermann T, Andersson G, Soder L: Distributed generation: a definition. Electric power systems research, DOI:10.1016/S0378-7796(01)00101-8, 57:195–204, 2001.

[2] Acharya N, Mahat P, Mithulananthn N: An analytical approach for DG allocation in primary distribution network. Electrical power and energy systems, DOI:10.1016/j.ijepes.2006.02.013, 28:669-678, 2006.

[3] Talaat HEA, Al-Ammar E: Optimal allocation and sizing of Distributed Generation in distribution networks using Genetic Algorithms. Electrical Power Quality and Utilization, DOI:10.1109/EPQU.2011.6128840, October 19, 2011.

[4] Rao RS, Ravindra K, Satish K, Narasimham SVL: Power loss minimization in distribution system using network reconfiguration in the presence of Distributed Generation. IEEE Transactions on Power Systems, DOI:10.1109/TPWRS.2012.2197227, May 30, 2012.

[5] Moradi MH, Abedini M: A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems. Electrical Power and Energy Systems, DOI:10.1016/j.ijepes.2011.08.023, 34:66–74, 2012.

[6]Vijayabaskar S, Manigandan T: Analysis of radial distribution system optimization with FACTS devices using hybrid Heuristic technique. J of Theoretical and Applied Information Technology, 58:397-404, 2013.

[7] Biju ER, Anitha M:Bacterial Foraging Algorithm for Reliability Performance of Radial Distribution System with DG.Int J of Computer Applications, DOI:10.5120/13855-1694, 80:6-12, 2013.

[8] Lee SH, Park JW: Optimal Placement and Sizing of Multiple DGs in a Practical Distribution System by Considering Power Loss. IEEE Trans on Industry Applications, DOI: 10.1109/TIA.2013.2260117, 49:2262-2270, 2013.

[9] Seker AA, Hocaoglu MH: Artificial Bee Colony algorithm for optimal placement and sizing of Distributed Generation. Electrical and Electronics Engineering (ELECO) Int Conference, DOI: 10.1109/ELECO.2013.6713817, November 30, 2013.

[10] Injeti SK, Kumar NP: A novel approach to identify optimal access point and capacity of multiple DGs in a small, medium and large scale radial distribution systems. Electrical Power and Energy Systems,DOI:10.1016/j.ijepes.2012.08.043, 45:142–151, 2013.

[11] Sharma S, Bhattacharjee S, Bhattacharya A: Optimal Location and Sizing of DG to Minimize Loss of Distribution System Using SIMBO-Q Method. Int Conf on Control, Instrumentation, Energy & Communication, DOI:10.1109/CIEC.2014.6959106, February 2, 2014.

[12] Devi S, Geethanjali M:Optimal location and sizing determination of Distributed Generation andDSTATCOM using Particle Swarm Optimization algorithm.Electrical Power and Energy Systems,DOI:10.1016/j.ijepes.2014.05.015, 62:562–570, 2014.

[13]Devi S, Geethanjali M: Application of Modified Bacterial Foraging Optimization algorithm for optimal placement and sizing of Distributed Generation. Expert Systems with Applications, DOI:10.1016/j.eswa.2013.10.010, 41:2772–2781, 2014.

[14] Imran AM, Kowsalya M, Kothari DP: A novel integration technique for optimal network reconfiguration and distributed generation placement in power distribution networks.Electrical Power and Energy Systems, DOI:10.1016/j.ijepes.2014.06.011, 63:461–472, 2014.

[15] Sultana S, Roy PK: Multi-objective quasi-oppositional teaching learning based optimization for optimal location of distributed generator in radial distribution systems. Electrical Power and Energy Systems, DOI:10.1016/j.ijepes.2014.06.031, 63:534–545, 2014.

[16] Mohamed Imran A, Kowsalya M: Optimal distributed generation and capacitor placement in power distribution networks for power loss minimization. Advances in Electrical Engineering (ICAEE), DOI:10.1109/ICAEE.2014.6838519, January 11, 2014.

[17] Kaur S, Kumbhar G, Sharma J: A MINLP technique for optimal placement of multiple DG units in distribution systems. Int J Electr Power Energy Syst, DOI: 10.1016/j.ijepes.2014.06.023, 63:609-617, 2014.

[18] Muttaqi KM, Le DT, Negnevitsky M, Ledwich G: An algebraic approach for determination of DG parameters to support voltage profiles in radial distribution networks. IEEE Transactions on Smart Grid, DOI:10.1109/TSG.2014.2303194, 5:1351-1360, 2014.

[19] Kaur S, Kumbhar G, Sharma J: Harmony Search and OPF based hybrid approach for optimal placement of multiple DG units. Power Systems Conference (NPSC), DOI:10.1109/NPSC.2014.7103842, December 20, 2014.

[20] Naik S, Naik G, Khatod DK, Sharma MP: Analytical approach for optimal siting and sizing of distributed generation in radial distribution networks.IET Gener Transm Distrib, DOI:10.1049/iet-gtd.2014.0603, 9:209–220, 2015.

[21] Murty VVSN, Kumar A: Optimal placement of DG in radial distribution systems based on new voltage stability index under load growth. Int J Electr Power Energy Syst. DOI: 10.1016/j.ijepes.2014.12.080, 69:246-256, 2015.

[22] Devabalaji KR, Ravi K: Optimal size and siting of multiple DG and DSTATCOM in radial distribution system using Bacterial Foraging Optimization Algorithm. Ain Shams Eng J, DOI:10.1016/j.asej.2015.07.002, august 18, 2015.

[23] Pradeepa H, Ananthapadmanabha T, Sandhya Rani DN, Bandhavya C: Optimal allocation of combined DG and capacitor units for voltage stability enhancement. Procedia Technology, DOI: 10.1016/j.protcy.2015.10.091, 21:216 – 223, 2015.

[24] Sasanka GA, Guntupalli R: Allocation of multiple distributed generators in radial distribution feeder for loss minimization. Int J of Latest Research in Engineering and Technology, 2:61-66, 2016.

[25] Nguyen TT, Truong AV, Phung TA: A novel method based on adaptive cuckoo search for optimal network reconfiguration and distributed generation allocation in distribution network. Electrical Power and Energy Systems,DOI:10.1016/j.ijepes.2015.12.030, 78:801–815, 2016.

[26] Sultana S, Roy PK: Krill herd algorithm for optimal location of distributed generator in radial distribution system. Applied Soft Computing, DOI:10.1016/j.asoc.2015.11.036, 40:391–404, 2016.

[27] Chakravorty M, Das D: Voltage Stability Analysis of radial distribution networks. Int J Electrical Power Energy System, DOI:10.1016/S0142-0615(00)00040-5, 23:129-135, 2001.

[28] Zhang D, Fu Z, Zhang L: An improved TS algorithm for loss-minimum reconfiguration in large-scale distribution systems. Electric Power Systems Research, DOI:10.1016/j.epsr.2006.06.005, 77:685–694, 2007.

[29] Passino KM: Bacterial foraging optimization. Int J of swarm intelligence research, DOI:10.4018/jsir.2010010101, 1:1-16, 2010.

[30] Nasiraghdam H: Bacterial Foraging Optimization for Dispersed Energy Resources Placement Considering Reliability Enhancement and Power Loss Reduction of Distribution Systems. World Applied Sciences J, DOI: 10.5829/idosi.wasj.2012.20.10.2068, 20:1426-1432, 2012.

[31] Ghasemi S, Moshtagh J: Radial distribution systems reconfiguration considering power losses cost and damage cost due to power supply interruption of consumers. Int J Electr Engg Informatics, DOI:10.15676/ijeei.2013.5.3.5, 5:297-315, 2013.

[32] Muthukumar K, Jayalalitha S, Ramasamy M ,Cherukuri SH: Optimal shunt capacitor allocation and sizing using harmony search algorithm for power loss minimization in radial distribution networks. Int J of Dev Research, 4:537-545, 2014.

[33] 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.

[34] 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. Int J of Engineering Science and Technology, DOI:10.1016/j.jestch.2015.09.002, 19:610–618, 2016.

[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] Augugliaro A, Dusonchet L, Favuzza S, Ippolito MG, Sanseverino ER: A backward sweep method for power flow solution in distribution networks. Int J Electr Power Energy Syst, DOI:10.1016/j.ijepes.2009.09.007,32:271-280, 2010.

[37] Rana AD, Darji JB, Pandya M: Backward / Forward sweep load flow algorithm for radial distribution system. Int J for Scientific Research & Development, 2:398-400, 2014.

[38] Baran M, Wu FF: Optimal capacitor placement on radial distributions systems, IEEE Trans. Power Deliv,DOI:10.1109/61.19265, 4:725–734, 1989.

APPENDIX-A

Table A.1System data of 69 nodeRDN [38]

Line Number	Branch		Branch impedance		Loads	
	Sending End	Receiving End	Resistance (Ω)	Reactance (Ω)	P (kW)	Q (kVAr)
1	1	2	0.036	0.01296	133.84	101.14
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

(Base voltage = 12.66 kV, Base MVA = 100)

Table A.2System data of 119 node RDN [28]

Line Number	Branch		Branch impedance		Loads	
	Sending End	Receiving End	Resistance (Ω)	Reactance (Ω)	P (kW)	Q (kVAr)
1	1	2	0.036	0.01296	133.84	101.14
2	2	3	0.033	0.01188	16.214	11.292
3	2	4	0.045	0.0162	34.315	21.845
4	4	5	0.015	0.054	73.016	63.604
5	5	6	0.015	0.054	144.2	68.604
6	6	7	0.015	0.0125	104.47	61.725
7	7	8	0.018	0.014	28.547	11.503
8	8	9	0.021	0.063	87.56	51.073
9	2	10	0.166	0.1344	198.2	106.77
10	10	11	0.112	0.0789	146.8	75.995
11	11	12	0.187	0.313	26.04	18.687
12	12	13	0.142	0.1512	52.1	23.22
13	13	14	0.18	0.118	141.9	117.5
14	14	15	0.15	0.045	21.87	28.79
15	15	16	0.16	0.18	33.37	26.45
16	16	17	0.157	0.171	32.43	25.23
17	11	18	0.218	0.285	20.234	11.906
18	18	19	0.118	0.185	156.94	78.523
19	19	20	0.16	0.196	546.29	351.4
20	20	21	0.12	0.189	180.31	164.2
21	21	22	0.12	0.0789	93.167	54.594
22	22	23	1.41	0.723	85.18	39.178
23	23	24	0.293	0.1348	168.1	95.178
24	24	25	0.133	0.104	125.11	150.22

25	25	26	0.178	0.134	16.03	24.62
26	26	27	0.178	0.134	26.03	24.62
27	4	28	0.015	0.0296	594.56	522.62
28	28	29	0.012	0.0276	120.62	59.117
29	29	30	0.12	0.2766	102.38	59.117
30	30	31	0.21	0.243	513.4	318..5
31	31	32	0.12	0.054	475.25	456.14
32	32	33	0.178	0.234	151.43	136.79
33	33	34	0.178	0.234	205.38	83.302
34	34	35	0.154	0.162	131.6	93.082
35	30	36	0.187	0.261	448.4	369.79
36	36	37	0.133	0.099	440.52	321.64
37	29	38	0.33	0.194	112.54	55.134
38	38	39	0.33	0.194	53.963	38.998
39	39	40	0.13	0.194	393.05	342.6
40	40	41	0.28	0.15	326.74	278.56
41	41	42	1.18	0.85	536.26	240.24
42	42	43	0.42	0.2436	76.247	66.562
43	43	44	0.27	0.0972	53.52	39.76
44	44	45	0.339	0.1221	40.328	31.964
45	45	46	0.27	0.1779	39.653	20.758
46	35	47	0.21	0.1383	66.195	42.361
47	47	48	0.12	0.0789	73.904	51.653
48	48	49	0.15	0.0987	114.77	57.965
49	49	50	0.15	0.0987	918.37	1205.1
50	50	51	0.24	0.1581	210.3	146.66
51	51	52	0.12	0.0789	66.68	56.608
52	52	53	0.405	0.1458	42.207	40.184
53	53	54	0.405	0.1458	433.74	283.41
54	29	55	0.391	0.141	62.1	26.86
55	55	56	0.406	0.1461	92.46	88.38

56	56	57	0.406	0.1461	85.188	55.436
57	57	58	0.706	0.5461	345.3	332.4
58	58	59	0.338	0.1218	22.5	16.83
59	59	60	0.338	0.1218	80.551	49.156
60	60	61	0.207	0.0747	95.86	90.758
61	61	62	0.247	0.8922	62.92	47.7
62	1	63	0.028	0.0418	478.8	463.74
63	63	64	0.117	0.2016	120.94	52.006
64	64	65	0.255	0.0918	139.11	100.34
65	65	66	0.21	0.0759	391.78	193.5
66	66	67	0.383	0.138	27.741	26.713
67	67	68	0.504	0.3303	52.814	25.257
68	68	69	0.406	0.1461	66.89	38.713
69	69	70	0.962	0.761	467.5	395.14
70	70	71	0.165	0.06	594.85	239.74
71	71	72	0.303	0.1092	132.5	84.363
72	72	73	0.303	0.1092	52.699	22.482
73	73	74	0.206	0.144	869.79	614.775
74	74	75	0.233	0.084	31.349	29.817
75	75	76	0.591	0.1773	192.39	122.43
76	76	77	0.126	0.0453	65.75	45.37
77	64	78	0.559	0.3687	238.15	223.22
78	78	79	0.186	0.1227	294.55	162.47
79	79	80	0.186	0.1227	485.57	437.92
80	80	81	0.26	0.139	243.53	183.03
81	81	82	0.154	0.148	243.53	183.03
82	82	83	0.23	0.128	134.25	119.29
83	83	84	0.252	0.106	22.71	27.96
84	84	85	0.18	0.148	49.513	26.515
85	79	86	0.16	0.182	383.78	257.16
86	86	87	0.2	0.23	49.64	20.6

87	87	88	0.16	0.393	22.473	11.806
88	65	89	0.669	0.2412	62.93	42.96
89	89	90	0.266	0.1227	30.67	34.93
90	90	91	0.266	0.1277	62.53	66.79
91	91	92	0.266	0.1277	114.57	81.748
92	92	93	0.266	0.1277	81.292	66.526
93	93	94	0.233	0.115	31.733	15.96
94	94	95	0.496	0.138	33.32	60.48
95	91	96	0.196	0.18	531.28	224.85
96	96	97	0.196	0.18	507.03	367.42
97	97	98	0.1866	0.122	26.39	11.7
98	98	99	0.0746	0.318	45.99	30.392
99	1	100	0.0625	0.0265	100.66	47.572
100	100	101	0.1501	0.234	456.48	350.3
101	101	102	0.1237	0.0888	522.56	449.29
102	102	103	0.2307	0.1203	408.43	168.46
103	103	104	0.447	0.1608	141.48	134.25
104	104	105	0.1632	0.0588	104.43	66.024
105	105	106	0.33	0.099	96.793	83.647
106	106	107	0.156	0.00561	493.92	419.34
107	107	108	0.3819	0.1374	225.38	135.88
108	108	109	0.1626	0.0585	509.21	387.21
109	109	110	0.3819	0.1374	188.5	173.46
110	110	111	0.2445	0.0879	918.03	898.55
111	110	112	0.2088	0.0753	305.08	215.37
112	112	113	0.2301	0.0828	54.38	40.97
113	100	114	0.6102	0.2196	211.14	192.9
114	114	115	0.1866	0.127	67.009	53.336
115	115	116	0.3732	0.246	162.07	90.321
116	116	117	0.405	0.367	48.785	29.156
117	117	118	0.489	0.438	33.9	18.98

(Base voltage = 11 kV, Base kVA = 100)

Gaurav_Thesis

ORIGINALITY REPORT

5%	3%	5%	3%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.dgnet.org Internet Source	1%
2	www.aedie.org Internet Source	1%
3	www.rspublication.com Internet Source	<1%
4	ctieware.eng.monash.edu.au Internet Source	<1%
5	Muthukumar, K., S. Jayalalitha, and M. Ramaswamy. "PSO Embedded Artificial Bee Colony Algorithm for Optimal Shunt Capacitor Allocation and Sizing in Radial Distribution Networks with Voltage Dependent Load Models", International Review of Electrical Engineering (IREE), 2015. Publication	<1%
6	Li, Yu, and Masato Ishikawa. "Sensitivity analysis of radially distributed power system under random penetration of photovoltaic generation", 2015 10th Asian Control	<1%